YAYASAN BRATA BHAKTI DAERAH JAWA TIMUR
UNIVERSITAS BHAYANGKARA SURABAYA
LEMBAGA PENELITIAN DAN PENGABDIAN PADA MASYARAKAT
(LPPM)
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SURAT KETERANGAN

Nomor: Sket/ 25 /I/2023/LPPM/UBHARA

Kepala Lembaga Penelitian dan Pengabdian kepada Masyarakat (LPPM) Universitas Bhayangkara Surabaya menerangkan bahwa:

Nama	: Dr. Amirullah, ST, MT.
NIP	: 197705202005011001
NIDN	: 0020057701
Unit Kerja	: Universitas Bhayangkara Surabaya

Benar telah melakukan kegiatan:

1. Menulis proseding berjudul Power Transfer Analysis Using UPQC-PV System under Sag and Interruption with Variable Irradiance (Amirullah, Adiananda, Adi Soeprijanto, Ontoseno Penangsang), yang telah dipublikasikan pada Proseding International Conference on Smart Tehcnology and Its Application (ICoSTA), Date of Conference: 20 February 2020, pp. 1-7, Faculty of Engineering, University of Bhayangkara Surabaya, Publisher IEEE. **Terindeks Ieeexplorer.**
2. Telah melakukan korespondensi melalui email dalam proses penerbitan jurnal tersebut. Bukti korespondensi email dan bukti pendukung adalah benar sudah dilakukan oleh yang bersangkutan serta sudah dilampirkan bersama surat ini.

Demikian surat keterangan ini dibuat untuk kepentingan kelengkapan pengusulan Guru Besar.

Surabaya, 20 Januari 2023
Kepala LPPM

Drs. Heru Irianto, M.Si.
NIP. 9000028

Lampiran 1

Bukti Korespondensi Email

dengan Editor Seminar

ICoSTA 2020

#196 (1570615953): Power Transfer Analysis Using UPQC-PV System Under Sag and Interruption With Variable Irradiance

#196 (1570615953): *Power Transfer Analysis Using UPQC-PV System Under Sag and Interruption With Variable Irradiance*

BibTeX

Property	Change Add	Value
Conference and *track*		**2020 International Conference on Smart Technology and Applications (ICoSTA)** - *Smart Technologies*
Authors		(see table below)
Title		*Power Transfer Analysis Using UPQC-PV System Under Sag and Interruption With Variable Irradiance*
Abstract		This paper presents analysis of UPQC-PV system model under sag and interruption voltage with variable irradiance. The PV is connected to a 3P3W distribu 380 volts (L-L) and a frequency of 50 hertz, through UPQC-DC link . This system is used to maintain and supply sensitive loads. This paper shows that in the irradiance levels of 200 W/m2 to 1200 W/m2, the 3P3W system uses UPQC-PV with proportional integral (PI) still able to maintain the load active power However, in the interruption voltage and same irradiance level, the load active power drops to between 2560 W and 2805 W. This research also show that in and same irradiance levels, the 3P3W system uses UPQC-PV with PI still able to generate PV power between 500 W to 920 W. In the interruption voltage and levels, the power that can be generated by PV increases between 1300 W to 1635 W. Otherwise, at 250 C and 1000 W/m2, the increase in PV power on inte has not been able to meet the load active power consumption, so it finally drops to 2650 W. This paper is simulated using Matlab/Simulink.
Keywords	Only the chairs can edit	UPQC; Photovoltaic; Sag; Interruption; Irradiance
Topics		Energy, Power Generation, and Distributon

Drag to change order	Name	ID	Edit	Flag	Affiliation (edit for paper)	Email	Country	Em
	Amirullah Amirullah	1356487			University of Bhayangkara Surabaya, Indonesia	amirullah.ubhara.surabaya@gmail.com	Indonesia	
	Adiananda Adiananda	1745930			University of Bhayangkara Surabaya, Indonesia	adiananda@ubhara.ac.id	Indonesia	
	Ontoseno Penangsang	1345789	not creator		Institut Teknologi Sepuluh Nopember Surabaya, Indonesia	ontosenop@ee.its.ac.id	Indonesia	
	Adi Soeprijanto	683323	not creator		Institut Teknologi Sepuluh Nopember, Indonesia	adisup@ee.its.ac.id	Indonesia	

Presenter(s)		Amirullah Amirullah (bio)
Session		PC5: *Parallel Class 5* from Thu, February 20, 2020 13:30 WIB until 16:30 (7th paper) in Room 5 (20.0 min.)
DOI	Only the chairs can edit	
Status		Accepted
Copyright form		IEEE; IEEE: Jan 25, 2020 11:20 America/New_York
Visa letter		none

Review manuscript	Presentation	Final manuscript	Stamped

Personal notes

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Reviews

2 Reviews

Review 1

None of the scores are visible for your roles.

Comment to Author (e.g. Major reasons of your overall recommendation)

There should be an explanation in the introduction regarding the percentage of how good of using PI method compared to FLC method in order to sharpen the method being proposed

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3. All figures must be presented in sequence
4. Conclusions must be based on the subjects discussed in the paper.
5. There are some grammatical errors

Gmail **Amirullah Amirullah <amirullah.ubhara.surabaya@gmail.com>**

[ICoSTA 2020] Your paper #1570615953 ('Power Transfer Analysis Using UPQC-PV System Under Sag and Interruption With Variable Irradiance')

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Dear Dr. Amirullah Amirullah:

Congratulations!

We are pleased to inform you that your manuscript #1570615953 ('Power Transfer Analysis Using UPQC-PV System Under Sag and Interruption With Variable Irradiance') has now been ACCEPTED by 2020 International Conference on Smart Technology and Applications (ICoSTA).

The reviews are included below, and can also be found at https://edas.info/showPaper.php?m=1570615953 using your EDAS login name amirullah.ubhara.surabaya@gmail.com.

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2. You are required to ensure that the similarity rating of your manuscript is less than 30%. Submissions with a similarity rating of 30% or above will be dropped and no longer considered for ICoSTA 2020.
3. Please ensure that your manuscript has been checked for grammatical and typographical errors and that your manuscript is IEEE pdf eXpress compliant by following the common IEEE conference style template. A guide to converting to pdf eXpress can be seen on the website. If the paper is more than 6 pages, then an additional fee of 30 dollars per page for international participants or IDR 300,000 for Indonesian participants.
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Once again, congratulations on the acceptance of your paper. We thank you for your patience and interest in ICoSTA 2020, we hope to see you in Surabaya.

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There should be an explanation in the introduction regarding the percentage of how good of using PI method compared to

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======= Review 2 =======

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Grammar perlu diperbaiki seperti:

convert →converts. because it only convert sunlight to generate electricity
reseources →resources. where the reseources are avialable in abundant
avialable →available. where the reseources are avialable in abundant
Pertub →Perturb. with Pertub and Observer (P and O),
hysterisis →hysteresis. hysterisis control in a three-phase
drawn →drew, has drawn. system drawn a constant sinusoidal
ans →and. to maintain ans supply sensitive loads
a functions →a function, functions. This device has a functions to adjust
a interruption →an interruption. in the case of a interruption voltage
accurs →occurs. accurs on source or point common
mantain →maintain. The UPQC-PV system uses PI to mantain voltage
is →are. parameters for the proposed model is shown in Appendix Section
are →is. +uctuating component of real power are selected as power references
distrurbance →disturbance, disturbances. There are two distrurbance scenarios i.e. sag voltage (Sag)
.agelt →agent, adult. o agelt(V
interuption →interruption. Fig. 7 shows that in the interuption
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> hysterisis →hysteresis. hysterisis control in a three-phase
> drawn →drew, has drawn. system drawn a constant sinusoidal
> ans →and. to maintain ans supply sensitive loads
> a functions →a function, functions. This device has a functions to adjust
> a interruption →an interruption. in the case of a interruption voltage
> accurs →occurs. accurs on source or point common
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Lampiran 2

Bukti Pendukung

Lampiran 2.1

Naskah makalah submitted

Power Transfer Analysis Using UPQC-PV System Under Sag and Interruption With Variable Irradiance

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***Abstract*— This paper present analysis of UPQC-PV system model under sag and interruption voltage under variable irradiance. The PV is connected to a 3P3W distribution system with 380 volts (L-L) and a frequency of 50 hertz, through UPQC-DC link . This system is used to maintain and supply sensitive loads. This paper shows that in sag voltage and irradiance levels of 200 W/m^2 to 1200 W/m^2, the 3P3W system uses UPQC-PV with proportional integral (PI) still able to maintain active load power above 3714 W. However, in the interruption voltage and same irradiance level, the active load power drops to between 2560 W and 2805 W. It also show that in sag voltage and same irradiance level, the 3P3W system uses UPQC-PV with PI still able to generate PV power between 500 W to 920 W. In the interruption voltage and same irradiance levels, the power that can be generated by PV increases between 1300 W to 1635 W. Otherwise, the increase on PV power in the interruption voltage has not been able to meet active load power consumption, so it finally drops to 2650 W. This paper is simulated using Matlab/Simulink.**

Keywords*—*UPQC, Photovoltaic, Sag, Interruption, Irradiance

I. Introduction

The decreasing of fossil energy sources and increasing concerns about environmental impacts have caused renewable energy (RE) sources i.e. photovoltaic (PV) and wind to develop into alternative energy on power generation. Solar or PV generator is one of the most potential RE technologies because it only convert sunlight to generate electricity, where the reseources are avialable in abundant and they are free and relatively clean. Indonesia has a huge energy potential from the sun because it is located in the equator. Almost all regions of Indonesia receive around 10 to 12 hours of sunshine per day, with an average irradiation intensity of 4.5 kWh/m^2 or equivalent to 112.000 GW.

Even though PV is able to generate power, this equipment also has disadvantage: it results in a number of voltage and current disturbances, as well as harmonics due to the presence of several types of PV devices and power converters and increasing the number of non-linear loads connected to the source, causing a decrease in power quality (PQ). In order to overcome this problem and to improve PQ due to the presence of non-linear load and integration of PV into the grid, UPQC is proposed. UPQC has a function to compensate for problems of voltage source quality i.e. sag, swell, unbalance, flicker, harmonics, and load current quality problems i.e. harmonics, imbalance, reactive current, and neutral current. UPQC is part of an active power filter consisting of shunt active filter and series active filter connected in parallel and serving as a superior controller to solve a number of PQ problems simultaneously [1]. UPQC series component is responsible for reducing a number of disturbances on source side i.e. sag/swell voltage, flicker, unbalanced voltage, and source voltage harmonics. This equipment serves to inject a certain amount of voltage to keep load voltage at desired level so that it returns to balance and distortion free. UPQC shunt component is responsible for overcoming current quality problems i.e.. low power factor, load current harmonics, and unbalanced currents. This equipment functions to inject current into AC system so that current source becomes a balanced sinusoidal and it is in phase with source voltage [2]. The dynamic performance of integrated PV with UPQC (PV-UPQC) under variable irradiance condition and sag/swell grid voltage has been investigated [3]. The proposed system is able to combine both the benefits of distributed generators (DGs) and active power filters. The PV-UPQC combination is also able to reduce harmonics due to nonlinear loads and is able to maintain total harmonics distortion (THD) of grid voltage, load voltage and grid current below the IEEE-519. The system was found to be stable under irradiation from 1000 $W/m2$ to 600 $W/m2$.

The dynamic performance of the proposed JAYA based auto tuned PI for PV-UPQC systems has been analyzed [4]. Online JAYA optimization methodology is implemented for PV-UPQC to determine the best value of PI gain. The Vector-Proportional Integral (UV-PI) and Proportional Resonant-Response (PR-R) controllers in shunt and series converters significantly increase PV-UPQC performance by reducing convergence time, settling time, switching harmonics, complexity and dynamic response which is more effective. PV-UPQC performance using control algorithm based on Synchronous Reference Frame (SRF) with Phase Lock Loop (PLL) mechanism has been presented [5]. Unbalanced load voltage contains harmonics and pure unbalanced pure load voltage has been compensated and balanced so that the load voltage is maintained constant.

UPQC is supplied by 64 PV panels using boost converters, PI controllers, maximum power point tracking (MPPT) with Pertub and Observer (P and O), and having a momentary reactive power theory (p-q theory) has been proposed [6]. The system has been able to carry out reactive power compensation and reduce source current and load voltage harmonics. However, this study does not address mitigation of sag voltage reduction and other disturbances caused by PV penetration. PV supported by UPQC using Space Vector Pulse Width Modulation (SVPWM) compared to hysterisis control in a three-phase distribution system has been proposed [7]. The system is used to improve PQ and reduce the burden of 3 phase AC network by supplying power obtained from PV. The UPQC system is able to supply reactive power needed to increase power factor, reduce voltage and current distortion and PV helps injection active power into the load. A conceptual study of UPQC on three phase four wire (3P4W) system connected to linear and non-linear loads simultaneously has been carried out [8]. The sinusoidal current control strategy drives UPQC in such a way that the supply system draws a constant sinusoidal current under steady state conditions. In addition, the shunt converter also produces reactive power as required by load so that it can improve an input power factor and reduce THD of source current.

Artificial neural networks based on SRF theory as a control to compensate for PQ problems of three phase three wire (3P3W) system through UPQC for various balanced/unbalanced/distorted conditions at load and source have been proposed [9]. The proposed model has been able to mitigate harmonic/reactive currents, unbalanced source and load, and unbalanced current/voltage. Investigation on the quality of enhancements including sag and source voltage harmonics on the grid using UPQC provided by PV array connected to DC links using PI compared to FLC have been carried out [10]. The simulation shows that FLC on UPQC and PV can increase THD voltage source better than PI. The improvement of PQ using UPQC on microgrid supplied by PV and wind turbine have been implemented using PI and FLC. Both methods were able to improve PQ and reduce distortion in output power [11]. The research on the use of Battery Energy Storage (BES) in UPQC is supplied by PV to improve PQ in three phase 3P3W distribution systems using FLC validated PI on various disturbances in source and load side have been investigated [12]. This reserch showed that FLC on UPQC-BES system supplied by PV was able to significantly reduce load current harmonics and source voltage harmonics in number of disturbances, especially in interruption voltage termination on source bus.

This research present analysis of UPQC-PV system model under sag and interruption voltage under variable irradiance. The PV is connected to a 3P3W system with 380 volts (L-L) and a frequency of 50 hertz, through UPQC-DC link . This system is used to maintain load voltage and active load power constant, as well as supply sensitive loads. This paper is presented as follow. Section 2 explains proposed method, UPQC-PV model, parameter simulation, PV model, active filter series and shunt filter control, application of PI, as well as UPQC model efficiency. Section 3 shows results and discussions of load voltage, load current, active source power transfer, active load power transfer, series active power, shunt active power, PV power using PI. In this section, six disturbance scenarios are presented and the results are verified with Matlab/Simulink. Finally, this paper is concluded in Section 4.

II. RESEARCH METHOD

A. Proposed Method

Fig. 1 shows proposed model in this paper. The PV is connected to a 3P3W distribution system with 380 volts (L-L) and a frequency of 50 hertz, through UPQC-DC link circuit. This system is known as UPQC-PV system and it is used to maintain ans supply sensitive loads. The PV array generates DC power at a constant temperature, variable solar irradiance, and it is connected to DC-link via a DC-DC boost converter. The MPPT method with P and O algorithm helps PV to generate maximum power, result an output voltage, which then becomes an input voltage for DC-DC boost converter. This device functions to adjust duty cycle value with PV output voltage as an input voltage to produce output voltage according to DC-link voltage of UPQC. The PV functions as an alternative source by injecting power to keep load voltage constant, in the case of a interruption voltage accurs on source or point common coupling (PCC) bus.

The proposed model analysis is carried out by determining sag and interruption voltage scenarios on source bus in 3P3W using UPQC-PV system. The measurement parameters are carried out at fixed temperature (T = 25^0 C) and variable irradiance i.e. 200 W/m^2, 400 W/m^2, 600 W/m^2, 800 W/m^2, 1000 W/m^2 and 1200 W/m^2. Each disturbance scenario at variable irradiance level amounts to 6 disturbance, so the total number of scenarios is 12 disturbances. The UPQC-PV system uses PI to mantain voltage in a series active filter and current in a shunt active filter to keep the voltage at sensitive load remains constant. The parameters investigated i.e. voltage and current on source bus, voltage and current on load bus, active source power, active series power, active shunt power , active load power, and PV power. The next step is to determine efficiency value of UPQC-PV system in sag and interruption voltage scenario in variable irradiance to show the contribution of PV in mitigation of both voltage disturbances on source bus. Fig. 2 shows power transfer using UPQC-PV system. Then, the parameters of proposed model simulation is showed in Appendix Section.

B. Modelling of PV Array

Fig. 3 shows the equivalent circuit and V-I characteristics of solar panel. It consists of several PV cells which have external connections in series, parallel, or series-parallel [13].

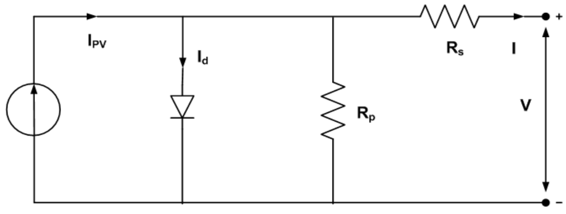


Fig. 3. Equivalent circuit of solar panel

The V-I characteristic is shown in Eq. (1):

$$I = I_{PV} - I_o\left[\exp\left(\frac{V + R_S I}{aV_t}\right) - 1\right] - \frac{V + R_S I}{R_P} \quad (1)$$

Where I_{PV} is photovoltaic current, I_o is saturated backflow, 'a' is the ideal diode constant, $V_t = N_S K T q^{-1}$ is thermal voltage, N_S is number of series cells, q is electron charge, K is Boltzmann constant, T temperature pn junction, R_S and R_P are series and parallel resistance of solar panels. I_{PV} has a linear relationship with light intensity and also varies with temperature variation. I_o is dependent value on the temperature variation. The value of I_{PV} and I_o are calculated as following of Eq (2) and Eq. (3):

$$I_{PV} = (I_{PV,n} + K_1 \Delta T)\frac{G}{G_n} I \quad (2)$$

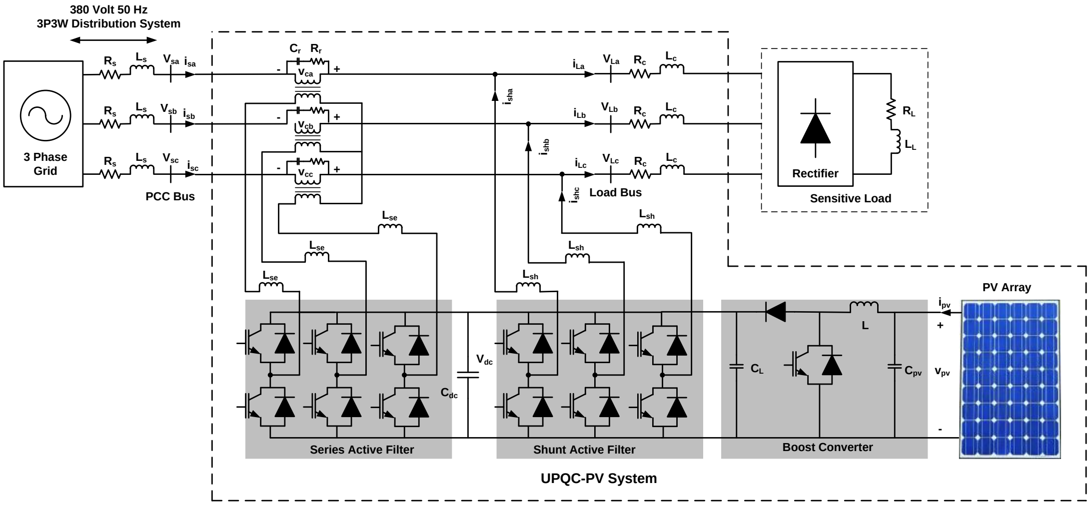


Fig. 1. Proposed model of as UPQC-PV system

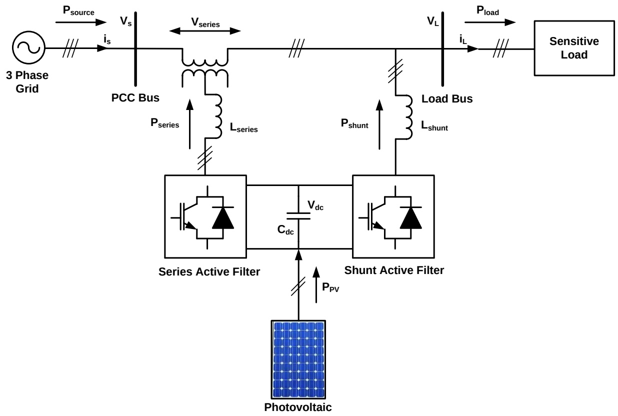


Fig. 2. Power transfer using UPQC-PV system

$$I_o = \frac{I_{SC,n} + K_I \Delta T}{\exp(V_{OC,n} + K_V \Delta T)/aV_t - 1} \quad (3)$$

Where I_{PV}, n, I_{SC}, and V_{OC}, n is the photovoltaic current, short circuit current, and open circuit voltage under standard conditions *(T_n = 25^0 C and G_n = 1000 Wm^{-2})* respectively. The K_I value is coefficient of short circuit current to temperature, $\Delta T = T - T_n$ is temperature deviation from standard temperature, G is light intensity and K_V is coefficient of open circuit voltage ratio to temperature. Open circuit voltage, short circuit current, and voltage-current related to maximum power are three important values of I-V characteristics of solar panel. These points are changed by variation in atmospheric conditions. By using Eq. (4) and Eq. (5) derived from PV model equation, short-circuit current and open circuit voltage can be calculated under different atmospheric conditions.

$$I_{SC} = (I_{SC} + K_1 \Delta T)\frac{G}{G_n} \quad (4)$$

$$V_{OC} = V_{OC} + K_V \Delta T \quad (5)$$

C. Control of Series Active Filter

The main function of series active filter is to protect sensitive load from a number of voltage disturbance at PCC bus. The algorithm of source voltage and load voltage control strategies in series active filter circuit is shown in Fig. 4. This control strategy generates the unit vector template from a distorted input source. Then, the template is expected to be an ideal sinusoidal signal with an unity amplitude. Then, the distorted source voltage is measured and divided by peak amplitude of base input voltage V_m as stated in Eq. (6) [6].

$$V_m = \sqrt{\frac{2}{3}\left(V_{sa}^2 + V_{sb}^2 + V_{sc}^2\right)} \quad (6)$$

A three phase PLL is used to produce sinusoidal unit vector templates with phase lagging through the use of sine function. The load voltage of reference signal is determined by multiplying unit vector templates by the peak value of base input voltage amplitude V_m. The load reference voltage *(V_{La}^*, V_{Lb}^*, V_c^*)* is then compared with sensed load voltage (V_{La}, V_{Lb}, V_{Lc}) with a pulse width modulation controller (PWM) used to generate the desired trigger signal in series active filter. Fig. 4 shows control of series active filter.

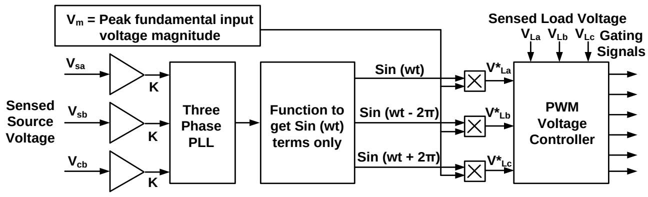


Fig. 4 Series active filter control

D. Control of Shunt Active Filter

The main function of shunt active filter is to mitigate PQ problems on the load side. The control methodology of shunt active filter is that the absorbed current from PCC bus is a balanced positive sequence current including an unbalanced sag voltage on PCC bus, an unbalanced, or a non-linear load. In order to obtain satisfactory compensation caused by interference due to non-linear load, many algorithms have been used in some references. This research uses the method of instantaneous reactive power theory theory or "p-q theory". The voltages and currents in Cartesian coordinates can be transformed into Cartesian coordinates αβ as stated in Eq. (7) and Eq. (8) [6].

$$\begin{bmatrix} v_\alpha \\ v_\beta \end{bmatrix} = \begin{bmatrix} 1 & -1/2 & -1/2 \\ 1 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} \quad (7)$$

$$\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} = \begin{bmatrix} 1 & -1/2 & -1/2 \\ 1 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} i_{La} \\ i_{Lb} \\ i_{Lc} \end{bmatrix} \quad (8)$$

Calculation of real power *(p)* and imaginary power *(q)* is shown in Eq. (9). Real and imaginary power are measured instantaneously power and expressed in matrix form. The presence of mean and fluctuating component in instantaneous component is shown in Eq. (10) [14].

$$\begin{bmatrix} p \\ q \end{bmatrix} = \begin{bmatrix} v_\alpha & v_\beta \\ -v_\beta & v_\alpha \end{bmatrix} \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} \tag{9}$$

$$p = \bar{p} + \tilde{p} \quad ; \quad q = \bar{q} + \tilde{q} \tag{10}$$

Where $\bar{p}$ = the average component of real power, $\tilde{p}$ = the fluctuating component of real power, $\bar{q}$ = the average component of imaginary power, $\tilde{q}$= the fluctuating component of imaginary power. The total imaginary power *(q)* and fluctuating component of real power are selected as power references and current references and are they are utilized through the use of Eq. (11) to compensate for harmonics and reactive power [15].

$$\begin{bmatrix} i_{c\alpha}^* \\ i_{c\beta}^* \end{bmatrix} = \frac{1}{v_\alpha^2 + v_\beta^2} \begin{bmatrix} v_\alpha & v_\beta \\ v_\beta & -v_\alpha \end{bmatrix} \begin{bmatrix} -\tilde{p} + \bar{p}_{loss} \\ -q \end{bmatrix} \quad 11)$$

The $\bar{p}_{loss}$ signal is obtained from the voltage regulator and is used as average real power. It can also be expressed as instantaneous active power associated with resistive losses and switching losses from UPQC. The error is obtained by comparing the actual DC-link capacitor voltage with the reference value processed using a PI controller, driven by a closed voltage control to minimize steady state errors from voltage through DC-link circuit to zero. The compensation current ($i_{c\alpha}^*$, $i_{c\beta}^*$) is needed to meet load power demand as shown in Eq. (12). The current is expressed in coordinates α-β. The compensation current is used to obtain source phase current by using Eq. (13) for compensation. The source phase current $(i_{sa}^*, i_{sa}^*, i_{sa}^*)$ is expressed in the abc axis obtained from the compensation current in α-β coordinates and is presented in Eq. 12 [15] .

$$\begin{bmatrix} i_{sa}^* \\ i_{sb}^* \\ i_{sc}^* \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 0 \\ -1/2 & \sqrt{3}/2 \\ -1/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} i_{c\alpha}^* \\ i_{c\beta}^* \end{bmatrix} \tag{12}$$

Fig. 5 show shunt active filter control [15].

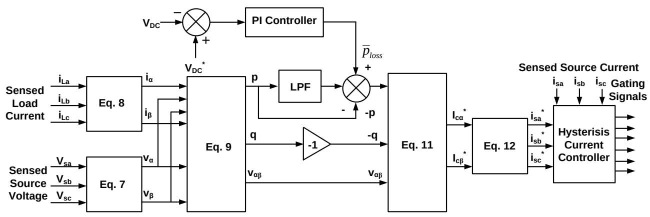


Fig. 5. Shunt active filter control

In order to operate properly, The UPQC-PV must have a minimum DC-link (V_{dc}) voltage. The general DC-link voltage value depends on the instantaneous energy that can be generated by UPQC which is defined in Eq.13 [16]:

$$V_{dc} = \frac{2\sqrt{2}V_{LL}}{\sqrt{3}m} \tag{13}$$

Where *m* is the modulation index and V_{LL} is the voltage of UPQC. Considering modulation index of 1 and the grid voltage between line-line (V_{LL}= 380 V), V_{dc} is obtained 620.54 V and chosen as 650 V.

The input of shunt active filter shown in Fig. 6 is DC voltage *(V_{dc})* dan DC voltage reference *(V_{dc}^*)*, while the output is P_{loss} by using the PI controller. Furthermore, P_{loss} of the input variables produce a reference source current) $(i_{sa}^*, i_{sa}^*, i_{sa}^*)$. Then, the reference source current output is compared with current source(i_{sa}, i_{sb}, i_{sc}) by hysteresis current controller to generate a trigger signal in IGBT circuit of shunt active filter. In this paper, PI controller as a DC voltage control algorithm on shunt active filter is proposed.

D. Efficiency of UPQC-PV

The research on the use of 3-Phase 4-Leg Unified Series-Parallel Active Filter Systems using Ultra Capacitor Energy Storage (UCES) to mitigate sag and unbalance voltage has been investigated [17]. In this paper, it was found that the implementation of UCES was able to help system reduce source current compensation when sag voltage on source bus to keep load voltage constant and balanced. During disturbance UCES generates extra power flow to load through a series active filter via dc-link and a series active filter to load. Although it provides an advantage of sag voltage compensation, the use of UCES in this proposed system is also capable of generating losses and efficiency system. By using the same procedure, the authors proposes Eq. (14) for efficiency of UPQC-PV system.

$$Eff\ (\%) = \frac{P_{Source} + P_{Series} + P_{Shunt} + P_{PV} + P_{BES}}{P_{Load}} \tag{14}$$

III. Result and Discussion

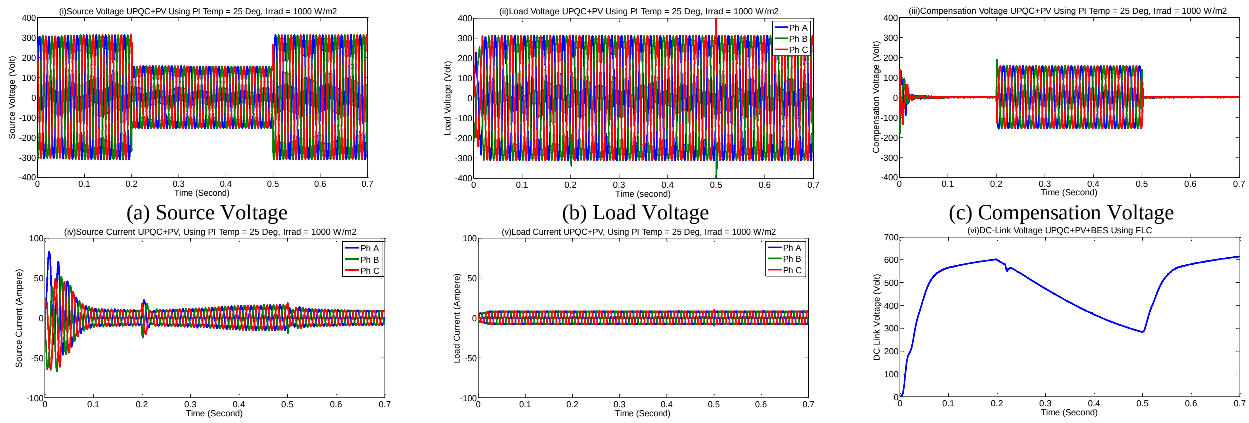
The proposed model analysis is UPQC connected 3P3W (on-grid) system through a DC link supplied by PV known as UPQC-PV system. The system then supplies sensitive voltage devices on load bus. There are two distrurbance scenarios i.e. sag voltage (Sag) and interruption voltage (Inter). In sag voltage scenario, the system is connected to a sensitive load and the source has a 50% sag voltage disturbance for 0.3 s between t = 0.2 s to t = 0.5 s. In interruption voltage scenario, the system is connected to sensitive load and the source experiences a source voltage interruption of 100% for 0.3 s between t = 0.2 s to t = 0.5 s. The UPQC-PV system uses PI controller with constant Kp and Ki are 0.2 and 1.5, respectively. PI controller is used as DC voltage controller on an active filter series and current controller on shunt active filter to keep load voltage constant in case of disturbance voltage happens on the source bus.

The proposed model analysis is carried out by determining sag voltage and interruption voltage on source bus in 3P3W of UPQC-PV system. The measurement parameters are carried out at fixed temperature conditions (T = 250 C) and the different radiation i.e. 200 W/m^2, 400 W/m^2, 600 W/ m^2, 800 W/m^2, 1000 W/m^2 and 1200 W/m^2 . Each of disturbance scenarios at the variable irradiance level amounts to 6 disturbances, so that the total number of scenarios is 12 interruptions. The UPQC-PV system uses controls mounted on the 3P3W System to keep the voltage at sensitive loads remains constant. Then, by using

Matlab/Simulink, the model is run in accordance with the scenario that was previously desired to get the source voltage curve (V_S), load voltage (V_L), compensation voltage (V_C), source current (V_S), load current (V_L), and DC-Link (V_{DC}) voltage. Based on this curve, the average values of source voltage, load voltage, source current and load current are obtained from value of each phase of voltage and current parameters previously obtained. The next research is determining value of active source power, series active power, active shunt power, active load power, PV power contribution, and system efficiency. The measurement of value of phase voltage, phase current, power transfer, and PV power is determined in one cycle starting at t = 0.35 s. The results of the average source voltage, source current, load voltage, and load current in the UPQC-PV system model are presented in Table 1.

TABLE I. VOLTAGE AND CURRENT USING UPQC-PV SYSTEM UNDER SAG AND INTERRUPTION WITH VARIABLE IRRADIANCE LEVEL

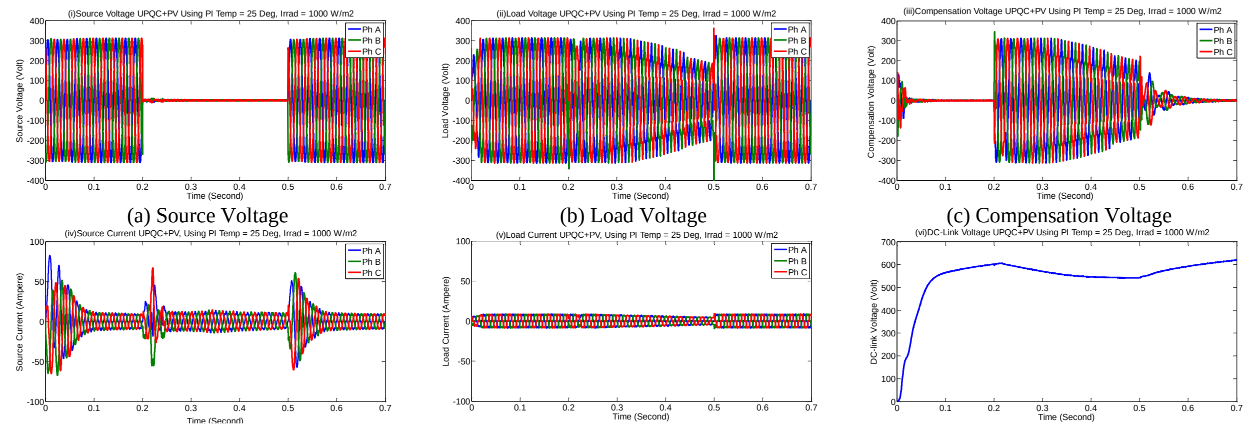
Irradiance (W/m^2)	Source Voltage V_S (Volt)				Load Voltage V_L (Volt)				Source Current I_S (Ampere)				Load Current I_L (Ampere)			
	Ph A	Ph B	Ph C	Avg	Ph A	Ph B	Ph C	Avg	Ph A	Ph B	Ph C	Avg	Ph A	Ph B	Ph C	Avg
Sag Voltage and T = 25^0 C																
200	153.9	153.9	153.9	**153.9**	310.1	310.1	310.1	**310.1**	11.77	11.79	11.35	**11.63**	8.590	8.589	8.587	**8.589**
400	154.1	154.1	154.1	**154.1**	310.1	310.1	310.1	**310.1**	10.91	10.98	10.94	**10.94**	8.589	8.590	8.588	**8.589**
600	154.1	154.1	154.1	**154.1**	310.1	310.1	310.1	**310.1**	10.92	10.88	10.98	**10.93**	8.589	8.588	8.589	**8.589**
800	154.0	154.0	154.0	**154.0**	310.1	310.1	310.1	**310.1**	11.45	10.38	11.49	**11.11**	8.588	8.589	8.589	**8.589**
1000	153.8	153.8	153.8	**153.8**	310.1	310.1	310.1	**310.1**	13.39	13.33	13.41	**13.38**	8.589	8.589	8.588	**8.589**
1200	153.8	153.8	153.8	**154.8**	310.1	310.1	310.1	**310.1**	13.69	13.58	13.69	**13.65**	8.589	8.589	8.588	**8.589**
Interuption Voltage and T = 25^0 C																
200	1.229	1.350	1.274	**1.284**	232.8	253.2	247.2	**244.4**	11.65	12.65	12.23	**12.18**	6.561	6.798	6.974	**6.778**
400	1.322	1.416	1.367	**1.368**	245.7	264.2	261.1	**257.0**	12.22	12.66	12.87	**12.51**	6.946	7.051	7.396	**7.131**
600	1.333	1.414	1.363	**1.370**	246.6	263.9	261.8	**257.4**	12.25	12.57	12.85	**12.56**	6.964	7.033	7.406	**7.134**
800	1.304	1.385	1.344	**1.341**	240.1	258.5	255.8	**251.5**	12.13	12.37	12.71	**12.40**	6.788	6.885	7.234	**6.969**
1000	1.190	1.316	1.237	**1.247**	229.2	249.1	242.8	**240.4**	11.31	11.86	11.91	**11.69**	6.443	6.698	6.289	**6.477**
1200	1.227	1.319	1.269	**1.272**	227.5	246.8	243.7	**239.2**	11.50	11.80	12.06	**11.78**	6.433	6.557	6.882	**6.624**



(a) Source Voltage (b) Load Voltage (c) Compensation Voltage

(d) Source Current (e) Load Curret (f) DC-Link Voltage

Fig 6. Performance of UPQC-PV system under sag voltage with temperature 25^0 C and irradiance 1000 W/m^2



(a) Source Voltage (b) Load Voltage (c) Compensation Voltage

(d) Source Current (e) Load Current (f) DC-Link Voltage

Fig 7. Performance of UPQC-PV system under interruption voltage with temperature 25^0 C and irradiance 1000 W/m^2

Fig. 6 shows that in sag voltage, UPQC-PV system at t = 0.2 s to t = 0.5 s, irradiance = 1000 W/m^2 and temperature = 25^0 using PI control, the average source voltage (V_S) (Fig. 6.a) decreased by 50% from 310.1 V to 153.8 V (Fig. 2.b). During this duration, the average source current increases slightly to 13.38 A (Fig. 6.d) because PV contributes power to the load through a DC-link series active filter series by injecting a compensation voltage (V_C) of 156.3 V (Fig. 12.c) through the injection transformer in an active series filter so that an average load voltage (V_L) remains stable at 310.1 V (Fig. 2.b). At that time, the PI controller on shunt active filter works to keep DC voltage (V_{DC}) stable and an average current source (I_S) increases close to 13.38 A (Fig. 12.d) to keep the average I_L stable at 8,589 A (Figure 12.e).

Fig. 7 shows that in the interuption voltage scenario, the UPQC-PV system at t = 0.2 s to t = 0.5 s, irradiation = 1000

W/m2 and temperature = 25^0 using PI controller, an average V_S drops by 100 % to 1.247 V (Fig. 7.a). Under these conditions, the UPQC-PV system is unable to produce maximum power to UPQC DC-link circuit and injects the average V_C (Fig. 3.c) through injection transformer in an active series filter. So at t = 0.2 s to t = 0.5, an average V_L (Fig. 7.b) decreases to 240.4 V. During the interruption period, application of the PI controller to an active shunt filter is unable to maintain average V_{DC} (Fig.7 .f) and V_C to remain constant, so an average I_L also decrease to 6,447 A (Fig. 7.e).

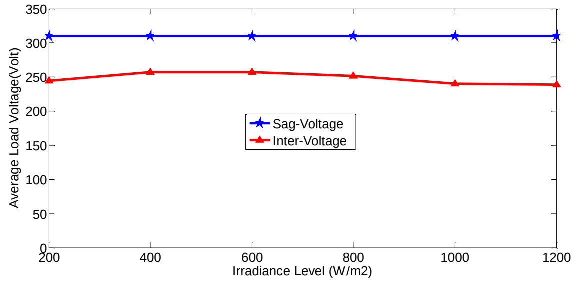


Fig. 8. The average load voltage of UPQC-PV system

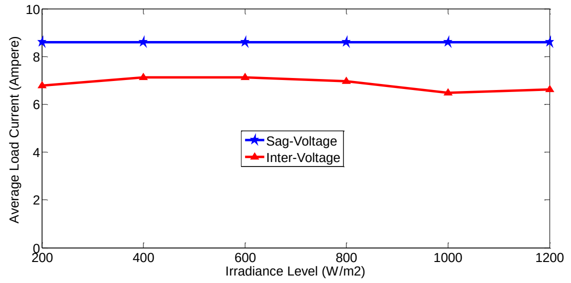


Fig. 9. The average load current of UPQC-PV system

Table 1 and Fig. 8 show that in sag voltage and irradiance level of 200W/m^2 to 1200 W/m^2, the 3P3W system using UPQC-PV with PI controller is still able to maintain an average load voltage of 310.1 V. However, in the interruption voltage and irradiance levels are equally sequential, the average load voltage drops to between 239.2 V and 257 V. Table 1 and Fig. 9 also show that in sag voltage and irradiance levels of 200 W/m^2 to 1200 W/m^2, the 3P3W system uses UPQC- PV with PI controller is still able to maintain an average load current of 8.589 A. However, in the scenario of interruption voltage and same irradiance levels, the average load current drops to between 6.624 A and 7.134 A. Thus, the UPQC-PV system is able maintain a load voltage, if there is a sag voltage at source bus. Otherwise, in interruption voltage scenario, the UPQC-PV system has not been able to maintain load voltage and load current remain constant.

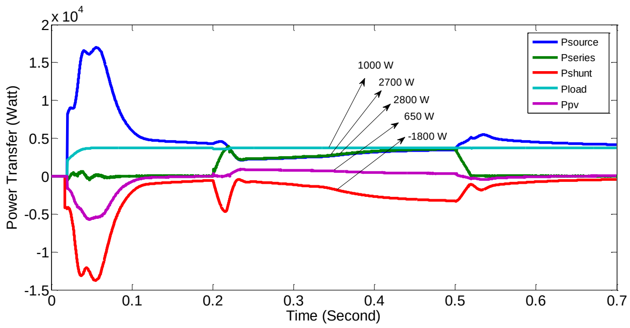


Fig. 10. Power transfer of UPQC-PV system under sag voltage under Temperature = 25^0 C and Irradiance = 1000 W/m^2

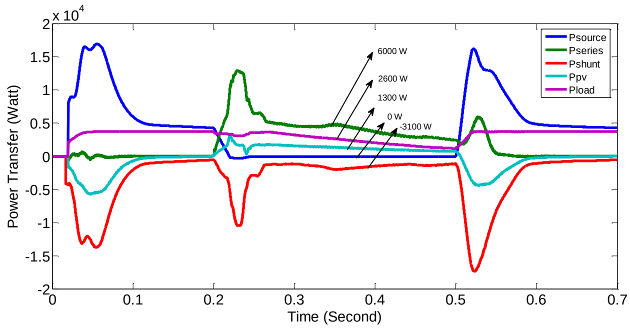


Fig. 11. Power transfer of UPQC-PV system under interruption voltage under Temperature = 25^0 C and Irradiance = 1000 W/m^2

Fig. 8 shows that in sag voltage, the UPQC-PV system at t = 0.2 s to t = 0.5 s, irradiance = 1000 W/m^2 and temperature = 25^0 C using PI controller, source power value (P_S) decreased to 2700 W. Series power (P_{se}) increased by 2800 W and shunt power (P_{Sh}) decreased by -1800 W, PV power by 650 W, so that load power (P_L) value is equal to 3715 W. Fig. 9 shows that in interruptions voltage, UPQC-PV system at t = 0.2 s to t = 0.5 s, irradiance = 1000 W/m^2 and temperature = 25^0 C, the value of the source power (P_S) drops to 0 W. The series power (P_{se}) increases by 6000 W and shunt power (P_{Sh}) decreased by -3100 W, and PV power increased by 1300 W, so that the load power (P_L) dropped to 2600 W.

TABLE II. POWER TRANSFER IN UPQC-PV SYSTEM

Irr (W/m^2)	Power Transfer (Watt)					Eff (%)
	Source Power	**Series Power**	**Shunt Power**	**Load Power**	**PV Power**	
Sag Voltage and T= 25^0 C						
200	2700	2800	-1720	3715	680	83.30
400	2455	2550	-1200	3714	920	78.60
600	2455	2550	-1200	3714	920	78.52
800	2534	2620	-1332	3714	810	80.18
1000	2700	2800	-1800	3715	650	85.40
1200	2960	3080	-2250	3715	500	86.59
Interruption Voltage and T= 25^0 C						
200	0	4950	-2000	2675	1440	60.93
400	0	4600	-1500	2805	1620	59.43
600	0	4650	-1515	2800	1635	58.70
800	0	4895	-1850	2754	1544	60.01
1000	0	4900	-1900	2650	1300	61.63
1200	0	4850	-1930	2560	1300	59.79

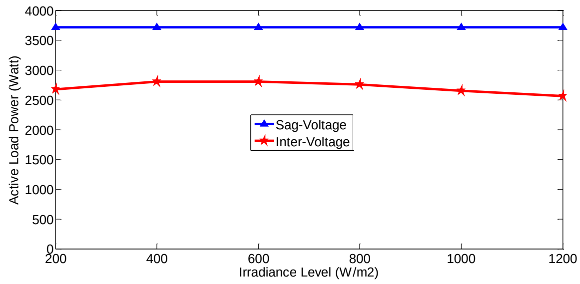


Fig. 12. Active load power on UPQC-PV system

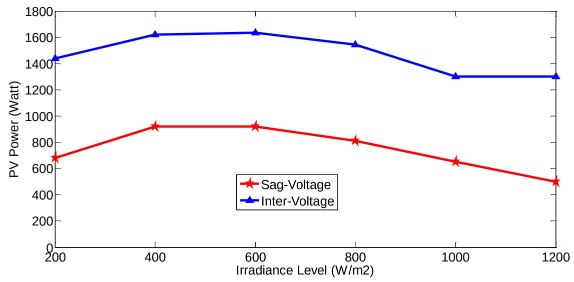


Fig. 13. PV power on UPQC-PV system

Table 2 and Fig. 12 show that in sag voltage and irradiance levels of 200 W/m^2 to 1200 W/m^2, the 3P3W system uses UPQC-PV with PI still able to maintain active power above 3714 W. However, in the interruption voltage and same irradiance level, active load power drops to between 2560 W and 2805 W. Table 2 and Fig. 13 also show that in sag voltage and irradiance levels of 200 W/m^2 to 1200 W/m^2, the 3P3W system uses UPQC-PV with PI still able to generate PV power between 500 W to 920 W. In the scenario of interruption voltage and irraradiation levels with the same sequence, the PV power increases between 1300 W to 1635 W. However, the increase on PV power in interruption voltage has not been able to meet power on load side so that load power finally drops to 2650 W.

Fig. 14 shows that in sag voltage and irrradiance level of 200 W/m^2 to 1200 W/m^2, the 3P3W system using UPQC-PV with PI controller is able to produce a system efficiency of 78.60% to 86.59%. Otherwise, in the interruption voltage and irrradiance increases, the efficiency of UPQC-PV decreases between 58.70% to 61.63%.

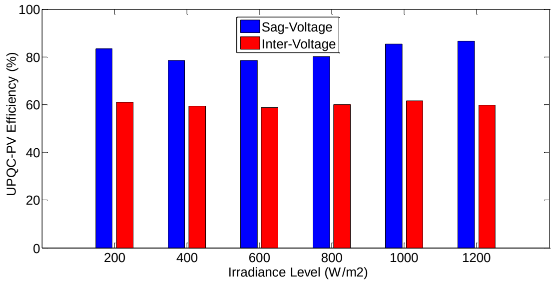


Fig. 14. Efficiency of UPQC-PV system under sag and interruption

IV. Conclusion

The analysis of UPQC-PV system model has been presented in this paper. The PV is connected to a 3P3W distribution system with 380 volts (L-L) and a frequency of 50 hertz, through UPQC-DC link circuit. This system is used to maintain and supply sensitive loads. This reseach shows that in sag voltage and irradiance levels of 200 W/m^2 to 1200 W/m^2, the 3P3W system uses UPQC-PV with PI still able to maintain active load power above 3714 W. However, in the interruption voltage and same irradiance level, the active load power drops to between 2560 W and 2805 W. This paper also show that in sag voltage and same irradiance level, the 3P3W system uses UPQC-PV with PI still able to generate PV power between 500 W to 920 W. In the scenario of interruption voltage and same irradiance levels, the power that can be generated by PV increases between 1300 W to 1635 W. However, the increase on PV power in the interruption voltage has not been able to meet active load power so it finally drops to 2650 W.

Appendix

Three phase grid: RMS voltage 380 volt (L-L), 50 Hz, line impedance: R_s = 0.1 Ohm L_s = 15 mH; series and shunt active filter: series inductance L_{se} = 0.015 mH; shunt inductance L_{sh} = 15 mH; injection transformers: rating 10 kVA, 50 Hz, turn ratio (N_1/N_2) = 1:1; sensitive load: resistance R_L = 60 ohm, inductance L_L = 0.15 mH, load impedance R_c = 0.4 ohm and L_c = 15 mH; unbalance load: resistance R_1 = 24 ohm, R_2 = 12 ohm, and R_3 = 6 ohm, capacitance C_1,C_2, C_3 = 2.2 μF; DC-link: voltage V_{DC} = 650 volt and capacitance C_{DC} = 3000 μF; photovoltaic: active power = 0.6 kW temperature = 25^0 C, irradiance = 1000 W/m^2; PI controller: K_p = 0.2, K_i = 1.5; input: error (V_{dc}) and delta error (ΔV_{dc}); output: instantaneous $\bar{p}_{loss}$.

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Lampiran 2.4

Revisi pertama makalah

Power Transfer Analysis Using UPQC-PV System Under Sag and Interruption With Variable Irradiance

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***Abstract*— This paper presents an analysis of the Unified Power Quality Conditioner-Photovoltaic (UPQC-PV) system under sag and interruption voltage with variable irradiance. The PV is connected to a three-phase three-wire (3P3W) distribution system with 380 volts (L-L) and a frequency of 50 hertz, through UPQC-DC link. This system is used to maintain and supply sensitive loads. This paper shows that in the sag voltage and irradiance levels of 200 W/m^2 to 1200 W/m^2, the 3P3W system uses UPQC-PV with proportional-integral (PI) still able to maintain the active load power above 3714 W. However, in the interruption voltage and same irradiance level, the load active power drops to between 2560 W and 2805 W. This research also shows that in the sag voltage and same irradiance levels, the 3P3W system uses UPQC-PV with PI still able to generate PV power between 500 W to 920 W. In the interruption voltage and same irradiance levels, the power that can be generated by PV increases between 1300 W to 1635 W. Otherwise, at 25^0 C and 1000 W/m^2, the increase in PV power on interruption voltage has not been able to meet the load active power consumption, so it finally drops to 2650 W. This paper is simulated using Matlab/Simulink.**

Keywords—UPQC, Photovoltaic, Sag, Interruption, Irradiance

I. INTRODUCTION

The decreasing of fossil energy sources and increasing concerns about environmental impacts have caused renewable energy (RE) sources i.e., photovoltaic (PV) and wind, to develop into alternative energy on power generation. Solar or PV generator is one of the most potential RE technologies because it only converts sunlight to generate electricity, where the resources are available in abundant and they are free and relatively clean. Indonesia has a huge energy potential from the sun because it is located in the equator. Almost all regions of Indonesia receive around 10 to 12 hours of sunshine per day, with an average irradiation intensity of 4.5 kWh/m^2 or equivalent to 112.000 GW.

Even though, PV can generate power, this device also has a disadvantage: it results in several voltage and current disturbances, as well as harmonics due to the presence of several types of PV devices and power converters and increasing the number of non-linear loads connected to the source, causing a decrease in power quality (PQ). To overcome this problem and to improve PQ due to the presence of non-linear load and integration of PV into the grid, UPQC is proposed. This device has been a function to compensate for problems of voltage source quality i.e. sag, swell, unbalance, flicker, harmonics, and load current quality problems i.e. harmonics, imbalance, reactive current, and neutral current. UPQC is part of an active power filter consisting of a shunt active filter and series active filter connected in parallel and serving as a superior controller to solve several PQ problems simultaneously [1]. UPQC series component is responsible for reducing the number of disturbances on source side i.e. sag/swell voltage, flicker, unbalanced voltage, and source voltage harmonics. This equipment has served to inject a certain amount of voltage to keep load voltage at desired level so that it returns to balance and distortion-free. UPQC shunt component is responsible for overcoming current quality problems i.e. low power factor, load current harmonics, and unbalanced currents. This equipment has been a function of injection current into the AC system so that the current source becomes a balanced sinusoidal and in phase with source voltage [2]. The design and dynamic performance of integrated PV with UPQC (PV-UPQC) under variable irradiance condition and voltage sag/swell, and load unbalance has been investigated [3]. The proposed system was able to combine both the benefits of distributed generators (DGs) and active power filters. The PV-UPQC combination was also able to reduce harmonics due to nonlinear loads and was able to maintain total harmonics distortion (THD) of grid voltage, load voltage and grid current below the IEEE-519. The system was found to be stable under radiation variations, voltage sag/swell, and load unbalances conditions.

The dynamic performance-based auto-tuned PI for UPQC-PV system has been analyzed [4]. This online optimization methodology is implemented for PV-UPQC to determine the best value of PI gain. The Vector-Proportional Integral (UV-PI) and Proportional Resonant-Response (PR-R) controllers in shunt and series converters significantly increase PV-UPQC performance by reducing convergence time, settling time, switching harmonics, complexity, and dynamic response so that they become more effective. PV-UPQC performance using a control algorithm based on Synchronous Reference Frame (SRF) with the Phase Lock Loop (PLL) mechanism has been presented [5]. Unbalanced load voltage containing harmonics and pure unbalanced pure load voltage has been compensated and balanced so that the load voltage is maintained constant. UPQC was supplied by 64 PV panels using boost converters, PI controllers,

maximum power point tracking (MPPT) with Perturb and Observer (P and O), and having a momentary reactive power theory (p-q theory) which has been proposed [6]. The system has successfully carried out reactive power compensation and reduced source current and load voltage harmonics. However, this study did not address the mitigation of sag voltage and other disturbances caused by PV penetration.

PV supported by UPQC using Space Vector Pulse Width Modulation (SVPWM) compared to hysteresis control in a three-phase distribution system has been proposed [7]. The system was used to improve PQ and to reduce the burden of 3 phase AC network by supplying power obtained from PV. The UPQC system can supply reactive power needed to increase power factor, reduce voltage and current distortion, and PV helps active injection power into the load. A conceptual study of UPQC on three-phase four-wire (3P4W) system connected to linear and non-linear loads simultaneously has been carried out [8]. The sinusoidal current control strategy drives UPQC in such a way that the supply system has drawn a constant sinusoidal current under steady-state conditions. Besides, the shunt converter also produced reactive power as required by load so that it can improve power factor and reduce THD of source current.

Artificial neural networks based on SRF theory as a control to compensate for PQ problems of 3P3W system through UPQC for various balanced/unbalanced/distorted conditions at load and source have been proposed [9]. The proposed model has successfully mitigated harmonic/reactive currents, unbalanced source and load, and unbalanced current/voltage. Investigation on enhancements PQ including sag and source voltage harmonics on the grid using UPQC provided by PV array connected to DC links using PI compared to FLC has been conducted [10]. The simulation shows that FLC on UPQC and PV could increase THD voltage source better than PI. The improvement of PQ using UPQC on microgrid supplied by PV and wind turbine have been implemented using PI and FLC. Both methods can improve PQ and to reduce distortion in output power [11]. Research on the use of Battery Energy Storage (BES) in UPQC supplied by PV to improve PQ in 3P3W system using FLC validated PI on various disturbances in source and load side has been investigated [12]. The research showed that FLC on the UPQC-Battery Energy Storage (BES) system supplied by PV was able to significantly reduce load current harmonics and source voltage harmonics in the number of disturbances, especially in interruption voltage that occurs on the source bus.

This research presents an analysis of the UPQC-PV system model under sag and interruption voltage with variable irradiance. The PV is connected to a 3P3W system with 380 volts (L-L) and a frequency of 50 hertz, through UPQC-DC link. This system is used to maintain load voltage and load active power constant, as well as to supply sensitive loads. This paper is presented as follows. Section 2 explains the proposed method, UPQC-PV model, parameter simulation, PV model, active filter series and shunt filter control, application of PI, as well as UPQC model efficiency. Section 3 shows results and discussion of load voltage, load current, source active power, load active power, series active power, shunt active power, PV power using PI. In this section, six disturbance scenarios are presented and the results are verified with Matlab/Simulink. Finally, this paper is concluded in Section 4.

II. Research Method

A. Proposed Method

Fig. 1 shows the proposed model in this paper. The PV is connected to a 3P3W distribution system with 380 volts (L-L) and a frequency of 50 hertz, through UPQC-DC link circuit. This system is known as the UPQC-PV system and it is used to maintain and supply sensitive loads. The PV array generates DC power at a constant temperature, variable solar irradiance, and it is connected to DC-link via a DC-DC boost converter. The MPPT method with the P and O algorithm helps PV to generate maximum power, result in an output voltage, which then becomes an input voltage for the DC-DC boost converter. This device has a function to adjust duty cycle value with PV output voltage as an input voltage to produce output voltage according to the DC-link voltage of UPQC. The PV has been a function as an alternative source by injecting power to keep load voltage constant, in the case of an interruption voltage that occurs on the source or points common coupling (PCC) bus.

The analysis of the proposed model is carried out by determining sag and interruption voltage scenarios on the source bus in 3P3W using the UPQC-PV system. The measurement parameters are carried out at fixed temperature (T = 25^0 C) and variable irradiance i.e. 200 W/m^2, 400 W/m^2, 600 W/m^2, 800 W/m^2, 1000 W/m^2 and 1200 W/m^2. Each disturbance scenario at variable irradiance level amounts to 6 disturbance, so the total number of scenarios is 12 disturbances. The UPQC-PV system uses PI to maintain voltage in a series active filter and current in an active shunt filter to keep the voltage at sensitive loads remains constant. The parameters investigated i.e. voltage and current on source bus, voltage and current on load bus, active source power, series active power, shunt active power, load active power, and PV power. The next step is to determine the efficiency value of the UPQC-PV system on sag and interruption voltage scenario in variable irradiance to show the contribution of PV in the mitigation of both voltage disturbances on source bus. Fig. 2 shows power transfer using the UPQC-PV system. Then, the simulation parameters for the proposed model are shown in Appendix Section.

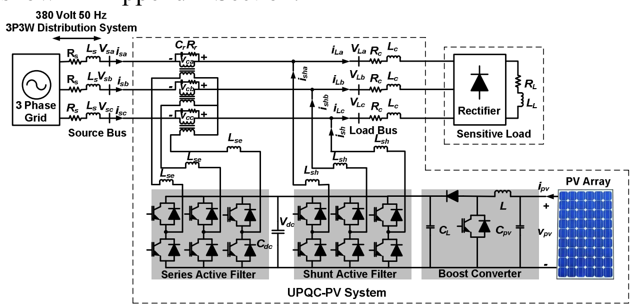

Fig. 1. Proposed model of as UPQC-PV system

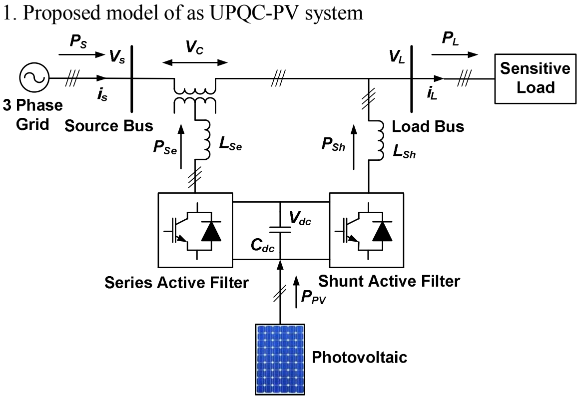

Fig. 2. Power transfer using UPQC-PV system

B. Modeling of PV Array

Fig. 3 shows the equivalent circuit and V-I characteristics of a solar panel. It consists of several PV cells that have external connections in series, parallel, or both combination [13].

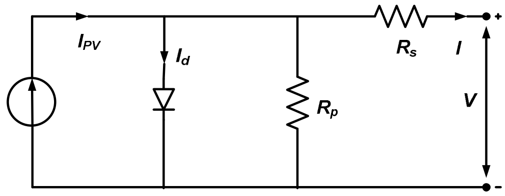

Fig. 3. Equivalent circuit of solar panel

The characteristic of V-I is shown in Eq. (1):

$$I = I_{PV} - I_o \left[exp\left(\frac{V+R_S I}{a\, V_t}\right) - 1\right] - \frac{V+R_S I}{R_P} \tag{1}$$

Where I_{PV} is PV current, I_o is saturated reverse current, $'a'$ is the ideal diode constant, $Vt = N_S KTq^{-1}$ is the thermal voltage, N_S is the number of series cells, q is electron charge, K is Boltzmann constant. T is temperature p-n junction. R_S and R_P are series and parallel resistance of the solar panels. I_{PV} has a linear relationship with the light intensity and also varies with temperature variations. I_o is dependent value on the temperature variations. The value of I_{PV} and I_o are determined using Eq (2) and Eq. (3):

$$I_{PV} = \left(I_{PV,n} + K_I \Delta T\right)\frac{G}{G_n} \tag{2}$$

$$I_o = \frac{I_{SC,n} + K_I \Delta T}{\exp(V_{OC,n} + K_V \Delta T)/aV_t - 1} \tag{3}$$

Where $I_{PV,n}$, $I_{SC,n}$, and $V_{OC,n}$ are PV current, short-circuit current, and open-circuit voltage under standard conditions ($T_n = 25^0C$ and $G_n = 1000\ W/m^2$), respectively. The K_I value is a coefficient of short circuit current to temperature, $\Delta T = T - T_n$ is temperature deviation from standard temperature, G is light intensity and K_V is a coefficient of open-circuit voltage ratio to temperature. Open-circuit voltage, short-circuit current, and voltage-current related to maximum power are three important values of I-V characteristics of a solar panel. These points are changed by variation in atmospheric conditions. By using Eq. (4) and Eq. (5) derived from PV model, short-circuit current, and open-circuit voltage can be calculated under different atmospheric conditions.

$$I_{SC} = (I_{SC} + K_I \Delta T)\frac{G}{G_n} \tag{4}$$

$$V_{OC} = (V_{OC} + K_V \Delta T) \tag{5}$$

C. Control of Series Active Filter

The main function of a series active filter is to protect the sensitive load from several voltage disturbances at the PCC bus. The algorithm of a source voltage and a load voltage control strategy in a series active filter circuit is shown in Fig. 4. This control strategy generates the unit vector template from a distorted input source. Then, the template is expected to be an ideal sinusoidal signal with a unity amplitude. Then, the distorted source voltage is measured and divided by peak the amplitude of base input voltage V_m as stated in Eq. (6) [6].

$$V_m = \sqrt{\frac{2}{3}(V_{sa}^2 + V_{sb}^2 + V_{sc}^2)} \tag{6}$$

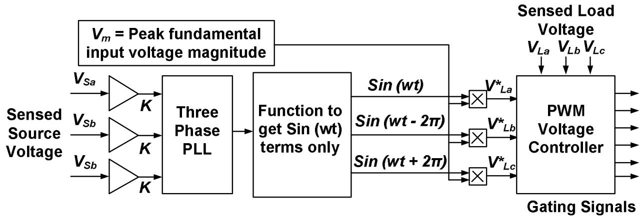

Fig. 4 Series active filter control

A three-phase PLL is used to produce sinusoidal unit vector templates with phase lagging through the use of sine function. The load voltage of the reference signal is determined by multiplying unit vector templates by the peak value of base input voltage amplitude V_m. The load reference voltage $(V_{La}^*, V_{Lb}^*, V_{Lc}^*)$ is then compared with sensed load voltage (V_{La}, V_{Lb}, V_{Lc}) with a PWM controller which is used to generate the desired trigger signal in a series active filter. Fig. 4 shows the control of a series active filter.

D. Control of Shunt Active Filter

The main function of an active shunt filter is to mitigate PQ problems on the load side. The control methodology of a shunt active filter is that the absorbed current from the PCC bus is a balanced positive sequence current including an unbalanced sag voltage on the PCC bus, an unbalanced, or a non-linear load. To obtain satisfactory compensation caused by interference due to non-linear load, many algorithms have been used in some references. This research uses the method of instantaneous reactive power theory or "p-q" theory. The voltages and currents in Cartesian coordinates can be transformed into Cartesian coordinates αβ as stated in Eq. (7) and Eq. (8) [6].

$$\begin{bmatrix} v_\alpha \\ v_\beta \end{bmatrix} = \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} \tag{7}$$

$$\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} = \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} \tag{8}$$

Calculation of real power (p) and imaginary power (q) is shown in Eq. (9). Real and imaginary power are measured power instantaneously and expressed in matrix form. The presence of mean and fluctuating components in an instantaneous component is shown in Eq. (10) [14].

$$\begin{bmatrix} p \\ q \end{bmatrix} = \begin{bmatrix} v_\alpha & v_\beta \\ -v_\beta & v_\alpha \end{bmatrix} \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} \tag{9}$$

$$p = \bar{p} + \tilde{p} \quad ; \quad q = \bar{q} + \tilde{q} \tag{10}$$

Where $\bar{p}$ = the average component of real power, $\tilde{p}$ = the fluctuating component of real power, $\bar{q}$ = the average component of imaginary power, $\tilde{q}$ = the fluctuating component of imaginary power. The total of imaginary power (q) and fluctuating components of real power $(\tilde{p})$ is selected as power references and current references and is utilized through the use of Eq. (10) to compensate for harmonics and reactive power [15]. Fig. 5 shows a shunt active filter control [15].

$$\begin{bmatrix} i_{c\alpha}^* \\ i_{c\beta}^* \end{bmatrix} = \frac{1}{v_\alpha^2 + v_\beta^2} \begin{bmatrix} v_\alpha & v_\beta \\ v_\beta & -v_\alpha \end{bmatrix} \begin{bmatrix} -\tilde{p} + \bar{p}_{loss} \\ -q \end{bmatrix} \tag{11}$$

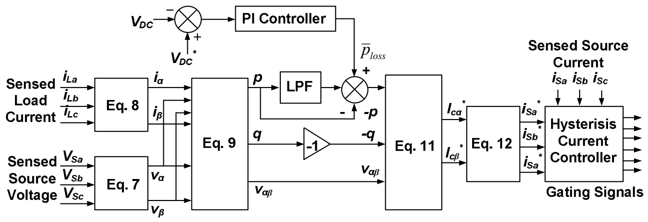

Fig. 5. Shunt active filter control

The $\bar{p}_{loss}$ signal is obtained from the voltage regulator and is used as average real power. It can also be expressed as instantaneous active power associated with resistive losses and switching losses from UPQC. The error is obtained by comparing the actual value of DC-link capacitor voltage with the reference value processed using a PI controller, driven by a closed voltage control to minimize steady-state errors from voltage through DC-link circuit to zero. The compensation current $(i_{c\alpha}^*, i_{c\beta}^*)$ is needed to meet load power demand as shown in Eq. (12). The current is expressed in coordinates $\alpha - \beta$. The compensation current is used to obtain the source phase current by using Eq. (13) for compensation. The source phase current $(i_{sa}^*, i_{sa}^*, i_{sa}^*)$ is expressed in the abc axis obtained from the compensation current in $\alpha - \beta$ coordinates and is presented in Eq. 12 [15] .

$$\begin{bmatrix} i_{sa}^* \\ i_{sb}^* \\ i_{sc}^* \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 0 \\ -1/2 & \sqrt{3}/2 \\ -1/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} i_{c\alpha}^* \\ i_{c\beta}^* \end{bmatrix} \tag{12}$$

To operate properly, The UPQC-PV must have a minimum DC-link voltage (V_{dc}) . The general DC-link voltage value depends on the instantaneous energy that can be generated by UPQC which is defined in Eq.13 [16]:

$$V_{dc} = \frac{2\sqrt{2V_{LL}}}{\sqrt{3}m} \tag{13}$$

Where m is the modulation index and V_{LL} is the voltage of UPQC. Considering the modulation index of 1 and the grid voltage between line-line $(V_{LL} = 380\,V)$, V_{dc} is obtained 620.54 V and chosen as 650 V.

The input of active shunt filter shown in Fig. 6 is DC voltage (V_{dc}) dan DC voltage reference (V_{dc}^*), while the output is P_{loss} using the PI controller. Furthermore, P_{loss} of the input variables produce a reference source current $(i_{sa}^*, i_{sa}^*, i_{sa}^*)$. Then, the reference source current output is compared with the current source (i_{sa}, i_{sb}, i_{sc}) by hysteresis current controller to generate a trigger signal in the IGBT circuit of shunt active filter. In this paper, the PI controller as a DC voltage control algorithm on an active shunt filter, is proposed.

D. Efficiency of UPQC-PV

The research on the use of 3-Phase 4-Leg Unified Series-Parallel Active Filter Systems using Ultra Capacitor Energy Storage (UCES) to mitigate sag and unbalance voltage has been investigated [17]. In this paper, it is found that the implementation of UCES can help the system reduce source current compensation when sag voltage on source bus to keep load voltage constant and balanced. During disturbance, UCES generates extra power flow to load through a series active filter via dc-link and a series active filter to load. Although providing an advantage of sag voltage compensation, the use of UCES in this proposed system is also able to generate losses and to reduce the efficiency of the system. Using the same procedure, the authors propose Eq. (14) for efficiency of UPQC-PV in the formula below.

$$Eff\ (\%) = \frac{P_{Source}+P_{Series}+P_{Shunt}+P_{PV}+P_{BES}}{P_{Load}} \tag{14}$$

III. RESULT AND DISCUSSION

The proposed model analysis is UPQC connected 3P3W (on-grid) system through a DC link supplied by PV known as UPQC-PV system. The system then supplies sensitive voltage devices on the load bus. There are two disturbances scenario i.e. sag voltage (Sag) and interruption voltage (Inter). In the sag voltage scenario, the system is connected to a sensitive load and the source has a 50% sag voltage disturbance for 0.3 s between t = 0.2 s to t = 0.5 s. In the interruption voltage scenario, the system is connected to a sensitive load and the source experiences a 100% source voltage interruption for 0.3 s between t = 0.2 s to t = 0.5 s. The UPQC-PV system uses a PI controller with constant K_P and K_I are 0.2 and 1.5, respectively. PI controller is used as a DC voltage controller on an active filter series and current controller on active shunt filter to keep load voltage constant in case of disturbance voltage happens on the source bus.

The proposed model analysis is carried out by determining sag voltage and interruption voltage on the source bus in 3P3W of the UPQC-PV system. The measurement parameters are carried out at fixed temperature conditions (T = 250 C) and the different radiation i.e. 200 W/m^2, 400 W/m^2, 600 W/ m^2, 800 W/m^2, 1000 W/m^2 and 1200 W/m^2. The disturbance scenarios at the variable irradiance level amounts to 6 disturbances so that the total number of scenarios is 12 interruptions. The UPQC-PV system uses controls mounted on the 3P3W System to keep the voltage at sensitive loads remains constant. Then, using Matlab/Simulink, the model is run following with the scenario that was previously desired to obtain the source voltage curve (V_S), load voltage (V_L), compensation voltage (V_C), source current (I_S), load current (I_L), and DC-Link voltage (V_{DC}). Based on this curve, the average values of source voltage, load voltage, source current and load current are obtained from value of each phase of voltage and current parameters previously obtained. The next research is determining the value of power transfer of active source power, active series power, active shunt power, active load power, PV power contribution, and system efficiency. The measurement of the value of phase voltage, phase current, power transfer, and PV power is determined in one cycle, starting at t = 0.35 s. The results of the average source voltage, source current, load voltage, and load current in the UPQC-PV system model are presented in Table 1.

TABLE I. VOLTAGE AND CURRENT USING UPQC-PV SYSTEM UNDER SAG AND INTERRUPTION WITH VARIABLE IRRADIANCE LEVEL

Irr (W/m^2)	Source Voltage V_S (Volt)				Load Voltage V_L (Volt)				Source Current I_S (Ampere)				Load Current I_L (Ampere)			
	Ph A	Ph B	Ph C	Avg	Ph A	Ph B	Ph C	Avg	Ph A	Ph B	Ph C	Avg	Ph A	Ph B	Ph C	Avg
Sag Voltage and T = 25^0 C																
200	153.9	153.9	153.9	**153.9**	310.1	310.1	310.1	**310.1**	11.77	11.79	11.35	**11.63**	8.590	8.589	8.587	**8.589**
400	154.1	154.1	154.1	**154.1**	310.1	310.1	310.1	**310.1**	10.91	10.98	10.94	**10.94**	8.589	8.590	8.588	**8.589**
600	154.1	154.1	154.1	**154.1**	310.1	310.1	310.1	**310.1**	10.92	10.88	10.98	**10.93**	8.589	8.588	8.589	**8.589**
800	154.0	154.0	154.0	**154.0**	310.1	310.1	310.1	**310.1**	11.45	10.38	11.49	**11.11**	8.588	8.589	8.589	**8.589**
1000	153.8	153.8	153.8	**153.8**	310.1	310.1	310.1	**310.1**	13.39	13.33	13.41	**13.38**	8.589	8.589	8.588	**8.589**
1200	153.8	153.8	153.8	**154.8**	310.1	310.1	310.1	**310.1**	13.69	13.58	13.69	**13.65**	8.589	8.589	8.588	**8.589**
Interuption Voltage and T = 25^0 C																
200	1.229	1.350	1.274	**1.284**	232.8	253.2	247.2	**244.4**	11.65	12.65	12.23	**12.18**	6.561	6.798	6.974	**6.778**
400	1.322	1.416	1.367	**1.368**	245.7	264.2	261.1	**257.0**	12.22	12.66	12.87	**12.51**	6.946	7.051	7.396	**7.131**
600	1.333	1.414	1.363	**1.370**	246.6	263.9	261.8	**257.4**	12.25	12.57	12.85	**12.56**	6.964	7.033	7.406	**7.134**
800	1.304	1.385	1.344	**1.341**	240.1	258.5	255.8	**251.5**	12.13	12.37	12.71	**12.40**	6.788	6.885	7.234	**6.969**
1000	1.190	1.316	1.237	**1.247**	229.2	249.1	242.8	**240.4**	11.31	11.86	11.91	**11.69**	6.443	6.698	6.289	**6.477**
1200	1.227	1.319	1.269	**1.272**	227.5	246.8	243.7	**239.2**	11.50	11.80	12.06	**11.78**	6.433	6.557	6.882	**6.624**

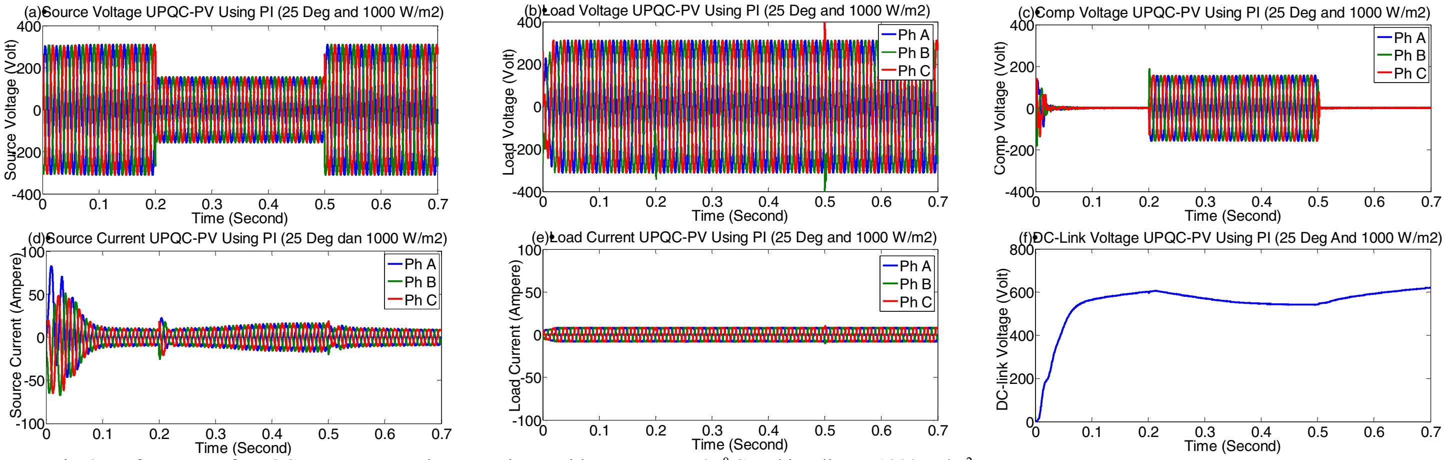

Fig 6. Performance of UPQC-PV system under sag voltage with temperature 25^0C and irradiance 1000 W/m^2

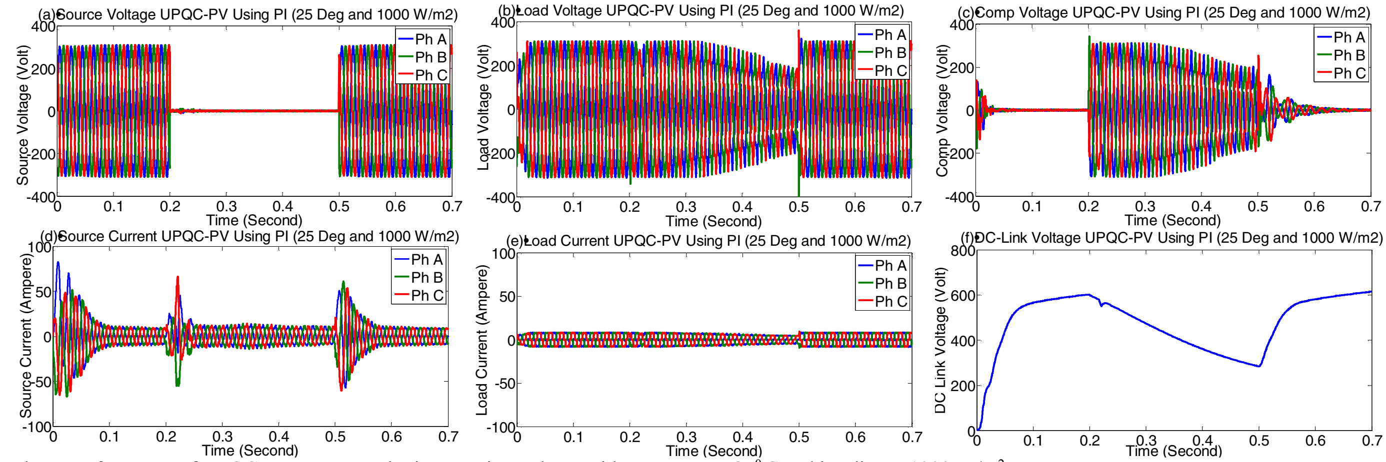

Fig 7. Performance of UPQC-PV system under interruption voltage with temperature 25^0C and irradiance 1000 W/m^2

Fig. 6 shows that in sag voltage, the UPQC-PV system at t = 0.2 s to t = 0.5 s, irradiance = 1000 W/m^2 and temperature = 25^0 using PI control, the average source voltage (V_S) (Fig. 6.a) decreased by 50% from 310.1 V to 153.8 V (Fig. 6.b). During this duration, the average source current (I_S) increases slightly to 13.38 A (Fig. 6.d) because the PV contributes power to the load through a DC-link series active filter by injecting a compensation voltage (V_C) of 156.3 V (Fig. 6.c) through the injection transformer in the active series filter so that an average load voltage (V_L) remains stable at 310.1 V (Fig. 6.b). At the same time, the PI controller on shunt active filter works to keep DC voltage (V_{DC}) stable and the average current source (I_S) increases close to 13.38 A (Fig. 6.d) to keep the average (I_L) stable at 8,589 A (Figure 6.e).

Fig. 7 shows that in the interruption voltage scenario, the UPQC-PV system at t = 0.2 s to t = 0.5 s, irradiation = 1000 W/m2 and temperature = 25^0 using PI controller, the average V_S drops by 100 % to 1.247 V (Fig. 7.a). Under these conditions, the UPQC-PV system is unable to produce maximum power to UPQC DC-link circuit and injects the average V_C (Fig. 7.c) through injection transformer in the active series filter. So at t = 0.2 s to t = 0.5, the average V_L (Fig. 7.b) decreases to 240.4 V. During the interruption period, the application of a PI controller to the active shunt filter is unable to maintain the average V_{DC} (Fig.7.f) and V_C to remain constant, so an average I_L also decreases to 6,447 A (Fig. 7.e).

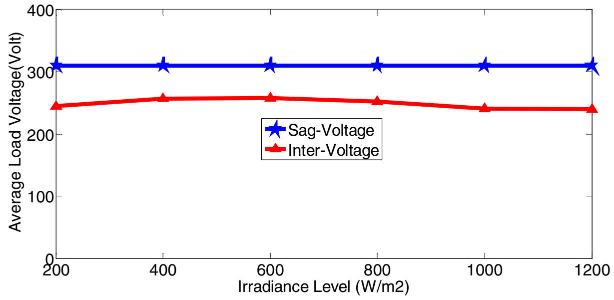

Fig. 8. Average load voltage of UPQC-PV system

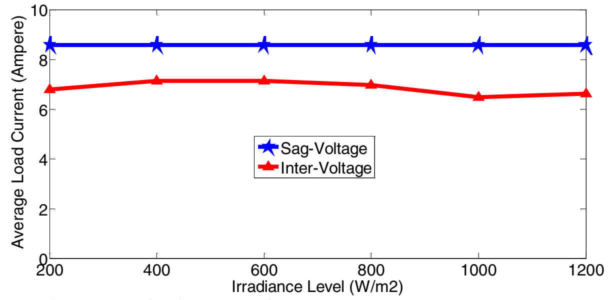

Fig. 9. The average load current of UPQC-PV system

Table 1 and Fig. 8 show that in sag voltage and irradiance level of 200W/m^2 to 1200 W/m^2, the 3P3W system using UPQC-PV with PI controller still can maintain the average load voltage $(V_L)$of 310.1 V. However, in the interruption voltage and the irradiance levels, are equally sequential, the average load voltage (V_L)drops to between 239.2 V and 257 V. Table 1 and Fig. 9 also show that in the sag voltage and the irradiance levels of 200 W/m^2 to 1200 W/m^2, the 3P3W system uses UPQC-PV with PI controller is still able to maintain the average load current (I_L) of 8.589 A. However, in the scenario of the interruption voltage and same irradiance levels, the average load current (I_L) drops to between 6.624 A and 7.134 A. Thus, the UPQC-PV system can maintain the load voltage (V_L), if there is the sag voltage happens at the source bus. Otherwise, in the interruption voltage scenario, the UPQC-PV system can not maintain load voltage (V_L), and the load current (I_L) remains constant.

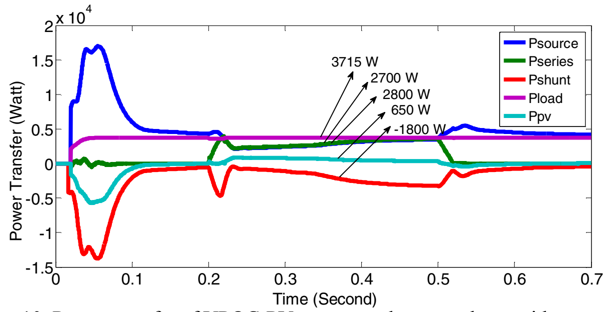

Fig. 10. Power transfer of UPQC-PV system under sag voltage with temperature = 25^0 C and irradiance = 1000 W/m^2

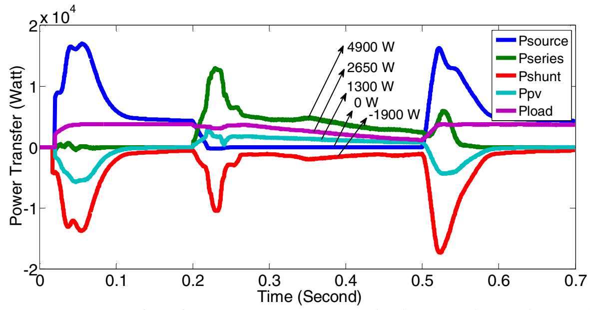

Fig. 11. Power transfer of UPQC-PV system under interruption voltage with temperature = 25^0 C and irradiance = 1000 W/m^2

Fig. 10 shows that in sag voltage, the UPQC-PV system at t = 0.2 s to t = 0.5 s, irradiance = 1000 W/m^2 and temperature = 25^0 C using PI controller, source power value (P_S) decreases to 2700 W. Series power (P_{Se}) increased by 2800 W and shunt power (P_{Sh}) decreased by -1800 W, PV power by 650 W, so that load power (P_L) value is equal to 3715 W. Fig. 11 shows that in interruption voltage, UPQC-PV system at t = 0.2 s to t = 0.5 s, irradiance = 1000 W/m^2 and temperature = 25^0 C, the value of the source power (P_S) drops to 0 W. The series power (P_{Se}) increases by 4900 W and shunt power (P_{Sh}) decreases by -1900 W, and PV power (P_{PV}) increases by 1300 W, so that the load power (P_L) dropped to 2650 W.

Table 2 and Fig. 12 show that in sag voltage and irradiance levels of 200 W/m^2 to 1200 W/m^2, the 3P3W system uses UPQC-PV with PI still able to maintain active power above 3714 W. However, in the interruption voltage and same irradiance level, active load power (P_L) drops to between 2560 W and 2805 W. Table 2 and Fig. 13 also show that in sag voltage and irradiance levels of 200 W/m^2 to 1200 W/m^2, the 3P3W system uses UPQC-PV with PI still able to generate PV power (P_{PV}) between 500 W to 920 W. In the scenario of interruption voltage and irradiance levels with the same condition, the PV power increases (P_{PV}) between 1300 W to 1635 W. However, the increase on PV power (P_{PV}) in interruption, voltage has not been able to meet power on load side so that load power (P_L) Finally it drops to 2650 W.

TABLE II. POWER TRANSFER IN UPQC-PV SYSTEM

Irr (W/m^2)	Power Transfer (Watt)					Eff (%)
	Source Power	Series Power	Shunt Power	Load Power	PV Power	
Sag Voltage and T= 25^0 C						
200	2700	2800	-1720	3715	680	83.30
400	2455	2550	-1200	3714	920	78.60
600	2455	2550	-1200	3714	920	78.52
800	2534	2620	-1332	3714	810	80.18
1000	2700	2800	-1800	3715	650	85.40
1200	2960	3080	-2250	3715	500	86.59
Interruption Voltage and T= 25^0 C						
200	0	4950	-2000	2675	1440	60.93
400	0	4600	-1500	2805	1620	59.43
600	0	4650	-1515	2800	1635	58.70
800	0	4895	-1850	2754	1544	60.01
1000	0	4900	-1900	2650	1300	61.63
1200	0	4850	-1930	2560	1300	59.79

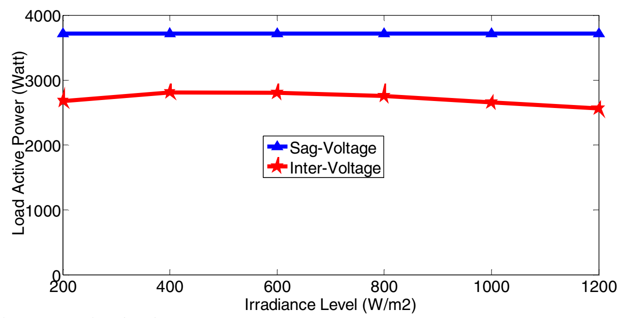

Fig. 12. Active load power on UPQC-PV system

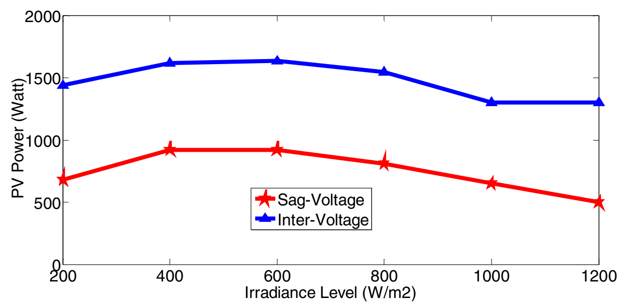

Fig. 13. PV power on UPQC-PV system

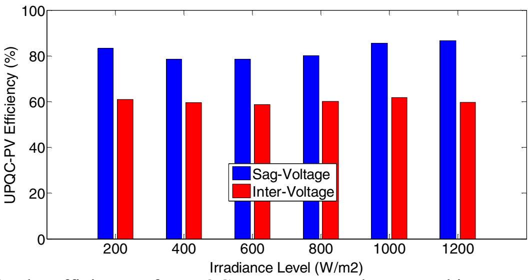

Fig. 14. The efficiency of UPQC-PV system under sag and interruption

Fig. 14 shows that in sag voltage and irradiance level of 200 W/m^2 to 1200 W/m^2, the 3P3W system using UPQC-PV with PI controller can produce a system efficiency of 78.60% to 86.59%. Otherwise, in the interruption voltage and irradiance increases, the efficiency of UPQC-PV decreases between 58.70% to 61.63%.

IV. Conclusion

The analysis of the UPQC-PV system model has been presented in this paper. The PV is connected to a 3P3W distribution system with 380 volts (L-L) and a frequency of 50 hertz, through UPQC-DC link circuit. This system is used to maintain and supply sensitive loads. This research shows that in the sag voltage and irradiance levels of 200 W/m^2 to 1200 W/m^2, the 3P3W system using UPQC-PV with PI can maintain the active load power above 3714 W. However, in the interruption voltage and same irradiance level, the active load power drops to between 2560 W and 2805 W. This paper also shows that in the sag voltage and same irradiance level, the 3P3W system using UPQC-PV with PI can generate PV power between 500 W to 920 W. In the scenario of the interruption voltage and same irradiance levels, the power that can be generated by PV increases between 1300 W to 1635 W. However, at 25^0 C and 1000 W/m^2, the increase in PV power on interruption voltage has not been able to meet the load power so it finally drops to 2650 W. The increase in PV power close to load power is proposed to overcome this problem.

Appendix

Three-phase grid: RMS voltage 380 volt (L-L), 50 Hz, line impedance: R_S = 0.1 Ohm L_S = 15 mH; series and shunt active filter: series inductance L_{Se} = 0.015 mH; shunt inductance L_{Sh} = 15 mH; injection transformers: rating 10 kVA, 50 Hz, turn ratio (N_1/N_2) = 1:1; sensitive load: resistance R_L = 60 ohm, inductance L_L = 0.15 mH, load impedance R_C = 0.4 ohm and L_C = 15 mH; unbalance load: resistance R_1 = 24 ohm, R_2= 12 ohm, and R_3 = 6 ohm, capacitance C_1, C_2, C_3 = 2.2 μF; DC-link: voltage V_{dc} = 650 volt and capacitance C_{dc} = 3000 μF; photovoltaic: active power P_{PV} = 0.6 kW temperature = 25^0 C, irradiance = 1000 W/m^2; PI controller: K_P = 0.2, K_I= 1.5; input: $V_{dc-error}$ and $\Delta V_{dc-error}$; output: instantaneous of power losses ($\bar{p}_{loss}$).

Acknowledgments

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Lampiran 2.3

Revisi kedua makalah

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***Abstract*— This paper presents an analysis of Unified Power Quality Conditioner-Photovoltaic (UPQC-PV) system under sag and interruption voltage with variable irradiance. The PV is connected to a three phase three wire (3P3W) distribution system with 380 volts (L-L) and a frequency of 50 hertz, through UPQC-DC link. This system is used to maintain and supply sensitive loads. This paper shows that in the sag voltage and irradiance levels of 200 W/m^2 to 1200 W/m^2, the 3P3W system uses UPQC-PV with proportional-integral (PI) still able to maintain the load active power above 3714 W. However, in the interruption voltage and same irradiance level, the load active power drops to between 2560 W and 2805 W. This research also shows that in the sag voltage and same irradiance levels, the 3P3W system uses UPQC-PV with PI still able to generate PV power between 500 W to 920 W. In the interruption voltage and same irradiance levels, the power that can be generated by PV increases between 1300 W to 1635 W. Otherwise, at 25^0 C and 1000 W/m^2, the increase in PV power on interruption voltage has not been able to meet the load active power consumption, so it finally drops to 2650 W. This paper is simulated using Matlab/Simulink.**

Keywords—UPQC, Photovoltaic, Sag, Interruption, Irradiance

I. INTRODUCTION

The decreasing of fossil energy sources and increasing concerns about environmental impacts have caused renewable energy (RE) sources i.e. photovoltaic (PV) and wind to develop into alternative energy on power generation. Solar or PV generator is one of the most potential RE technologies because it only converts sunlight to generate electricity, where the resources are available in abundant and they are free and relatively clean. Indonesia has a huge energy potential from the sun because it is located in the equator. Almost all regions of Indonesia receive around 10 to 12 hours of sunshine per day, with an average irradiation intensity of 4.5 kWh/m^2 or equivalent to 112.000 GW.

Even though, PV can generate power, this device also has disadvantage: it results in several voltage and current disturbances, as well as harmonics due to the presence of several types of PV devices and power converters and increasing the number of non-linear loads connected to the source, causing a decrease in power quality (PQ). To overcome this problem and to improve PQ due to the presence of non-linear load and integration of PV into the grid, UPQC is proposed. This device has been a function to compensate for problems of voltage source quality i.e. sag, swell, unbalance, flicker, harmonics, and load current quality problems i.e. harmonics, imbalance, reactive current, and neutral current. UPQC is part of an active power filter consisting of shunt active filter and series active filter connected in parallel and serving as a superior controller to solve several PQ problems simultaneously [1]. UPQC series component is responsible for reducing the number of disturbances on source side i.e. sag/swell voltage, flicker, unbalanced voltage, and source voltage harmonics. This equipment has served to inject a certain amount of voltage to keep load voltage at desired level so that it returns to balance and distortion-free. UPQC shunt component is responsible for overcoming current quality problems i.e. low power factor, load current harmonics, and unbalanced currents. This equipment has been a function of injection current into the AC system so that the current source becomes a balanced sinusoidal and in phase with source voltage [2]. The design and dynamic performance of integrated PV with UPQC (PV-UPQC) under variable irradiance condition and voltage sag/swell, and load unbalance has been investigated [3]. The proposed system was able to combine both the benefits of distributed generators (DGs) and active power filters. The PV-UPQC combination was also able to reduce harmonics due to nonlinear loads and was able to maintain total harmonics distortion (THD) of grid voltage, load voltage and grid current below the IEEE-519. The system was found to be stable under radiation variations, voltage sag/swell, and load unbalance conditions.

The dynamic performance-based auto-tuned PI for UPQC-PV system has been analyzed [4]. This online optimization methodology is implemented for PV-UPQC to determine the best value of PI gain. The Vector-Proportional Integral (UV-PI) and Proportional Resonant-Response (PR-R) controllers in shunt and series converters significantly increase PV-UPQC performance by reducing convergence time, settling time, switching harmonics, complexity, and dynamic response so that they become more effective. PV-UPQC performance using a control algorithm based on Synchronous Reference Frame (SRF) with the Phase Lock Loop (PLL) mechanism has been presented [5]. Unbalanced load voltage containing harmonics and pure unbalanced pure load voltage has been compensated and balanced so that the load voltage is maintained constant. UPQC was supplied by 64 PV panels using boost converters, PI controllers,

maximum power point tracking (MPPT) with Perturb and Observer (P and O), and having a momentary reactive power theory (p-q theory) which has been proposed [6]. The system has successfully carried out reactive power compensation and reduced source current and load voltage harmonics. However, this study did not address the mitigation of sag voltage and other disturbances caused by PV penetration.

PV supported by UPQC using Space Vector Pulse Width Modulation (SVPWM) compared to hysteresis control in a three-phase distribution system has been proposed [7]. The system was used to improve PQ and to reduce the burden of 3 phase AC network by supplying power obtained from PV. The UPQC system can supply reactive power needed to increase power factor, reduce voltage and current distortion, and PV helps injection active power into the load. A conceptual study of UPQC on three-phase four wire (3P4W) system connected to linear and non-linear loads simultaneously have been carried out [8]. The sinusoidal current control strategy drives UPQC in such a way that the supply system has drawn a constant sinusoidal current under steady-state conditions. Besides, the shunt converter also produced reactive power as required by load so that it can improve power factor and reduce THD of source current.

Artificial neural networks based on SRF theory as a control to compensate for PQ problems of 3P3W system through UPQC for various balanced/unbalanced/distorted conditions at load and source have been proposed [9]. The proposed model has successfully mitigated harmonic/reactive currents, unbalanced source and load, and unbalanced current/voltage. Investigation on enhancements PQ including sag and source voltage harmonics on the grid using UPQC provided by PV array connected to DC links using PI compared to FLC has been conducted [10]. The simulation shows that FLC on UPQC and PV could increase THD voltage source better than PI. The improvement of PQ using UPQC on microgrid supplied by PV and wind turbine have been implemented using PI and FLC. Both methods can improve PQ and to reduce distortion in output power [11]. Research on the use of Battery Energy Storage (BES) in UPQC supplied by PV to improve PQ in 3P3W system using FLC validated PI on various disturbances in source and load side has been investigated [12]. The research showed that FLC on the UPQC-Battery Energy Storage (BES) system supplied by PV was able to significantly reduce load current harmonics and source voltage harmonics in the number of disturbances, especially in interruption voltage that occurs on the source bus.

This research presents an analysis of the UPQC-PV system model under sag and interruption voltage with variable irradiance. The PV is connected to a 3P3W system with 380 volts (L-L) and a frequency of 50 hertz, through UPQC-DC link. This system is used to maintain load voltage and load active power constant, as well as to supply sensitive loads. This paper is presented as follows. Section 2 explains the proposed method, UPQC-PV model, parameter simulation, PV model, active filter series and shunt filter control, application of PI, as well as UPQC model efficiency. Section 3 shows results and discussion of load voltage, load current, source active power, load active power, series active power, shunt active power, PV power using PI. In this section, six disturbance scenarios are presented and the results are verified with Matlab/Simulink. Finally, this paper is concluded in Section 4.

II. Research Method

A. Proposed Method

Fig. 1 shows the proposed model in this paper. The PV is connected to a 3P3W distribution system with 380 volts (L-L) and a frequency of 50 hertz, through UPQC-DC link circuit. This system is known as the UPQC-PV system and it is used to maintain and supply sensitive loads. The PV array generates DC power at a constant temperature, variable solar irradiance, and it is connected to DC-link via a DC-DC boost converter. The MPPT method with the P and O algorithm helps PV to generate maximum power, result in an output voltage, which then becomes an input voltage for the DC-DC boost converter. This device has a function to adjust duty cycle value with PV output voltage as an input voltage to produce output voltage according to the DC-link voltage of UPQC. The PV has been a function as an alternative source by injecting power to keep load voltage constant, in the case of an interruption voltage occurs on the source or point common coupling (PCC) bus.

The analysis of the proposed model is carried out by determining sag and interruption voltage scenarios on the source bus in 3P3W using the UPQC-PV system. The measurement parameters are carried out at fixed temperature (T = 25^0 C) and variable irradiance i.e. 200 W/m^2, 400 W/m^2, 600 W/m^2, 800 W/m^2, 1000 W/m^2 and 1200 W/m^2. Each disturbance scenario at variable irradiance level amounts to 6 disturbance, so the total number of scenarios is 12 disturbances. The UPQC-PV system uses PI to maintain voltage in a series active filter and current in a shunt active filter to keep the voltage at sensitive loads remains constant. The parameters investigated i.e. voltage and current on source bus, voltage and current on load bus, source active power, series active power, shunt active power, load active power, and PV power. The next step is to determine the efficiency value of the UPQC-PV system on sag and interruption voltage scenario in variable irradiance to show the contribution of PV in mitigation of both voltage disturbances on source bus. Fig. 2 shows power transfer using the UPQC-PV system. Then, the simulation parameters for the proposed model are shown in Appendix Section.

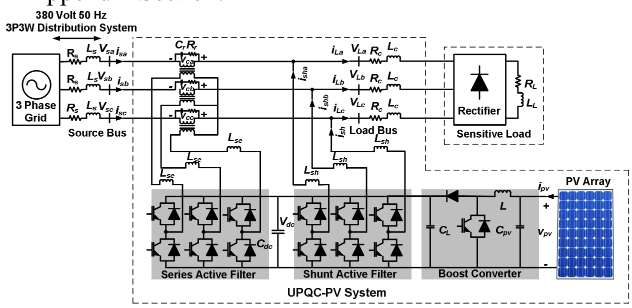

Fig. 1. Proposed model of as UPQC-PV system

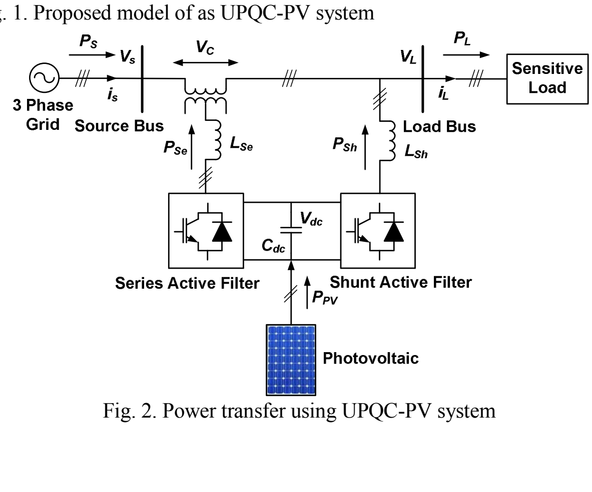

Fig. 2. Power transfer using UPQC-PV system

B. Modeling of PV Array

Fig. 3 shows the equivalent circuit and V-I characteristics of a solar panel. It consists of several PV cells that have external connections in series, parallel, or both combination [13].

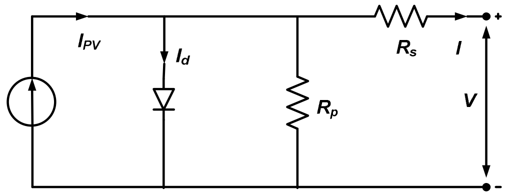

Fig. 3. Equivalent circuit of solar panel

The characteristic of V-I is shown in Eq. (1):

$$I = I_{PV} - I_o \left[exp\left(\frac{V+R_S I}{a\,V_t}\right) - 1\right] - \frac{V+R_S I}{R_P} \qquad (1)$$

Where I_{PV} is PV current, I_o is saturated reverse current, $'a'$ is the ideal diode constant, $Vt = N_S K T q^{-1}$ is the thermal voltage, N_S is the number of series cells, q is electron charge, K is Boltzmann constant, T temperature p-n junction, R_S and R_P are series and parallel resistance of the solar panels. I_{PV} has a linear relationship with the light intensity and also varies with temperature variations. I_o is dependent value on the temperature variations. The value of I_{PV} and I_o are determined using Eq (2) and Eq. (3):

$$I_{PV} = \left(I_{PV,n} + K_I \Delta T\right)\frac{G}{G_n} \qquad (2)$$

$$I_o = \frac{I_{SC,n} + K_I \Delta T}{\exp(V_{OC,n} + K_V \Delta T)/aV_t - 1} \qquad (3)$$

Where $I_{PV,n}$, $I_{SC,n}$, and $V_{OC,n}$ are PV current, short-circuit current, and open-circuit voltage under standard conditions ($T_n = 25^0 C$ and $G_n = 1000\ W/m^2$), respectively. The K_I value is coefficient of short circuit current to temperature, $\Delta T = T - T_n$ is temperature deviation from standard temperature, G is light intensity and K_V is coefficient of open circuit voltage ratio to temperature. Open-circuit voltage, short-circuit current, and voltage-current related to maximum power are three important values of I-V characteristics of a solar panel. These points are changed by variation in atmospheric conditions. By using Eq. (4) and Eq. (5) derived from PV model, short-circuit current, and open-circuit voltage can be calculated under different atmospheric conditions.

$$I_{SC} = (I_{SC} + K_I \Delta T)\frac{G}{G_n} \qquad (4)$$

$$V_{OC} = (V_{OC} + K_V \Delta T) \qquad (5)$$

C. Control of Series Active Filter

The main function of a series active filter is to protect the sensitive load from several voltage disturbances at the PCC bus. The algorithm of a source voltage and a load voltage control strategies in a series active filter circuit is shown in Fig. 4. This control strategy generates the unit vector template from a distorted input source. Then, the template is expected to be an ideal sinusoidal signal with a unity amplitude. Then, the distorted source voltage is measured and divided by peak the amplitude of base input voltage V_m as stated in Eq. (6) [6].

$$V_m = \sqrt{\frac{2}{3}\left(V_{sa}^2 + V_{sb}^2 + V_{sc}^2\right)} \qquad (6)$$

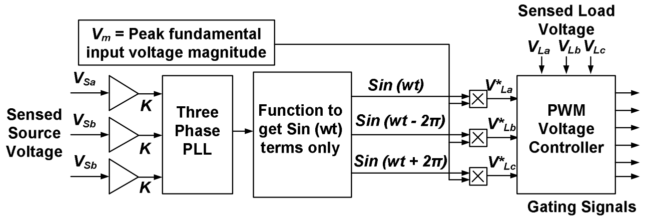

Fig. 4 Series active filter control

A three-phase PLL is used to produce sinusoidal unit vector templates with phase lagging through the use of sine function. The load voltage of the reference signal is determined by multiplying unit vector templates by the peak value of base input voltage amplitude V_m. The load reference voltage $(V_{La}^*, V_{Lb}^*, V_{Lc}^*)$ is then compared with sensed load voltage (V_{La}, V_{Lb}, V_{Lc}) with a PWM controller which is used to generate the desired trigger signal in a series active filter. Fig. 4 shows the control of a series active filter.

D. Control of Shunt Active Filter

The main function of a shunt active filter is to mitigate PQ problems on the load side. The control methodology of a shunt active filter is that the absorbed current from the PCC bus is a balanced positive sequence current including an unbalanced sag voltage on the PCC bus, an unbalanced, or a non-linear load. To obtain satisfactory compensation caused by interference due to non-linear load, many algorithms have been used in some references. This research uses the method of instantaneous reactive power theory or "p-q" theory. The voltages and currents in Cartesian coordinates can be transformed into Cartesian coordinates αβ as stated in Eq. (7) and Eq. (8) [6].

$$\begin{bmatrix} v_\alpha \\ v_\beta \end{bmatrix} = \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} \qquad (7)$$

$$\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} = \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} \qquad (8)$$

Calculation of real power (p) and imaginary power (q) is shown in Eq. (9). Real and imaginary power are measured instantaneously power and expressed in matrix form. The presence of a mean and fluctuating components in an instantaneous component is shown in Eq. (10) [14].

$$\begin{bmatrix} p \\ q \end{bmatrix} = \begin{bmatrix} v_\alpha & v_\beta \\ -v_\beta & v_\alpha \end{bmatrix} \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} \qquad (9)$$

$$p = \bar{p} + \tilde{p} \quad ; \quad q = \bar{q} + \tilde{q} \qquad (10)$$

Where $\bar{p}$ = the average component of real power, $\tilde{p}$ = the fluctuating component of real power, $\bar{q}$ = the average component of imaginary power, $\tilde{q}$ = the fluctuating component of imaginary power. The total of imaginary power (q) and a fluctuating components of real power $(\tilde{p})$ is selected as power references and current references and is utilized through the use of Eq. (10) to compensate for harmonics and reactive power [15]. Fig. 5 shows a shunt active filter control [15].

$$\begin{bmatrix} i_{c\alpha}^* \\ i_{c\beta}^* \end{bmatrix} = \frac{1}{v_\alpha^2 + v_\beta^2} \begin{bmatrix} v_\alpha & v_\beta \\ v_\beta & -v_\alpha \end{bmatrix} \begin{bmatrix} -\tilde{p} + \bar{p}_{loss} \\ -q \end{bmatrix} \qquad (11)$$

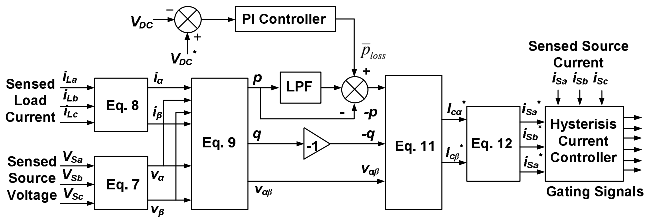

Fig. 5. Shunt active filter control

The $\bar{p}_{loss}$ signal is obtained from the voltage regulator and is used as average real power. It can also be expressed as instantaneous active power associated with resistive losses and switching losses from UPQC. The error is obtained by comparing the actual value of DC-link capacitor voltage with the reference value processed using a PI controller, driven by a closed voltage control to minimize steady-state errors from voltage through DC-link circuit to zero. The compensation current $(i_{c\alpha}^*, i_{c\beta}^*)$ is needed to meet load power demand as shown in Eq. (12). The current is expressed in coordinates $\alpha - \beta$. The compensation current is used to obtain the source phase current by using Eq. (13) for compensation. The source phase current $(i_{sa}^*, i_{sa}^*, i_{sa}^*)$ is expressed in the abc axis obtained from the compensation current in $\alpha - \beta$ coordinates and is presented in Eq. 12 [15] .

$$\begin{bmatrix} i_{sa}^* \\ i_{sb}^* \\ i_{sc}^* \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 0 \\ -1/2 & \sqrt{3}/2 \\ -1/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} i_{c\alpha}^* \\ i_{c\beta}^* \end{bmatrix} \qquad (12)$$

To operate properly, The UPQC-PV must have a minimum DC-link voltage (V_{dc}) . The general DC-link voltage value depends on the instantaneous energy that can be generated by UPQC which is defined in Eq.13 [16]:

$$V_{dc} = \frac{2\sqrt{2V_{LL}}}{\sqrt{3}m} \qquad (13)$$

Where m is the modulation index and V_{LL} is the voltage of UPQC. Considering the modulation index of 1 and the grid voltage between line-line $(V_{LL} = 380\,V)$, V_{dc} is obtained 620.54 V and chosen as 650 V.

The input of shunt active filter shown in Fig. 6 is DC voltage (V_{dc}) dan DC voltage reference (V_{dc}^*), while the output is P_{loss} using the PI controller. Furthermore, P_{loss} of the input variables produce a reference source current $(i_{sa}^*, i_{sa}^*, i_{sa}^*)$. Then, the reference source current output is compared with the current source (i_{sa}, i_{sb}, i_{sc}) by hysteresis current controller to generate a trigger signal in the IGBT circuit of shunt active filter. In this paper, the PI controller as a DC voltage control algorithm on a shunt active filter is proposed.

D. Efficiency of UPQC-PV

The research on the use of 3-Phase 4-Leg Unified Series-Parallel Active Filter Systems using Ultra Capacitor Energy Storage (UCES) to mitigate sag and unbalance voltage has been investigated [17]. In this paper, it is found that the implementation of UCES can help the system reduce source current compensation when sag voltage on source bus to keep load voltage constant and balanced. During disturbance, UCES generates extra power flow to load through a series active filter via dc-link and a series active filter to load. Although providing an advantage of sag voltage compensation, the use of UCES in this proposed system is also able to generate losses and to reduce the efficiency of the system. Using the same procedure, the authors proposes Eq. (14) for efficiency of UPQC-PV in the formula below.

$$Eff\,(\%) = \frac{P_{Source} + P_{Series} + P_{Shunt} + P_{PV} + P_{BES}}{P_{Load}} \qquad (14)$$

III. Result and Discussion

The proposed model analysis is UPQC connected 3P3W (on-grid) system through a DC link supplied by PV known as UPQC-PV system. The system then supplies sensitive voltage devices on the load bus. There are two disturbances scenario i.e. sag voltage (Sag) and interruption voltage (Inter). In the sag voltage scenario, the system is connected to a sensitive load and the source has a 50% sag voltage disturbance for 0.3 s between t = 0.2 s to t = 0.5 s. In the interruption voltage scenario, the system is connected to a sensitive load and the source experiences a 100% source voltage interruption for 0.3 s between t = 0.2 s to t = 0.5 s. The UPQC-PV system uses a PI controller with constant K_P and K_I are 0.2 and 1.5, respectively. PI controller is used as a DC voltage controller on an active filter series and current controller on shunt active filter to keep load voltage constant in case of disturbance voltage happens on the source bus.

The proposed model analysis is carried out by determining sag voltage and interruption voltage on the source bus in 3P3W of the UPQC-PV system. The measurement parameters are carried out at fixed temperature conditions (T = 250 C) and the different radiation i.e. 200 W/m^2, 400 W/m^2, 600 W/ m^2, 800 W/m^2, 1000 W/m^2 and 1200 W/m^2. The disturbance scenarios at the variable irradiance level amounts to 6 disturbances, so that the total number of scenarios is 12 interruptions. The UPQC-PV system uses controls mounted on the 3P3W System to keep voltage at sensitive loads remains constant. Then, using Matlab/Simulink, the model is run following with the scenario that was previously desired to obtain the source voltage curve (V_S), load voltage (V_L), compensation voltage (V_C), source current (I_S), load current (I_L), and DC-Link voltage (V_{DC}). Based on this curve, the average values of source voltage, load voltage, source current and load current are obtained from value of each phase of voltage and current parameters previously obtained. The next research is determining the value of power transfer of active source power, series active power, active shunt power, active load power, PV power contribution, and system efficiency. The measurement of the value of phase voltage, phase current, power transfer, and PV power is determined in one cycle starting at t = 0.35 s. The results of the average source voltage, source current, load voltage, and load current in the UPQC-PV system model are presented in Table 1.

TABLE I. VOLTAGE AND CURRENT USING UPQC-PV SYSTEM UNDER SAG AND INTERRUPTION WITH VARIABLE IRRADIANCE LEVEL

Irr (W/m^2)	Source Voltage V_S (Volt)				Load Voltage V_L (Volt)				Source Current I_S (Ampere)				Load Current I_L (Ampere)			
	Ph A	Ph B	Ph C	Avg	Ph A	Ph B	Ph C	Avg	Ph A	Ph B	Ph C	Avg	Ph A	Ph B	Ph C	Avg
Sag Voltage and T = 25^0 C																
200	153.9	153.9	153.9	**153.9**	310.1	310.1	310.1	**310.1**	11.77	11.79	11.35	**11.63**	8.590	8.589	8.587	**8.589**
400	154.1	154.1	154.1	**154.1**	310.1	310.1	310.1	**310.1**	10.91	10.98	10.94	**10.94**	8.589	8.590	8.588	**8.589**
600	154.1	154.1	154.1	**154.1**	310.1	310.1	310.1	**310.1**	10.92	10.88	10.98	**10.93**	8.589	8.588	8.589	**8.589**
800	154.0	154.0	154.0	**154.0**	310.1	310.1	310.1	**310.1**	11.45	10.38	11.49	**11.11**	8.588	8.589	8.589	**8.589**
1000	153.8	153.8	153.8	**153.8**	310.1	310.1	310.1	**310.1**	13.39	13.33	13.41	**13.38**	8.589	8.589	8.588	**8.589**
1200	153.8	153.8	153.8	**154.8**	310.1	310.1	310.1	**310.1**	13.69	13.58	13.69	**13.65**	8.589	8.589	8.588	**8.589**
Interuption Voltage and T = 25^0 C																
200	1.229	1.350	1.274	**1.284**	232.8	253.2	247.2	**244.4**	11.65	12.65	12.23	**12.18**	6.561	6.798	6.974	**6.778**
400	1.322	1.416	1.367	**1.368**	245.7	264.2	261.1	**257.0**	12.22	12.66	12.87	**12.51**	6.946	7.051	7.396	**7.131**
600	1.333	1.414	1.363	**1.370**	246.6	263.9	261.8	**257.4**	12.25	12.57	12.85	**12.56**	6.964	7.033	7.406	**7.134**
800	1.304	1.385	1.344	**1.341**	240.1	258.5	255.8	**251.5**	12.13	12.37	12.71	**12.40**	6.788	6.885	7.234	**6.969**
1000	1.190	1.316	1.237	**1.247**	229.2	249.1	242.8	**240.4**	11.31	11.86	11.91	**11.69**	6.443	6.698	6.289	**6.477**
1200	1.227	1.319	1.269	**1.272**	227.5	246.8	243.7	**239.2**	11.50	11.80	12.06	**11.78**	6.433	6.557	6.882	**6.624**

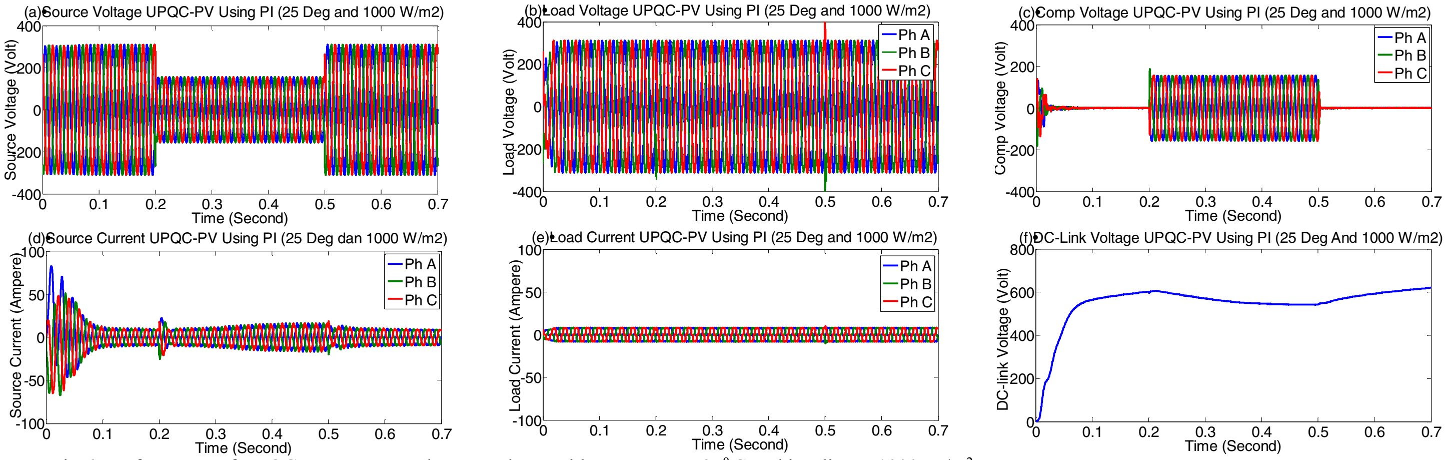

Fig 6. Performance of UPQC-PV system under sag voltage with temperature 25^0 C and irradiance 1000 W/m^2

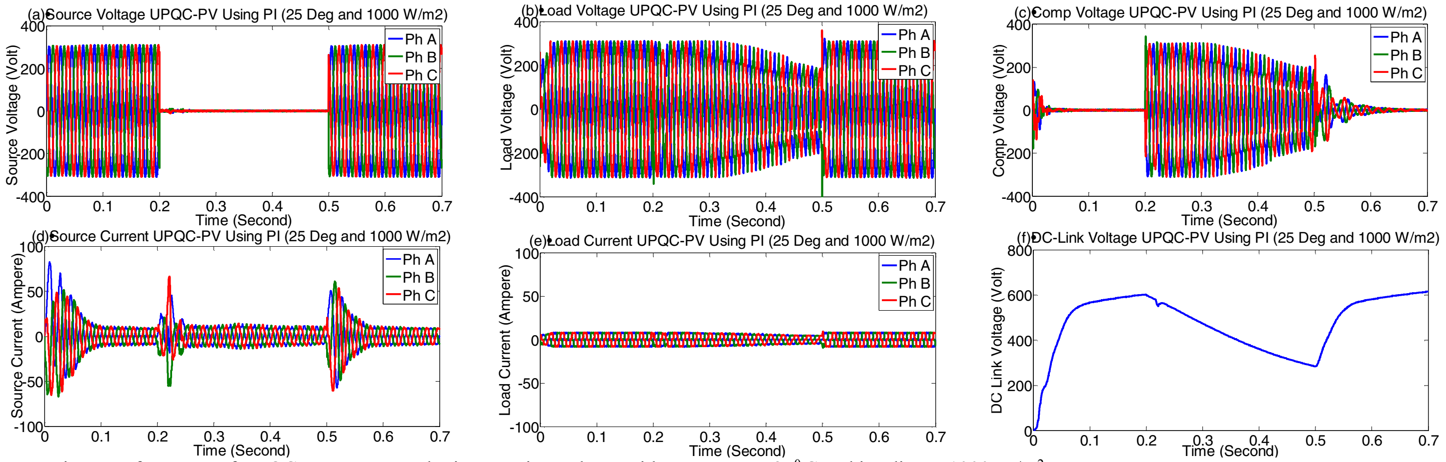

Fig 7. Performance of UPQC-PV system under interruption voltage with temperature 25^0 C and irradiance 1000 W/m^2

Fig. 6 shows that in sag voltage, the UPQC-PV system at t = 0.2 s to t = 0.5 s, irradiance = 1000 W/m^2 and temperature = 25^0 using PI control, the average source voltage (V_S) (Fig. 6.a) decreased by 50% from 310.1 V to 153.8 V (Fig. 6.b). During this duration, the average source current (I_S) increases slightly to 13.38 A (Fig. 6.d) because the PV contributes power to the load through a DC-link series active filter by injecting a compensation voltage (V_C) of 156.3 V (Fig. 6.c) through the injection transformer in the active series filter so that an average load voltage (V_L) remains stable at 310.1 V (Fig. 6.b). At the same time, the PI controller on shunt active filter works to keep DC voltage (V_{DC}) stable and the average current source (I_S) increases close to 13.38 A (Fig. 6.d) to keep the average (I_L) stable at 8,589 A (Figure 6.e).

Fig. 7 shows that in the interruption voltage scenario, the UPQC-PV system at t = 0.2 s to t = 0.5 s, irradiation = 1000 W/m2 and temperature = 25^0 using PI controller, the average V_S drops by 100 % to 1.247 V (Fig. 7.a). Under these conditions, the UPQC-PV system is unable to produce maximum power to UPQC DC-link circuit and injects the average V_C (Fig. 7.c) through injection transformer in the active series filter. So at t = 0.2 s to t = 0.5, the average V_L (Fig. 7.b) decreases to 240.4 V. During the interruption period, the application of a PI controller to the active shunt filter is unable maintain the average V_{DC} (Fig.7.f) and V_C to remain constant, so an the average I_L also decreases to 6,447 A (Fig. 7.e).

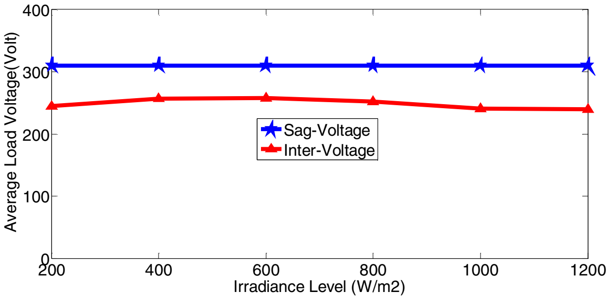

Fig. 8. Average load voltage of UPQC-PV system

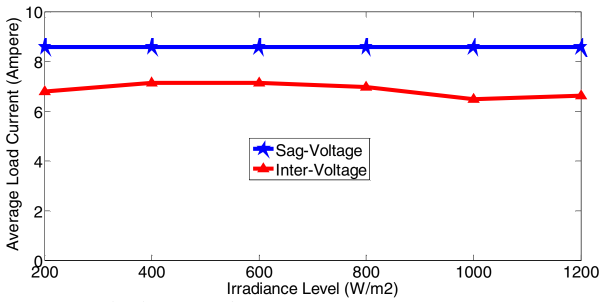

Fig. 9. Average load current of UPQC-PV system

Table 1 and Fig. 8 show that in sag voltage and irradiance level of 200W/m^2 to 1200 W/m^2, the 3P3W system using UPQC-PV with PI controller still can maintain the average load voltage $(V_L)$of 310.1 V. However, in the interruption voltage and the irradiance levels are equally sequential, the average load voltage (V_L)drops to between 239.2 V and 257 V. Table 1 and Fig. 9 also show that in the sag voltage and the irradiance levels of 200 W/m^2 to 1200 W/m^2, the 3P3W system uses UPQC-PV with PI controller is still able to maintain the average load current (I_L) of 8.589 A. However, in the scenario of the interruption voltage and same irradiance levels, the average load current (I_L) drops to between 6.624 A and 7.134 A. Thus, the UPQC-PV system can maintain the load voltage (V_L), if there is the sag voltage happens at the source bus. Otherwise, in the interruption voltage scenario, the UPQC-PV system can not maintain load voltage (V_L), and the load current (I_L) remains constant.

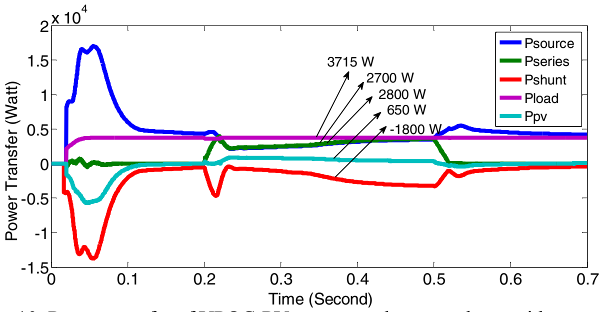

Fig. 10. Power transfer of UPQC-PV system under sag voltage with temperature = 25^0 C and irradiance = 1000 W/m^2

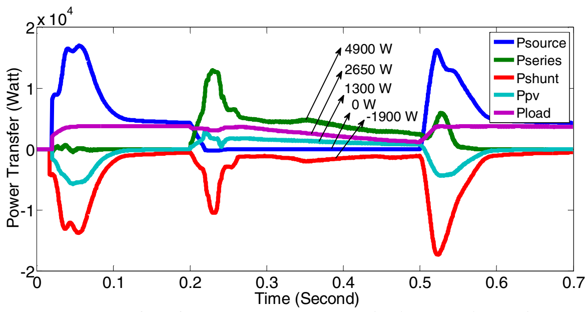

Fig. 11. Power transfer of UPQC-PV system under interruption voltage with temperature = 25^0 C and irradiance = 1000 W/m^2

Fig. 10 shows that in sag voltage, the UPQC-PV system at t = 0.2 s to t = 0.5 s, irradiance = 1000 W/m^2 and temperature = 25^0 C using PI controller, source power value (P_S) decreases to 2700 W. Series power (P_{Se}) increased by 2800 W and shunt power (P_{Sh}) decreased by -1800 W, PV power by 650 W, so that load power (P_L) value is equal to 3715 W. Fig. 11 shows that in interruption voltage, UPQC-PV system at t = 0.2 s to t = 0.5 s, irradiance = 1000 W/m^2 and temperature = 25^0 C, the value of the source power (P_S) drops to 0 W. The series power (P_{Se}) increases by 4900 W and shunt power (P_{Sh}) decreases by -1900 W, and PV power (P_{PV}) increases by 1300 W, so that the load power (P_L) dropped to 2650 W.

Table 2 and Fig. 12 show that in sag voltage and irradiance levels of 200 W/m^2 to 1200 W/m^2, the 3P3W system uses UPQC-PV with PI still able to maintain active power above 3714 W. However, in the interruption voltage and same irradiance level, active load power (P_L) drops to between 2560 W and 2805 W. Table 2 and Fig. 13 also show that in sag voltage and irradiance levels of 200 W/m^2 to 1200 W/m^2, the 3P3W system uses UPQC-PV with PI still able to generate PV power (P_{PV}) between 500 W to 920 W. In the scenario of interruption voltage and irradiance levels with the same condition, the PV power increases (P_{PV}) between 1300 W to 1635 W. However, the increase on PV power (P_{PV}) in interruption voltage has not been able to meet power on load side so that load power (P_L) finally drops to 2650 W.

TABLE II. POWER TRANSFER IN UPQC-PV SYSTEM

Irr (W/m^2)	Power Transfer (Watt)					Eff (%)
	Source Power	Series Power	Shunt Power	Load Power	PV Power	
Sag Voltage and T= 25^0 C						
200	2700	2800	-1720	3715	680	83.30
400	2455	2550	-1200	3714	920	78.60
600	2455	2550	-1200	3714	920	78.52
800	2534	2620	-1332	3714	810	80.18
1000	2700	2800	-1800	3715	650	85.40
1200	2960	3080	-2250	3715	500	86.59
Interruption Voltage and T= 25^0 C						
200	0	4950	-2000	2675	1440	60.93
400	0	4600	-1500	2805	1620	59.43
600	0	4650	-1515	2800	1635	58.70
800	0	4895	-1850	2754	1544	60.01
1000	0	4900	-1900	2650	1300	61.63
1200	0	4850	-1930	2560	1300	59.79

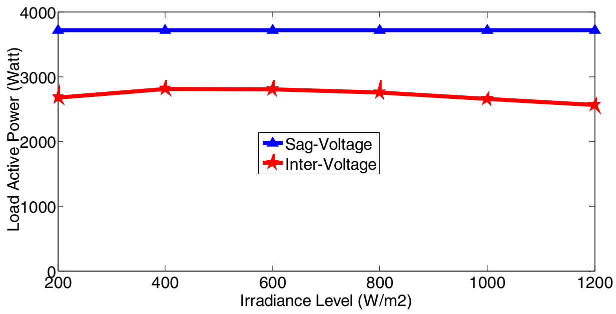

Fig. 12. Active load power on UPQC-PV system

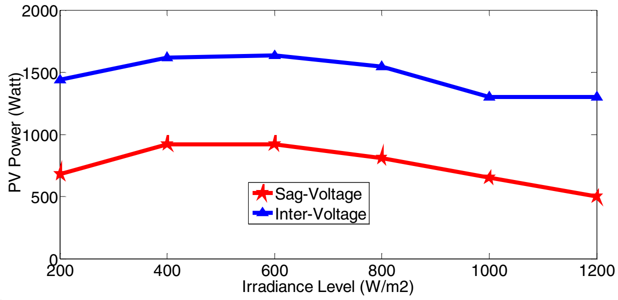

Fig. 13. PV power on UPQC-PV system

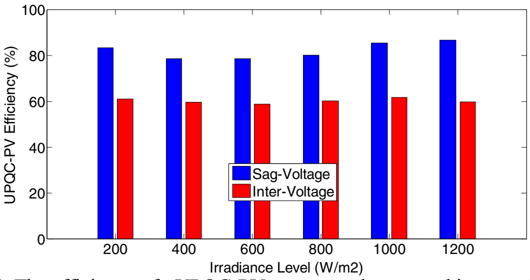

Fig. 14. The efficiency of UPQC-PV system under sag and interruption

Fig. 14 shows that in sag voltage and irradiance level of 200 W/m^2 to 1200 W/m^2, the 3P3W system using UPQC-PV with PI controller can produce a system efficiency of 78.60% to 86.59%. Otherwise, in the interruption voltage and irradiance increases, the efficiency of UPQC-PV decreases between 58.70% to 61.63%.

IV. Conclusion

The analysis of the UPQC-PV system model has been presented in this paper. The PV is connected to a 3P3W distribution system with 380 volts (L-L) and a frequency of 50 hertz, through UPQC-DC link circuit. This system is used to maintain and supply sensitive loads. This research shows that in the sag voltage and irradiance levels of 200 W/m^2 to 1200 W/m^2, the 3P3W system using UPQC-PV with PI can maintain the active load power above 3714 W. However, in the interruption voltage and same irradiance level, the load active power drops to between 2560 W and 2805 W. This paper also shows that in the sag voltage and same irradiance level, the 3P3W system using UPQC-PV with PI can generate PV power between 500 W to 920 W. In the scenario of the interruption voltage and same irradiance levels, the power that can be generated by PV increases between 1300 W to 1635 W. However, at 25^0 C and 1000 W/m^2, the increase in PV power on interruption voltage has not been able to meet the load power so it finally drops to 2650 W. The increase in PV power close to load power is proposed to overcome this problem.

Appendix

Three-phase grid: RMS voltage 380 volt (L-L), 50 Hz, line impedance: R_S = 0.1 Ohm L_S = 15 mH; series and shunt active filter: series inductance L_{Se} = 0.015 mH; shunt inductance L_{Sh} = 15 mH; injection transformers: rating 10 kVA, 50 Hz, turn ratio (N_1/N_2) = 1:1; sensitive load: resistance R_L = 60 ohm, inductance L_L = 0.15 mH, load impedance R_C = 0.4 ohm and L_C = 15 mH; unbalance load: resistance R_1 = 24 ohm, R_2= 12 ohm, and R_3 = 6 ohm, capacitance C_1, C_2, C_3 = 2.2 µF; DC-link: voltage V_{dc} = 650 volt and capacitance C_{dc} = 3000 µF; photovoltaic: active power P_{PV} = 0.6 kW temperature = 25^0 C, irradiance = 1000 W/m^2; PI controller: K_P = 0.2, K_I= 1.5; input: $V_{dc-error}$ and $\Delta V_{dc-error}$; output: instantaneous of power losses ($\bar{p}_{loss}$).

Acknowledgments

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Lampiran 2.4

Cek gramarly makalah

Power Transfer Analysis Using UPQC-PV System Under Sag and Interruption With Variable Irradiance

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***Abstract*— This paper presents analysis of UPQC-PV system model under sag and interruption voltage with variable irradiance. The PV is connected to a 3P3W distribution system with 380 volts (L-L) and a frequency of 50 hertz, through UPQC-DC link . This system is used to maintain and supply sensitive loads. This paper shows that in the sag voltage and irradiance levels of 200 W/m^2 to 1200 W/m^2, the 3P3W system uses UPQC-PV with proportional integral (PI) still able to maintain the load active power above 3714 W. However, in the interruption voltage and same irradiance level, the load active power drops to between 2560 W and 2805 W. This research also show that in the sag voltage and same irradiance levels, the 3P3W system uses UPQC-PV with PI still able to generate PV power between 500 W to 920 W. In the interruption voltage and same irradiance levels, the power that can be generated by PV increases between 1300 W to 1635 W. Otherwise, at 25^0 C and 1000 W/m^2, the increase in PV power on interruption voltage has not been able to meet the load active power consumption, so it finally drops to 2650 W. This paper is simulated using Matlab/Simulink.**

Keywords—UPQC, Photovoltaic, Sag, Interruption, Irradiance

I. INTRODUCTION

The decreasing of fossil energy sources and increasing concerns about environmental impacts have caused renewable energy (RE) sources i.e. photovoltaic (PV) and wind to develop into alternative energy on power generation. Solar or PV generator is one of the most potential RE technologies because it only convert sunlight to generate electricity, where the reseources are avialable in abundant and they are free and relatively clean. Indonesia has a huge energy potential from the sun because it is located in the equator. Almost all regions of Indonesia receive around 10 to 12 hours of sunshine per day, with an average irradiation intensity of 4.5 kWh/m^2 or equivalent to 112.000 GW.

Even though, PV is able to generate power, this device also has disadvantage: it results in a number of voltage and current disturbances, as well as harmonics due to the presence of several types of PV devices and power converters and increasing the number of non-linear loads connected to the source, causing a decrease in power quality (PQ). In order to overcome this problem and to improve PQ due to the presence of non-linear load and integration of PV into the grid, UPQC is proposed. This device has been a function to compensate for problems of voltage source quality i.e. sag, swell, unbalance, flicker, harmonics, and load current quality problems i.e. harmonics, imbalance, reactive current, and neutral current. UPQC is part of an active power filter consisting of shunt active filter and series active filter connected in parallel and serving as a superior controller to solve a number of PQ problems simultaneously [1]. UPQC series component is responsible for reducing a number of disturbances on source side i.e. sag/swell voltage, flicker, unbalanced voltage, and source voltage harmonics. This equipment has served to inject a certain amount of voltage to keep load voltage at desired level so that it returns to balance and distortion free. UPQC shunt component is responsible for overcoming current quality problems i.e.. low power factor, load current harmonics, and unbalanced currents. This equipment has been a function of injection current into AC system so that current source becomes a balanced sinusoidal and in phase with source voltage [2]. The dynamic performance of integrated PV with UPQC (PV-UPQC) under variable irradiance condition and sag/swell grid voltage has been investigated [3]. The proposed system was able to combine both the benefits of distributed generators (DGs) and active power filters. The PV-UPQC combination was also able to reduce harmonics due to nonlinear loads and was able to maintain total harmonics distortion (THD) of grid voltage, load voltage and grid current below the IEEE-519. The system was found to be stable under irradiation from 1000 $W/m2$ to 600 $W/m2$.

The dynamic performance based auto tuned PI for PV-UPQC systems has been analyzed [4]. This online optimization methodology is implemented for PV-UPQC to determine the best value of PI gain. The Vector-Proportional Integral (UV-PI) and Proportional Resonant-Response (PR-R) controllers in shunt and series converters significantly increase PV-UPQC performance by reducing convergence time, settling time, switching harmonics, complexity, and dynamic response so that they become more effective. PV-UPQC performance using control algorithm based on Synchronous Reference Frame (SRF) with Phase Lock Loop (PLL) mechanism has been presented [5]. Unbalanced load voltage containing harmonics and pure unbalanced pure load voltage has been compensated and balanced so that the load voltage is maintained constant. UPQC was supplied by 64 PV panels using boost converters, PI controllers, maximum power point tracking (MPPT) with Pertub and Observer (P and O), and having a momentary reactive power theory (p-q theory) which has been proposed [6]. The system has successfully carried out reactive power compensation and reduced source current and load voltage harmonics. However, this study did not address mitigation of sag voltage reduction and other disturbances caused by PV penetration.

PV supported by UPQC using Space Vector Pulse Width Modulation (SVPWM) compared to hysterisis control in a three-phase distribution system has been proposed [7]. The system was used to improve PQ and to reduce the burden

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of 3 phase AC network by supplying power obtained from PV. The UPQC system is able to supply reactive power needed to increase power factor, reduce voltage and current distortion, and PV helps injection active power into the load. A conceptual study of UPQC on three phase four wire (3P4W) system connected to linear and non-linear loads simultaneously have been carried out [8]. The sinusoidal current control strategy drives UPQC in such a way that the supply system drawn a constant sinusoidal current under steady state conditions. In addition, the shunt converter also produced reactive power as required by load so that it can improve an input power factor and reduce THD of source current.

Artificial neural networks based on SRF theory as a control to compensate for PQ problems of three phase three wire (3P3W) system through UPQC for various balanced/unbalanced/distorted conditions at load and source have been proposed [9]. The proposed model has successfully mitigated harmonic/reactive currents, unbalanced source and load, and unbalanced current/voltage. Investigation on enhancements PQ including sag and source voltage harmonics on the grid using UPQC provided by PV array connected to DC links using PI compared to FLC has been conducted [10]. The simulation shows that FLC on UPQC and PV could increase THD voltage source better than PI. The improvement of PQ using UPQC on microgrid supplied by PV and wind turbine have been implemented using PI and FLC. Both methods are able to improve PQ and to reduce distortion in output power [11]. Research on the use of Battery Energy Storage (BES) in UPQC supplied by PV to improve PQ in three phase 3P3W systems using FLC validated PI on various disturbances in source and load side has been investigated [12]. The research showed that FLC on UPQC-BES system supplied by PV was able to significantly reduce load current harmonics and source voltage harmonics in number of disturbances, especially in interruption voltage that occurs on source bus.

This research presents analysis of UPQC-PV system model under sag and interruption voltage under variable irradiance. The PV is connected to a 3P3W system with 380 volts (L-L) and a frequency of 50 hertz, through UPQC-DC link . This system is used to maintain load voltage and load active power constant, as well as supply sensitive loads. This paper is presented as follows. Section 2 explains proposed method, UPQC-PV model, parameter simulation, PV model, active filter series and shunt filter control, application of PI, as well as UPQC model efficiency. Section 3 shows results and discussion of load voltage, load current, source active power, load active power, series active power, shunt active power, PV power using PI. In this section, six disturbance scenarios are presented and the results are verified with Matlab/Simulink. Finally, this paper is concluded in Section 4.

II. Research Method

A. Proposed Method

Fig. 1 shows proposed model in this paper. The PV is connected to a 3P3W distribution system with 380 volts (L-L) and a frequency of 50 hertz, through UPQC-DC link circuit. This system is known as UPQC-PV system and it is used to maintain ans supply sensitive loads. The PV array generates DC power at a constant temperature, variable solar irradiance, and it is connected to DC-link via a DC-DC boost converter. The MPPT method with P and O algorithm helps PV to generate maximum power, result an output voltage, which then becomes an input voltage for DC-DC boost converter. This device has a functions to adjust duty cycle value with PV output voltage as an input voltage to produce output voltage according to DC-link voltage of UPQC. The PV has been a function as an alternative source by injecting power to keep load voltage constant, in the case of a interruption voltage accurs on source or point common coupling (PCC) bus.

The proposed model analysis is carried out by determining sag and interruption voltage scenarios on source bus in 3P3W using UPQC-PV system. The measurement parameters are carried out at fixed temperature (T = 25^0 C) and variable irradiance i.e. 200 W/m^2, 400 W/m^2, 600 W/m^2, 800 W/m^2, 1000 W/m^2 and 1200 W/m^2. Each disturbance scenario at variable irradiance level amounts to 6 disturbance, so the total number of scenarios is 12 disturbances. The UPQC-PV system uses PI to mantain voltage in a series active filter and current in a shunt active filter to keep the voltage at sensitive loads remains constant. The parameters investigated i.e. voltage and current on source bus, voltage and current on load bus, source active power, series active power, shunt active power , load active power, and PV power. The next step is to determine efficiency value of UPQC-PV system on sag and interruption voltage scenario in variable irradiance to show the contribution of PV in mitigation of both voltage disturbances on source bus. Fig. 2 shows power transfer using UPQC-PV system. Then, simulation parameters for the proposed model is shown in Appendix Section.

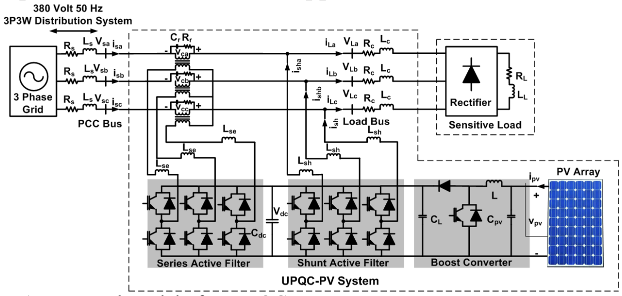

Fig. 1. Proposed model of as UPQC-PV system

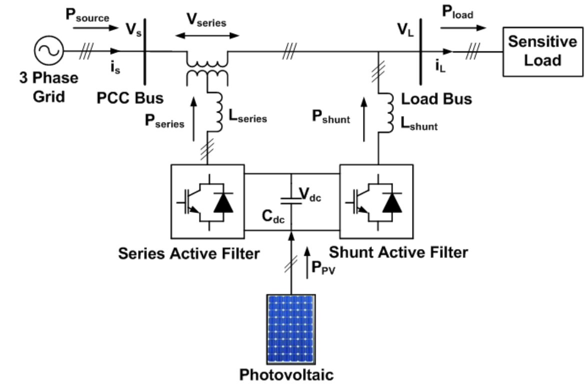

Fig. 2. Power transfer using UPQC-PV system

B. Modelling of PV Array

Fig. 3 shows the equivalent circuit and V-I characteristics of solar panel. It consists of several PV cells which have external connections in series, parallel, or both combination [13].

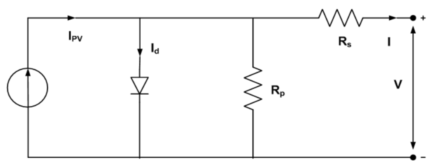

Fig. 3. Equivalent circuit of solar panel

The characteristic of V-I is shown in Eq. (1):

$$I = I_{PV} - I_o\left[exp\left(\frac{V+R_S I}{a\,V_t}\right)-1\right]-\frac{V+R_S I}{R_P} \quad (1)$$

Where I_{PV} is PV current, I_o is saturated reverse current, $'a'$ is the ideal diode constant, $V_t = N_S KTq^{-1}$ is thermal voltage, N_S is number of series cells, q is electron charge, K is Boltzmann constant, T temperature pn junction, R_S and R_P are series and parallel resistance of solar panels. I_{PV} has a linear relationship with light intensity and also varies with temperature variations. I_o is dependent value on the temperature variations. The value of I_{PV} and I_o are determined using Eq (2) and Eq. (3):

$$I_{PV} = \left(I_{PV,n} + K_I \Delta T\right)\frac{G}{G_n} \quad (2)$$

$$I_o = \frac{I_{SC,n}+K_I\Delta T}{\exp(V_{OC,n}+K_V\Delta T)/aV_t - 1} \quad (3)$$

Where $I_{PV,n}$, $I_{SC,n}$, and $V_{OC,n}$ are PV current, short circuit current, and open circuit voltage under standard conditions *(T_n = 25^0 C and G_n = 1000 Wm^{-2})* respectively. The K_I value is coefficient of short circuit current to temperature, $\Delta T = T - T_n$ is temperature deviation from standard temperature, G is light intensity and K_V is coefficient of open circuit voltage ratio to temperature. Open circuit voltage, short circuit current, and voltage-current related to maximum power are three important values of I-V characteristics of solar panel. These points are changed by variation in atmospheric conditions. By using Eq. (4) and Eq. (5) derived from PV model, short-circuit current, and open circuit voltage can be calculated under different atmospheric conditions.

$$I_{SC} = (I_{SC} + K_I \Delta T)\frac{G}{G_n} \quad (4)$$

$$V_{OC} = (V_{OC} + K_V \Delta T) \quad (5)$$

C. Control of Series Active Filter

The main function of series active filter is to protect sensitive load from a number of voltage disturbance at PCC bus. The algorithm of source voltage and load voltage control strategies in series active filter circuit is shown in Fig. 4. This control strategy generates the unit vector template from a distorted input source. Then, the template is expected to be an ideal sinusoidal signal with an unity amplitude. Then, the distorted source voltage is measured and divided by peak amplitude of base input voltage V_m as stated in Eq. (6) [6].

$$V_m = \sqrt{\frac{2}{3}\left(V_{sa}^2 + V_{sb}^2 + V_{sc}^2\right)} \quad (6)$$

A three phase PLL is used to produce sinusoidal unit vector templates with phase lagging through the use of sine function. The load voltage of reference signal is determined by multiplying unit vector templates by the peak value of base input voltage amplitude V_m. The load reference voltage $(V_{La}^*, V_{Lb}^*, V_{Lc}^*)$ is then comparedβ with sensed load voltage(V_{La}, V_{Lb}, V_{Lc}) with a PWM controller which is used to generate the desired trigger signal in series active filter. Fig. 4 shows control of series active filter.

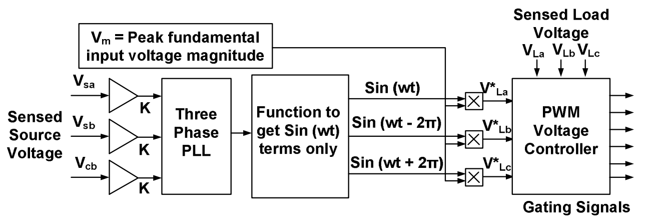

Fig. 4 Series active filter control

D. Control of Shunt Active Filter

The main function of shunt active filter is to mitigate PQ problems on the load side. The control methodology of shunt active filter is that the absorbed current from PCC bus is a balanced positive sequence current including an unbalanced sag voltage on PCC bus, an unbalanced, or a non-linear load. In order to obtain satisfactory compensation caused by interference due to non-linear load, many algorithms have been used in some references. This research uses the method of instantaneous reactive power theory theory or "p-q" theory. The voltages and currents in Cartesian coordinates can be transformed into Cartesian coordinates αβ as stated in Eq. (7) and Eq. (8) [6].

$$\begin{bmatrix} v_\alpha \\ v_\beta \end{bmatrix} = \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix}\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} \quad (7)$$

$$\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} = \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix}\begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} \quad (8)$$

Calculation of real power (p) and imaginary power (q) is shown in Eq. (9). Real and imaginary power are measured instantaneously power and expressed in matrix form. The presence of mean and fluctuating component in instantaneous component is shown in Eq. (10) [14].

$$\begin{bmatrix} p \\ q \end{bmatrix} = \begin{bmatrix} v_\alpha & v_\beta \\ -v_\beta & v_\alpha \end{bmatrix}\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} \quad (9)$$

$$p = \bar{p} + \tilde{p} \;\; ; \;\; q = \bar{q} + \tilde{q} \quad (10)$$

Where $\bar{p}$ = the average component of real power, $\tilde{p}$ = the fluctuating component of real power, $\bar{q}$ = the average component of imaginary power, $\tilde{q}$ = the fluctuating component of imaginary power. The total imaginary power (q) and fluctuating component of real power are selected as power references and current references and are utilized through the use of Eq. (10) to compensate for harmonics and reactive power [15].

$$\begin{bmatrix} i_{c\alpha}^* \\ i_{c\beta}^* \end{bmatrix} = \frac{1}{v_\alpha^2 + v_\beta^2}\begin{bmatrix} v_\alpha & v_\beta \\ v_\beta & -v_\alpha \end{bmatrix}\begin{bmatrix} -\tilde{p} + \bar{p}_{loss} \\ -q \end{bmatrix} \quad (11)$$

The $\bar{p}_{loss}$ signal is obtained from the voltage regulator and is used as average real power. It can also be expressed as instantaneous active power associated with resistive losses and switching losses from UPQC. The error is obtained by comparing the actual value of DC-link capacitor voltage with the reference value processed using a PI controller, driven by a closed voltage control to minimize steady state errors from voltage through DC-link circuit to zero. The compensation current $(i_{c\alpha}^*, i_{c\beta}^*)$ is needed to meet load power demand as shown in Eq. (12). The current is expressed in coordinates α-β. The compensation current is used to obtain source phase current by using Eq. (13) for compensation. The source phase current $(i_{sa}^*, i_{sa}^*, i_{sa}^*)$ is expressed in the abc axis obtained from the compensation current in $\alpha - \beta$ coordinates and is presented in Eq. 12 [15].

Fig. 5 show shunt active filter control [15].

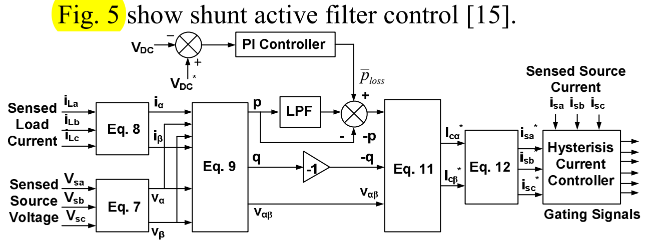

Fig. 5. Shunt active filter control

$$\begin{bmatrix} i_{sa}^* \\ i_{sb}^* \\ i_{sc}^* \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 0 \\ -1/2 & \sqrt{3}/2 \\ -1/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} i_{c\alpha}^* \\ i_{c\beta}^* \end{bmatrix} \quad (12)$$

In order to operate properly, The UPQC-PV must have a minimum DC-link (V_{dc}) voltage. The general DC-link voltage value depends on the instantaneous energy that can be generated by UPQC which is defined in Eq.13 [16]:

$$V_{dc} = \frac{2\sqrt{2V_{LL}}}{\sqrt{3}m} \quad (13)$$

Where m is the modulation index and V_{LL} is the voltage of UPQC. Considering modulation index of 1 and the grid voltage between line-line (V_{LL}= 380 V), V_{dc} is obtained 620.54 V and chosen as 650 V.

The input of shunt active filter shown in Fig. 6 is DC voltage (V_{dc}) dan DC voltage reference (V_{dc}^*), while the output is P_{loss} using the PI controller. Furthermore, P_{loss} of the input variables produce a reference source current) ($i_{sa}^*, i_{sa}^*, i_{sa}^*$. Then, the reference source current output is compared with current source (i_{sa}, i_{sb}, i_{sc}) by hysteresis current controller to generate a trigger signal in IGBT circuit of shunt active filter. In this paper, PI controller as a DC voltage control algorithm on shunt active filter is proposed.

D. Efficiency of UPQC-PV

The research on the use of 3-Phase 4-Leg Unified Series-Parallel Active Filter Systems using Ultra Capacitor Energy Storage (UCES) to mitigate sag and unbalance voltage has been investigated [17]. In this paper, it is found that the implementation of UCES is able to help system reduce source current compensation when sag voltage on source bus to keep load voltage constant and balanced. During disturbance UCES generates extra power flow to load through a series active filter via dc-link and a series active filter to load. Although providing an advantage of sag voltage compensation, the use of UCES in this proposed system is also able to generate losses and to reduce an efficiency of system. Using the same procedure, the authors proposes Eq. (14) for efficiency of UPQC-PV in the formula below.

$$Eff\ (\%) = \frac{P_{Source}+P_{Series}+P_{Shunt}+P_{PV}+P_{BES}}{P_{Load}} \quad (14)$$

III. Result and Discussion

The proposed model analysis is UPQC connected 3P3W (on-grid) system through a DC link supplied by PV known as UPQC-PV system. The system then supplies sensitive voltage devices on load bus. There are two distrurbance scenarios i.e. sag voltage (Sag) and interruption voltage (Inter). In sag voltage scenario, the system is connected to a sensitive load and the source has a 50% sag voltage disturbance for 0.3 s between t = 0.2 s to t = 0.5 s. In interruption voltage scenario, the system is connected to sensitive load and the source experiences a 100% source voltage interruption for 0.3 s between t = 0.2 s to t = 0.5 s. The UPQC-PV system uses PI controller with constant *Kp* and *Ki* are 0.2 and 1.5, respectively. PI controller is used as DC voltage controller on an active filter series and current controller on shunt active filter to keep load voltage constant in case of disturbance voltage happens on the source bus.

The proposed model analysis is carried out by determining sag voltage and interruption voltage on source bus in 3P3W of UPQC-PV system. The measurement parameters are carried out at fixed temperature conditions (T = 250 C) and the different radiation i.e. 200 W/m^2, 400 W/m^2, 600 W/ m^2, 800 W/m^2, 1000 W/m^2 and 1200 W/m^2 . Each of disturbance scenarios at the variable irradiance level amounts to 6 disturbances, so that the total number of scenarios is 12 interruptions. The UPQC-PV system uses controls mounted on the 3P3W System to keep the voltage at sensitive loads remains constant. Then, using Matlab/Simulink, the model is run in accordance with the scenario that was previously desired to obtain the source voltage curve (V_S), load voltage (V_L), compensation voltage (V_C), source current (V_S), load current (V_L), and DC-Link (V_{DC}) voltage. Based on this curve, the average values of source voltage, load voltage, source current and load current are obtained from value of each phase of voltage and current parameters previously obtained. The next research is determining the value of power transfer of active source power, series active power, active shunt power, active load power, PV power contribution, and system efficiency. The measurement of the value of phase voltage, phase current, power transfer, and PV power is determined in one cycle starting at t = 0.35 s. The results of the average source voltage, source current, load voltage, and load current in the UPQC-PV system model are presented in Table 1.

TABLE I. VOLTAGE AND CURRENT USING UPQC-PV SYSTEM UNDER SAG AND INTERRUPTION WITH VARIABLE IRRADIANCE LEVEL

Irr (W/m^2)	Source Voltage V_S (Volt)				Load Voltage V_L (Volt)				Source Current I_S (Ampere)				Load Current I_L (Ampere)			
	Ph A	Ph B	Ph C	Avg	Ph A	Ph B	Ph C	Avg	Ph A	Ph B	Ph C	Avg	Ph A	Ph B	Ph C	Avg
Sag Voltage and T = 25^0 C																
200	153.9	153.9	153.9	**153.9**	310.1	310.1	310.1	**310.1**	11.77	11.79	11.35	**11.63**	8.590	8.589	8.587	**8.589**
400	154.1	154.1	154.1	**154.1**	310.1	310.1	310.1	**310.1**	10.91	10.98	10.94	**10.94**	8.589	8.590	8.588	**8.589**
600	154.1	154.1	154.1	**154.1**	310.1	310.1	310.1	**310.1**	10.92	10.88	10.98	**10.93**	8.589	8.588	8.589	**8.589**
800	154.0	154.0	154.0	**154.0**	310.1	310.1	310.1	**310.1**	11.45	10.38	11.49	**11.11**	8.588	8.589	8.589	**8.589**
1000	153.8	153.8	153.8	**153.8**	310.1	310.1	310.1	**310.1**	13.39	13.33	13.41	**13.38**	8.589	8.589	8.588	**8.589**
1200	153.8	153.8	153.8	**154.8**	310.1	310.1	310.1	**310.1**	13.69	13.58	13.69	**13.65**	8.589	8.589	8.588	**8.589**
Interuption Voltage and T = 25^0 C																
200	1.229	1.350	1.274	**1.284**	232.8	253.2	247.2	**244.4**	11.65	12.65	12.23	**12.18**	6.561	6.798	6.974	**6.778**
400	1.322	1.416	1.367	**1.368**	245.7	264.2	261.1	**257.0**	12.22	12.66	12.87	**12.51**	6.946	7.051	7.396	**7.131**
600	1.333	1.414	1.363	**1.370**	246.6	263.9	261.8	**257.4**	12.25	12.57	12.85	**12.56**	6.964	7.033	7.406	**7.134**
800	1.304	1.385	1.344	**1.341**	240.1	258.5	255.8	**251.5**	12.13	12.37	12.71	**12.40**	6.788	6.885	7.234	**6.969**
1000	1.190	1.316	1.237	**1.247**	229.2	249.1	242.8	**240.4**	11.31	11.86	11.91	**11.69**	6.443	6.698	6.289	**6.477**
1200	1.227	1.319	1.269	**1.272**	227.5	246.8	243.7	**239.2**	11.50	11.80	12.06	**11.78**	6.433	6.557	6.882	**6.624**

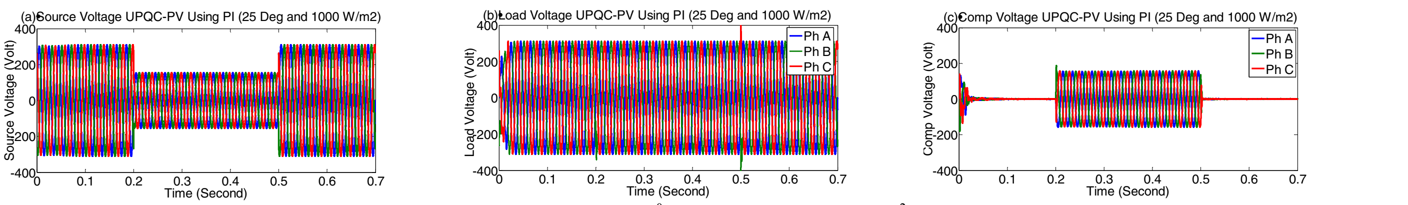

Fig 6. Performance of UPQC-PV system under sag voltage with temperature 25^0 C and irradiance 1000 W/m^2 *(continue)*

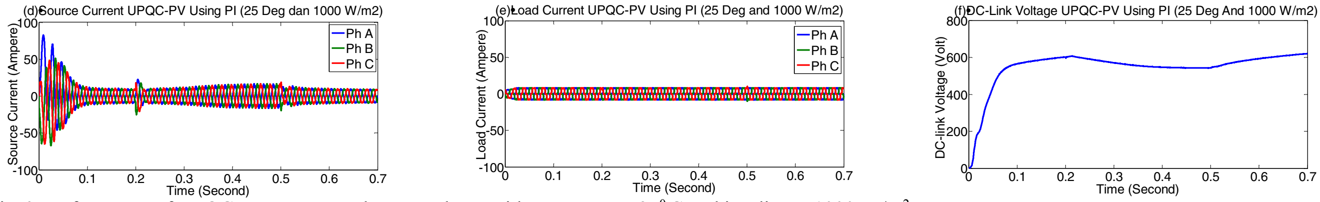

Fig 6. Performance of UPQC-PV system under sag voltage with temperature 25^0 C and irradiance 1000 W/m^2

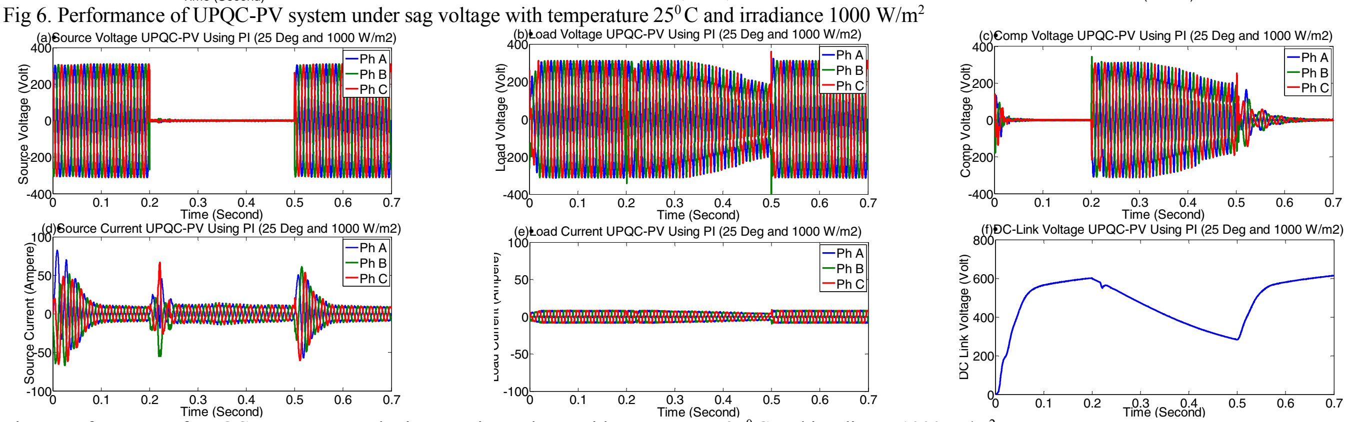

Fig 7. Performance of UPQC-PV system under interruption voltage with temperature 25^0 C and irradiance 1000 W/m^2

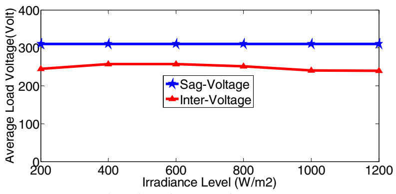

Fig. 8. Average load voltage of UPQC-PV system

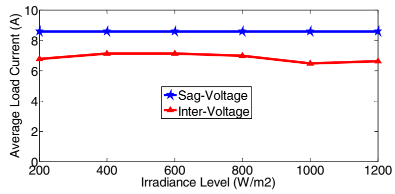

Fig. 9. Average load current of UPQC-PV system

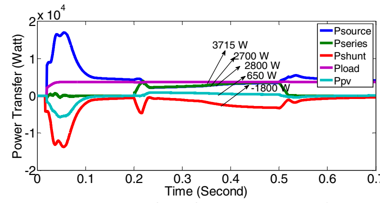

Fig. 10. Power transfer of UPQC-PV under sag

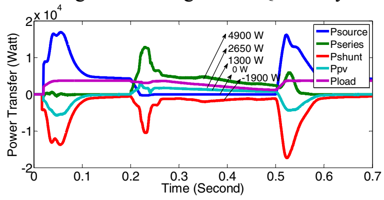

Fig. 11. Power transfer UPQC-PV under interruption

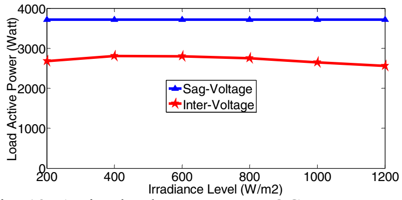

Fig. 12. Active load power on UPQC-PV system

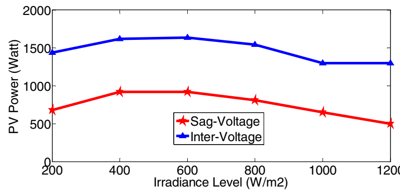

Fig. 13. PV power on UPQC-PV system

Fig. 6 shows that in sag voltage, the UPQC-PV system at t = 0.2 s to t = 0.5 s, irradiance = 1000 W/m^2 and temperature = 25^0 using PI control, the average source voltage (V_S) (Fig. 6.a) decreased by 50% from 310.1 V to 153.8 V (Fig. 6.b). During this duration, the average source current increases slightly to 13.38 A (Fig. 6.d) because the PV contributes power to the load through a DC-link series active filter by injecting a compensation voltage (V_C) of 156.3 V (Fig. 6.c) through the injection transformer in the active series filter so that an average load voltage (V_L) remains stable at 310.1 V (Fig. 6.b). At the same time, the PI controller on shunt active filter works to keep DC voltage (V_{DC}) stable and the average current source (I_S) increases close to 13.38 A (Fig. 6.d) to keep the average I_L stable at 8,589 A (Figure 12.e).

Fig. 7 shows that in the interuption voltage scenario, the UPQC-PV system at t = 0.2 s to t = 0.5 s, irradiation = 1000 W/m2 and temperature = 25^0 using PI controller, the average V_S drops by 100 % to 1.247 V (Fig. 7.a). Under this conditions, the UPQC-PV system is unable to produce maximum power to UPQC DC-link circuit and injects the average V_C (Fig. 3.c) through injection transformer in an active series filter. So at t = 0.2 s to t = 0.5, the average V_L (Fig. 7.b) decreases to 240.4 V. During the interruption period, the application of PI controller to the active shunt filter is unable to maintain the average V_{DC} (Fig.7 .f) and V_C to remain constant, so an the average I_L also decrease to 6,447 A (Fig. 7.e).

Table 1 and Fig. 8 show that in sag voltage and irradiance level of 200W/m^2 to 1200 W/m^2, the 3P3W system using UPQC-PV with PI controller is still able to maintain the average load voltage of 310.1 V. However, in the interruption voltage and the irradiance levels are equally sequential, the average load voltage drops to between 239.2 V and 257 V. Table 1 and Fig. 9 also show that in sag voltage and irradiance levels of 200 W/m^2 to 1200 W/m^2, the 3P3W system uses UPQC-PV with PI controller is still able to maintain an average load current of 8.589 A. However, in the scenario of interruption voltage and same irradiance levels, the average load current drops to between 6.624 A and 7.134 A. Thus, the UPQC-PV system is able to maintain a load voltage, if there is the sag voltage at source bus. Otherwise, in interruption voltage scenario, the UPQC-PV system has not been able to maintain load voltage and load current remain constant. Fig. 8 shows that in sag voltage, the UPQC-PV system at t = 0.2 s to t = 0.5 s, irradiance = 1000 W/m^2 and temperature = 25^0 C using PI controller, source power value (P_S) decreased to 2700 W. Series power (P_{se}) increased by 2800 W and shunt power (P_{Sh}) decreased by -1800 W, PV power by 650 W, so that load power (P_L) value is equal to 3715 W. Fig. 9 shows that in interruption voltage, UPQC-PV system at t = 0.2 s to t = 0.5 s, irradiance = 1000 W/m^2 and temperature = 25^0 C, the value of the source power (P_S) drops to 0 W. The series power (P_{se}) increases by 6000 W and shunt power (P_{Sh}) decreased by -3100 W, and PV power increased by 1300 W, so that the load power (P_L) dropped to 2600 W.

Table 2 and Fig. 12 show that in sag voltage and irradiance levels of 200 W/m^2 to 1200 W/m^2, the 3P3W system uses UPQC-PV with PI still able to maintain active power above 3714 W. However, in the interruption voltage and same irradiance level, active load power drops to between 2560 W and 2805 W. Table 2 and Fig. 13 also show that in sag voltage and irradiance levels of 200 W/m^2 to 1200 W/m^2, the 3P3W system uses UPQC-PV with PI still able to generate PV power between 500 W to 920 W. In the scenario of interruption voltage and irraradiation levels with the same sequence, the PV power increases between 1300 W to 1635 W. However, the increase on PV power in interruption voltage has not been able to meet load power so finally drops to 2650 W.

TABLE II. POWER TRANSFER IN UPQC-PV SYSTEM

Irr (W/m^2)	Power Transfer (Watt)					Eff (%)
	Source Power	Series Power	Shunt Power	Load Power	PV Power	
Sag Voltage and T= 25^0 C						
200	2700	2800	-1720	3715	680	83.30
400	2455	2550	-1200	3714	920	78.60
600	2455	2550	-1200	3714	920	78.52
800	2534	2620	-1332	3714	810	80.18
1000	2700	2800	-1800	3715	650	85.40
1200	2960	3080	-2250	3715	500	86.59
Interruption Voltage and T= 25^0 C						
200	0	4950	-2000	2675	1440	60.93
400	0	4600	-1500	2805	1620	59.43
600	0	4650	-1515	2800	1635	58.70
800	0	4895	-1850	2754	1544	60.01
1000	0	4900	-1900	2650	1300	61.63
1200	0	4850	-1930	2560	1300	59.79

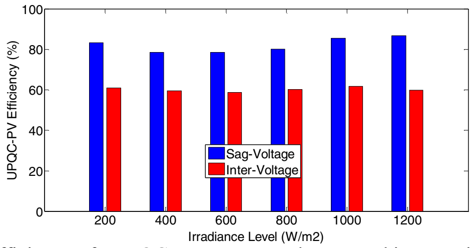

Fig. 14. Efficiency of UPQC-PV system under sag and interruption

Fig. 14 shows that in sag voltage and irrradiance level of 200 W/m^2 to 1200 W/m^2, the 3P3W system using UPQC-PV with PI controller is able to produce a system efficiency of 78.60% to 86.59%. Otherwise, in the interruption voltage and irrradiance increases, the efficiency of UPQC-PV decreases between 58.70% to 61.63%.

IV. CONCLUSSION

The analysis of UPQC-PV system model has been presented in this paper. The PV is connected to a 3P3W distribution system with 380 volts (L-L) and a frequency of 50 hertz, through UPQC-DC link circuit. This system is used to maintain and supply sensitive loads. This research shows that in the sag voltage and irradiance levels of 200 W/m^2 to 1200 W/m^2, the 3P3W system using UPQC-PV with PI is able to maintain the active load power above 3714 W. However, in the interruption voltage and same irradiance level, the load active power drops to between 2560 W and 2805 W. This paper also shows that in the sag voltage and same irradiance level, the 3P3W system using UPQC-PV with PI is able to generate PV power between 500 W to 920 W. In the scenario of the interruption voltage and same irradiance levels, the power that can be generated by PV increases between 1300 W to 1635 W. However, at 25^0 C and 1000 W/m^2, the increase in PV power on interruption voltage has not been able to meet the load power so it finally drops to 2650 W. The increase in PV power close to load power is proposed to overcome this problem.

APPENDIX

Three phase grid: RMS voltage 380 volt (L-L), 50 Hz, line impedance: R_s = 0.1 Ohm L_s = 15 mH; series and shunt active filter: series inductance L_{se} = 0.015 mH; shunt inductance L_{sh} = 15 mH; injection transformers: rating 10 kVA, 50 Hz, turn ratio (N_1/N_2) = 1:1; sensitive load: resistance R_L = 60 ohm, inductance L_L = 0.15 mH, load impedance R_c = 0.4 ohm and L_c = 15 mH; unbalance load: resistance R_1 = 24 ohm, R_2 = 12 ohm, and R_3 = 6 ohm, capacitance C_1,C_2, C_3 = 2.2 µF; DC-link: voltage V_{DC} = 650 volt and capacitance C_{DC} = 3000 µF; photovoltaic: active power = 0.6 kW temperature = 25^0 C, irradiance = 1000 W/m^2; PI controller: K_p = 0.2, K_i = 1.5; input: error (V_{dc}) and delta error (ΔV_{dc}); output: instantaneous of R losses $\bar{p}_{loss}$.

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Power Transfer Analysis Using UPQC-PV System Under Sag and Interruption With Variable Irradiance

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Abstract— This paper presents analysis [1] of UPQC-PV [2] system model under sag and interruption voltage with variable irradiance. The PV is connected to a 3P3W distribution system with 380 volts (L-L) and a frequency of 50 hertz, through UPQC-DC link . [3] This system is used to maintain and supply sensitive loads. This paper shows that in the sag voltage and irradiance levels of 200 W/m2 to 1200 W/m2, the 3P3W system uses UPQC-PV with proportional integral (PI) still able to maintain the load active power above 3714 W. However, in the interruption voltage and same irradiance level, the load active power drops to between 2560 W and 2805 W. This research also show that in the sag voltage and same irradiance levels, the 3P3W system uses UPQC-PV with PI still able to generate PV power between 500 W to 920 W. In the interruption voltage and same irradiance levels, the power that can be generated by PV increases between 1300 W to 1635 W. Otherwise, at 250 C and 1000 W/m2, the increase in PV power on interruption voltage has not been able to meet the load active power consumption, so it finally drops to 2650 W. This paper is simulated using Matlab/Simulink.

Keywords—UPQC, Photovoltaic, Sag, Interruption, Irradiance

INTRODUCTION

The decreasing of fossil energy sources and increasing concerns about environmental impacts have caused renewable energy (RE) sources i.e. photovoltaic (PV) and wind to develop into alternative energy on power generation. Solar or PV generator is one of the most potential RE technologies because it only convert [5] sunlight to generate electricity, where the reseources [6] are avialable [7] in abundant and they are free and relatively clean. Indonesia has a huge energy potential from the sun because it is located in the equator. Almost all regions of Indonesia receive around 10 to 12 hours of sunshine per day, with an average irradiation intensity of 4.5 kWh/m2 or equivalent to 112.000 GW.

Even though, [8] PV is able to [9] generate power, this device also has disadvantage: it results in a number of [10] voltage and current disturbances, as well as harmonics due to the presence of several types of PV devices and power converters and increasing the number of non-linear loads connected to the source, causing a decrease in power quality (PQ). In order to [11] overcome this problem and to improve PQ due to the presence of non-linear load and integration of PV into the grid, UPQC is proposed. This device has been a function to compensate for problems of voltage source quality i.e. sag, swell, unbalance, flicker, harmonics, and load current quality problems i.e. harmonics, imbalance, reactive current, and neutral current. UPQC is part of an active power filter consisting of shunt active filter and series active filter

connected in parallel and serving as a superior controller to solve a number of [12] PQ problems simultaneously [1]. UPQC series component is responsible for reducing a number [13] of disturbances on source [14] side i.e. sag/swell voltage, flicker, unbalanced voltage, and source voltage harmonics. This equipment has served to inject a certain amount of voltage to keep load voltage at desired[15] level so that it returns to balance and distortion free[16]. UPQC shunt component is responsible for overcoming current quality problems i.e[17].[18]. low power factor, load current harmonics, and unbalanced currents. This equipment has been a function of injection current into AC[19] system so that current[20] source becomes a balanced sinusoidal and in phase with source voltage [2]. The dynamic performance of integrated PV with UPQC (PV-UPQC) under variable irradiance condition and sag/swell grid voltage has been investigated [3]. The proposed system was able to combine both the benefits of distributed generators (DGs) and active power filters. The PV-UPQC combination was also able to reduce harmonics due to nonlinear loads and was able to maintain total harmonics distortion (THD) of grid voltage, load voltage and grid current below the IEEE-519. The system was found to be stable under irradiation from

1000 / 2 to 600 / 2.

The dynamic performance based[21] auto tuned[22] PI for PV-UPQC systems has been analyzed [4]. This online optimization methodology is implemented for PV-UPQC to determine the best value of PI gain. The Vector-Proportional Integral (UV-PI) and Proportional Resonant-Response (PR-R) controllers in shunt and series converters significantly increase PV-UPQC performance by reducing convergence time, settling time, switching harmonics, complexity, and dynamic response so that they become more effective. PV-UPQC performance using control[23] algorithm based on Synchronous Reference Frame (SRF) with Phase[24] Lock Loop (PLL) mechanism has been presented [5]. Unbalanced load voltage containing harmonics and pure unbalanced pure load voltage has been compensated and balanced so that the load voltage is maintained constant. UPQC was supplied by 64 PV panels using boost converters, PI controllers, maximum power point tracking (MPPT) with Pertub [25] and Observer (P and O), and having a momentary reactive power theory (p-q theory) which has been proposed [6]. The system has successfully carried out reactive power compensation and reduced source current and load voltage harmonics. However, this study did not address mitigation [26] of sag voltage reduction and other disturbances caused by PV penetration.

PV supported by UPQC using Space Vector Pulse Width Modulation (SVPWM) compared to hysterisis [27] control in a three-phase distribution system has been proposed [7]. The system was used to improve PQ and to reduce the burden

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of 3 phase AC network by supplying power obtained from PV. The UPQC system is able to [28] supply reactive power needed to increase power factor, reduce voltage and current distortion, and PV helps injection active power into the load. A conceptual study of UPQC on three phase [29,30] four wire (3P4W) system connected to linear and non-linear loads simultaneously have been carried out [8]. The sinusoidal current control strategy drives UPQC in such a way that the supply system drawn [31] a constant sinusoidal current under steady state [32] conditions. In addition [33], the shunt converter also produced reactive power as required by load so that it can improve an input power factor and reduce THD of source current.

Artificial neural networks based on SRF theory as a control to compensate for PQ problems of three phase [34,35] three wire (3P3W) system through UPQC for various balanced/unbalanced/distorted conditions at load and source have been proposed [9]. The proposed model has successfully mitigated harmonic/reactive currents, unbalanced source and load, and unbalanced current/voltage. Investigation on enhancements PQ including sag and source voltage harmonics on the grid using UPQC provided by PV array connected to DC links using PI compared to FLC has been conducted [10]. The simulation shows that FLC on UPQC and PV could increase THD voltage source better than PI. The improvement of PQ using UPQC on microgrid supplied by PV and wind turbine have been implemented using PI and FLC. Both methods are able to [36] improve PQ and to reduce distortion in output power [11]. Research on the use of Battery Energy Storage (BES) in UPQC supplied by PV to improve PQ in three phase [37,38] 3P3W systems using FLC validated PI on various disturbances in source and load side has been investigated [12]. The research showed that FLC on UPQC-BES [39] system supplied by PV was able to significantly reduce load current harmonics and source voltage harmonics in number [40] of disturbances, especially in interruption voltage that occurs on source [41] bus.

This research presents analysis [42] of UPQC-PV [43] system model under sag and interruption voltage under variable irradiance. The PV is connected to a 3P3W system with 380 volts (L-L) and a frequency of 50 hertz, through UPQC-DC link . [44] This system is used to maintain load voltage and load active power constant, as well as supply sensitive loads. This paper is presented as follows. Section 2 explains proposed [45] method, UPQC-PV model, parameter simulation, PV model, active filter series and shunt filter control, application of PI, as well as UPQC model efficiency. Section 3 shows results and discussion of load voltage, load current, source active power, load active power, series active power, shunt active power, PV power using PI. In this section, six disturbance scenarios are presented and the results are verified with Matlab/Simulink. Finally, this paper is concluded in Section 4.

RESEARCH METHOD

Proposed Method

Fig. 1 shows proposed[46] model in this paper. The PV is connected to a 3P3W distribution system with 380 volts (L-L) and a frequency of 50 hertz, through UPQC-DC link circuit. This system is known as UPQC-PV[47] system and it is used to maintain ans[48] supply sensitive loads. The PV array generates DC power at a constant temperature, variable solar irradiance, and it is connected to DC-link via a DC-DC boost converter. The MPPT method with P[49] and O algorithm helps PV to

generate maximum power, result[50] an output voltage, which then becomes an input voltage for DC-DC[51] boost converter. This device has a functions[52] to adjust duty cycle value with PV output voltage as an input voltage to produce output voltage according to DC-link[53] voltage of UPQC. The PV has been a function as an alternative source by injecting power to keep load voltage constant, in the case of a interruption[54] voltage accurs[55] on source[56] or point common coupling (PCC) bus.

The proposed model analysis is carried out by determining sag and interruption voltage scenarios on source[57] bus in 3P3W using UPQC-PV[58] system. The measurement parameters are carried out at fixed temperature (T = 250 C) and variable irradiance i.e. 200 W/m2, 400 W/m2, 600 W/m2, 800 W/m2, 1000 W/m2 and 1200 W/m2. Each disturbance scenario at variable irradiance level amounts to 6 disturbance, so the total number of scenarios is 12 disturbances.

The UPQC-PV system uses PI to mantain [59] voltage in a series active filter and current in a shunt active filter to keep the voltage at sensitive loads remains constant. The parameters investigated i.e. voltage and current on source bus, voltage and current on load bus, source active power, series active power, shunt active power , [60] load active power, and PV power. The next step is to determine efficiency [61] value of UPQC-PV [62] system on sag and interruption voltage scenario in variable irradiance to show the contribution of PV in mitigation of both voltage disturbances on source bus. Fig. 2 shows power transfer using UPQC-PV [63] system. Then, simulation [64] parameters for the proposed model is [65] shown in Appendix Section.

Fig. 1. Proposed model of as UPQC-PV system

Fig. 2. Power transfer using UPQC-PV system

B. Modelling[66] of PV Array

Fig. 3 shows the equivalent circuit and V-I characteristics of solar[67] panel. It consists of several PV cells which have[68] external connections in series, parallel, or both combination [13].

Fig. 3. Equivalent circuit of solar panel

The characteristic of V-I is shown in Eq. (1):

= −

− 1 −

(1)

Where

is PV current,

is saturated reverse

current, 'a' is the ideal diode constant, Vt = NS KTq-1 is thermal[69] voltage, NS is number[70] of series cells, q is electron

charge,

is Boltzmann constant,

temperature

pn[71]

junction,

and

are series and parallel resistance

of

solar panels.[72]

has a linear relationship with light

intensity[73] and also varies with temperature variations.

is

dependent value on the temperature variations. The value of

IPV and Io are determined using Eq (2) and Eq. (3):

=

, +

(2)

=

,

(3)

(

,

)/

Where

, , , , and, are PV current, short

circuit current, and open circuit [74] voltage under standard conditions (Tn = 250 C

and Gn = 1000 Wm-2) respectively.

The

value

is coefficient

of short circuit current to

temperature,

= −

is

temperature deviation

from

standard

temperature,

is

light intensity and

is

(

coefficient of open circuit [75] voltage ratio to temperature. Open circuit voltage, short circuit current, and voltage-current related to maximum power are three important values of I-V characteristics of solar [76] panel. These points are changed by variation in atmospheric conditions. By using Eq. (4) and Eq.

derived from PV [77] model, short-circuit current, and open circuit [78] voltage can be calculated under different atmospheric conditions.

= (

+

)

(4)

= (

+

)

(5)

C. Control of Series Active Filter

The main function of series [79] active filter is to protect sensitive [80] load from a number of voltage [81] disturbance [82] at [83] PCC [84] bus. The algorithm of source voltage and load voltage control strategies in series [85] active filter circuit is shown in Fig. 4. This control strategy generates the unit vector template from a distorted input source. Then, the template is expected to be an ideal sinusoidal signal with an unity [86] amplitude. Then, the distorted source voltage is measured and divided by

peak

amplitude [87] of base input voltage

as stated in Eq. (6) [6].

(6)

=

(

+

+

)

A three phase[88] PLL is used to produce sinusoidal unit vector templates with phase lagging through the use of sine function. The load voltage of reference[89] signal is determined by multiplying unit vector templates by the peak value of base input voltage amplitude .[90] The load reference voltage

∗ , ∗ , ∗) is then[91] comparedβ[92] with[93] sensed[94] load[95] voltage(,[96] ,[97]) with a PWM controller which is used to generate the desired trigger signal in series[98] active filter. Fig. 4 shows control[99] of series[100] active filter.

Fig. 4 Series active filter control

D. Control of Shunt Active Filter

The main function of shunt[101] active filter is to mitigate PQ problems on the load side. The control methodology of shunt active filter is that the absorbed current from PCC[102] bus is a balanced positive sequence current including an unbalanced sag voltage on PCC[103] bus, an unbalanced, or a non-linear load. In order to[104] obtain satisfactory compensation caused by interference due to non-linear load, many algorithms have been used in some references. This research uses the method of instantaneous reactive power theory theory[105] or "p-q" theory. The voltages and currents in Cartesian coordinates can be transformed into Cartesian coordinates αβ as stated in Eq. (7) and Eq. (8) [6].

= 1

−1⁄2

−1⁄2

(7)

0

√3⁄2

−√3⁄2

= 1

−1⁄2

−1⁄2

(8)

0

√3⁄2

−√3⁄2

Calculation of real power ( ) and imaginary power ( ) is shown in Eq. (9). Real and imaginary power are[106] measured instantaneously power and expressed in matrix form. The presence of mean[107] and fluctuating component[108] in instantaneous[109] component is shown in Eq. (10) [14].

=

−

(9)

= ̄ +

;

= +

(10)

Where

= the average component of real power, =

the fluctuating component of real power,

= the average

component

of

imaginary power,

=

the fluctuating

component of imaginary power. The total imaginary power

) and fluctuating [110] component [111] of real power are [112] selected as power references

and current references and are utilized through the use of Eq. (10) to

compensate for harmonics and reactive power [15].

∗

−

+

(11)

∗

=

–

–

The‾ signal is obtained from the voltage regulator and is used as average real power. It can also be expressed as instantaneous active power associated with resistive losses and switching losses from UPQC. The error is obtained by comparing the actual value of DC-link capacitor voltage with the reference value processed using a PI controller, driven by a closed voltage control to minimize steady state[113] errors from voltage through DC-link circuit to zero. The compensation current (∗ , ∗) is needed to meet load power demand as shown in Eq. (12). The current is expressed in coordinates α-β. The compensation current is used to obtain source[114] phase current by using Eq. (13) for compensation. The source phase current (∗ , ∗ , ∗) is expressed in the abc[115] axis obtained from the compensation current in – coordinates and is presented in Eq. 12 [15].

Fig. 5 show[116] shunt active filter control [15].

ploss[117]

Fig. 5. Shunt active filter control

∗

1

0

*

*

−1⁄2

(12)

=

√3

⁄2 *

*

$-1/2$

$-\sqrt{3}/2$

In order to[118] operate properly, The UPQC-PV must have a minimum DC-link (Vdc) voltage. The general DC- link voltage value depends on the instantaneous energy that can be generated by UPQC which is defined in Eq.13 [16]:

=

(13)

√

Where

is the modulation index and

is the voltage

of UPQC. Considering modulation [119] index of 1 and the grid

voltage [120] between line-line (VLL= 380 V),

is

obtained

620.54 V and chosen as 650 V.

The input of shunt active filter shown in Fig. 6 is DC

voltage (

) dan DC voltage reference (

∗), while the

output is

using the PI controller. Furthermore,

of

the input

variables produce a reference source

current)

∗ , ∗ , ∗ . Then, the reference source current output is compared with current [121]

source (, [122] , [123]) by hysteresis current controller to generate a trigger signal in

IGBT [124] circuit of shunt active filter. In this paper, PI [125] controller as a DC voltage

control algorithm on shunt [126] active filter is proposed.

D. Efficiency of UPQC-PV

The research on the use of 3-Phase 4-Leg Unified Series-Parallel Active Filter Systems using Ultra Capacitor Energy Storage (UCES) to mitigate sag and unbalance voltage has been investigated [17]. In this paper, it is found that the implementation of UCES is able to [127] help system [128] reduce source current compensation when sag voltage on source bus to keep load voltage constant and balanced. During disturbance [129] UCES generates extra power flow to load through a series active filter via dc-link and a series active filter to load. Although providing an advantage of sag voltage compensation, the use of UCES in this proposed system is also able to generate losses and to reduce an efficiency [130] of system [131]. Using the same procedure, the authors proposes [132] Eq. (14) for efficiency [133] of UPQC-PV in the formula below.

(%) =

(14)

RESULT AND DISCUSSION

The proposed model analysis is UPQC connected 3P3W (on-grid) system through a DC link supplied by PV known as

UPQC-PV system. The system then supplies sensitive voltage devices on load [134] bus. There are two distrurbance [135] scenarios i.e. sag voltage (Sag) and interruption voltage (Inter). In sag [136] voltage scenario, the system is connected to a sensitive load and the source has a 50% sag voltage disturbance for 0.3 s between t = 0.2 s to t = 0.5 s. In interruption [137] voltage scenario, the system is connected to sensitive [138] load and the source experiences a 100% source voltage interruption for 0.3 s between t = 0.2 s to t = 0.5 s. The UPQC-PV system uses PI controller with constant Kp and Ki are 0.2 and 1.5, respectively. PI controller is used as DC [140] voltage controller on an active filter series and current controller on shunt active filter to keep load voltage constant in case of disturbance voltage happens on the source bus.

The proposed model analysis is carried out by determining sag voltage and interruption voltage on source[141] bus in 3P3W of UPQC-PV[142] system. The measurement parameters are carried out at fixed temperature conditions (T = 250 C) and the different radiation i.e. 200 W/m2, 400 W/m2, 600 W/ m2, 800 W/m2, 1000 W/m2 and 1200 W/m2 . Each of disturbance[143] scenarios at the variable irradiance level amounts to 6 disturbances,[144] so that the total number of scenarios is 12 interruptions. The UPQC-PV system uses controls mounted on the 3P3W System to keep the voltage at sensitive loads remains constant. Then, using Matlab/Simulink, the model is run in accordance with[145] the scenario that was previously desired to obtain the source voltage curve (VS), load voltage (VL), compensation voltage (VC), source current (VS), load current (VL), and DC-Link (VDC) voltage. Based on this curve, the average values of source voltage, load voltage, source current and load current are obtained from value[146] of each phase of voltage and current parameters previously obtained. The next research is determining the value of power transfer of active source power, series active power, active shunt power, active load power, PV power contribution, and system efficiency. The measurement of the value of phase voltage, phase current, power transfer, and PV power is determined in one cycle starting at t = 0.35 s. The results of the average source voltage, source current, load voltage, and load current in the UPQC-PV system model are presented in Table 1.

TABLE I. VOLTAGE AND CURRENT USING UPQC-PV SYSTEM UNDER SAG AND INTERRUPTION WITH VARIABLE IRRADIANCE LEVEL

Irr

Source Voltage VS (Volt)

Load Voltage VL (Volt)

Source Current IS (Ampere)

Load Current IL (Ampere)

(W/m2)

Ph A

Ph B

Ph C

Avg

Ph A

Ph B

Ph C

Avg

Ph A

Ph B

Ph C

Avg

Ph A

Ph B

Ph C

Avg

Sag Voltage

and T = 250 C

200

153.9

153.9

153.9

153.9

310.1

310.1

310.1

310.1

11.77

11.79

11.35

11.63

8.590

8.589

8.587

8.589

400

154.1

154.1

154.1

154.1

310.1

310.1

310.1

310.1

10.91

10.98

10.94

10.94

8.589

8.590

8.588

8.589

600

154.1

154.1

154.1

154.1

310.1

310.1

310.1

310.1

10.92

10.88

10.98

10.93

8.589

8.588

8.589

8.589

800

154.0

154.0

154.0

154.0

310.1

310.1

310.1

310.1

11.45

10.38

11.49

11.11

8.588

8.589

8.589

8.589

1000

153.8

153.8

153.8

153.8

310.1

310.1

310.1

310.1

13.39

13.33

13.41

13.38

8.589

8.589

8.588

8.589

1200

153.8

153.8

153.8

154.8

310.1

310.1

310.1

310.1

13.69

13.58

13.69

13.65

8.589

8.589

8.588

8.589

Interuption Voltage and T = 250 C

200

1.229

1.350

1.274

1.284

232.8

253.2

247.2

244.4

11.65

12.65

12.23

12.18

6.561

6.798

6.974

6.778

400

1.322

1.416

1.367

1.368

245.7

264.2

261.1

257.0

12.22

12.66

12.87

12.51

6.946

7.051

7.396

7.131

600

1.333

1.414

1.363

1.370

246.6

263.9

261.8

257.4

12.25

12.57

12.85

12.56

6.964

7.033

7.406

7.134

800

1.304

1.385

1.344

1.341

240.1

258.5

255.8

251.5

12.13

12.37

12.71

12.40

6.788

6.885

7.234

6.969

1000

1.190

1.316

1.237

1.247

229.2

249.1

242.8

240.4

11.31

11.86

11.91

11.69

6.443

6.698

6.289

6.477

1200

1.227

1.319

1.269

1.272

227.5

246.8

243.7

239.2

11.50

11.80

12.06

11.78

6.433

6.557

6.882

6.624

(a)•Source Voltage UPQC-PV Using PI (25 Deg and 1000 W/m2)

400

(Volt)

200

Voltage

0

Source

-200

(b)•Load Voltage UPQC-PV Using PI (25 Deg and 1000 W/m2)

400

Ph A

(Volt)

200

Ph B

Ph C

Voltage

0

Load

-200

Comp Voltage (Volt)

(c)•Comp Voltage UPQC-PV Using PI (25 Deg and 1000 W/m2)

400

Ph A

200

Ph B

Ph C

0

-200

-4000

0.1

0.2

0.3

0.4

0.5

0.6

0.7

-4000

0.1

0.2

0.3

0.4

0.5

0.6

0.7

-4000

0.1

0.2

0.3

0.4

0.5

0.6

0.7

Time (Second)

Time (Second)

Time (Second)

Fig 6. Performance of UPQC-PV system under sag voltage with temperature 250 C and irradiance 1000 W/m2 (continue)

(d)•Source Current UPQC-PV Using PI (25 Deg dan 1000 W/m2)

(e)•Load Current UPQC-PV Using PI (25 Deg and 1000 W/m2)

100

100

SourceCurrent[147](Ampere)

Ph A

LoadCurrent[148](Ampere)

Ph A

50

Ph B

50

Ph B

Ph C

Ph C

0

0

-50

-50

-1000

0.1

0.2

0.3

0.4

0.5

0.6

0.7

-1000

0.1

0.2

0.3

0.4

0.5

0.6

0.7

Time (Second)

Time (Second)

Fig 6. Performance of UPQC-PV system under sag voltage with temperature 250 C and irradiance 1000 W/m2

(f)•DC-Link Voltage UPQC-PV Using PI (25 Deg And 1000 W/m2)

800

(Volt)

600

-linkVoltage[149]

200

400

DC

00

0.1

0.2

0.3

0.4

0.5

0.6

0.7

Time (Second)

(a)•Source Voltage UPQC-PV Using PI (25 Deg and 1000 W/m2)

400

Ph A

(Volt)

200

Ph C

Voltage

Ph B

0

Source

-200

-4000

0.1

0.2

0.3

0.4

0.5

0.6

0.7

Time (Second)

(b)•Load Voltage UPQC-PV Using PI (25 Deg and 1000 W/m2)

400

Ph A

(Volt)

200

Ph C

Ph B

Voltage

0

Load

-200

-4000

0.1

0.2

0.3

0.4

0.5

0.6

0.7

Time (Second)

(c)•Comp Voltage UPQC-PV Using PI (25 Deg and 1000 W/m2)

400

Ph A

(Volt)

200

Ph C

Voltage

Ph B

0

Comp

-200

-4000

0.1

0.2

0.3

0.4

0.5

0.6

0.7

Time (Second)

(d)•Source Current UPQC-PV Using PI (25 Deg and 1000 W/m2)

(e)•Load Current UPQC-PV Using PI (25 Deg and 1000 W/m2)

(f)•DC-Link Voltage UPQC-PV Using PI (25 Deg and 1000 W/m2)

100

100

800

(Ampere)

Ph A

LoadCurrent(Ampere)

Ph A

DCLinkVoltage(Volt)

Source

50

Ph B

Ph B

Ph C

50

600

Ph C

Current

0

0

400

-50

-50

200

-1000

0.1

0.2

0.3

0.4

0.5

0.6

0.7

-1000

0.1

0.2

0.3

0.4

0.5

0.6

0.7

00

0.1

0.2

0.3

0.4

0.5

0.6

0.7

Time (Second)

Time (Second)

Time (Second)

Fig 7. Performance of UPQC-PV system under interruption voltage with temperature 250 C and irradiance 1000 W/m2

olt)[151]

400

o agelt(V[152]

300

V

200

Sag-Voltage

oaLd[153]

Inter-Voltage

verageA[154]

100

0

400

600

800

1000

1200

200

Irradiance Level (W/m2)

Fig. 8. Average load voltage of UPQC-PV system

(A)

10

Current

8

6

Load

4

Sag-Voltage

Average

Inter-Voltage

2

0

400

600

800

1000

1200

200

Irradiance Level (W/m2)

Fig. 9. Average[155] load current of UPQC-PV system

2x 104

Psource[156]

(Watt)

3715 W

Pseries[157]

1

2700 W

Pshunt

2800 W

Pload[158]

Transfer

650 W

Ppv

-1800 W

0

Power

-1

-20

0.1

0.2

0.3

0.4

0.5

0.6

0.7

Time (Second)

Fig. 10. Power transfer of UPQC-PV under sag

4

4000

2x 10

LoadActivePower(Watt)

2000

PowerTransfer[159](Watt)

Psource[160]

[161]

PVPower(Watt)

4900 W

Pseries [162]

2650 W

3000

1500

1

Pshunt

1

1300 W

0 W

Ppv

-1900 W

Pload[163]

2000

Sag-Voltage

1000

0

Inter-Voltage

-1

1000

500

Sag-Voltage

Inter-Voltage

-2

0.1

0.2

0.3

0.4

0.5

0.6

0.7

0

400

600

800

1000

1200

0

400

600

800

1000

1200

0

200

200

Time (Second)

Irradiance Level (W/m2)

Irradiance Level (W/m2)

Fig. 11. Power transfer UPQC-PV under interruption

Fig. 12. Active load power on UPQC-PV system

Fig. 13. PV power on UPQC-PV system

Fig. 6 shows that in sag voltage, the UPQC-PV system at t

Table 1 and Fig. 8 show that in sag voltage and irradiance

= 0.2 s to t = 0.5 s, irradiance = 1000 W/m2 and temperature =

level of 200W/m2 to 1200 W/m2, the 3P3W system using

250 using PI control, the average source voltage (VS) (Fig. 6.a)

UPQC-PV with PI controller is still able to maintain the

decreased by 50% from 310.1 V to 153.8 V (Fig. 6.b). During

average load voltage of 310.1 V. However, in the interruption

this duration, the average source current increases slightly to

voltage and the irradiance levels are equally sequential, the

13.38 A (Fig. 6.d) because the PV contributes power to the average load voltage drops to between 239.2 V and 257 V.

load through a DC-link series active filter by injecting a

Table 1 and Fig. 9 also show that in sag voltage and irradiance

compensation voltage (VC) of 156.3 V (Fig. 6.c) through the

levels of 200 W/m2 to 1200 W/m2, the 3P3W system uses

injection transformer in the active series filter so that an

UPQC-PV with PI controller is still able to maintain an

average load voltage (VL) remains stable at 310.1 V (Fig. 6.b).

164

average load current of 8.589 A. However, in the scenario of

At the same time, the PI controller on shunt active filter works

interruption voltage and same irradiance levels, the average

to keep DC voltage (VDC) stable and the average current source

load current drops to between 6.624 A and 7.134 A. Thus, the

(IS) increases close to 13.38 A (Fig. 6.d) to keep the average IL

165 166

UPQC-PV system is able to maintain a load voltage, if there is

stable at 8,589 A (Figure 12.e).

the sag voltage at source[167] bus. Otherwise, in interruption

Fig. 7 shows that in the interuption[168] voltage scenario, the

voltage scenario, the UPQC-PV system has not been able to
UPQC-PV system at t = 0.2 s to t = 0.5 s, irradiation = 1000

maintain load voltage and load current remain constant. Fig. 8
W/m2 and temperature = 250 using PI[169] controller, the average

shows that in sag voltage, the UPQC-PV system at t = 0.2 s to t
VS drops by 100 % to 1.247 V (Fig. 7.a). Under this conditions,[170]

= 0.5 s, irradiance = 1000 W/m2 and temperature = 250 C using
the UPQC-PV system is unable to produce maximum power to

PI controller, source power value (PS) decreased to 2700 W.
UPQC DC-link circuit and injects the average VC (Fig. 3.c)

Series power (Pse) increased by 2800 W and shunt power (PSh)[171]
through injection transformer in an active series filter. So at t =

decreased by -1800 W, PV power by 650 W, so that load
0.2 s to t = 0.5, the average VL (Fig. 7.b) decreases to 240.4 V.

power (PL) value is equal to 3715 W. Fig. 9 shows that in

During

the

interruption

period,

the

application

of

PI

interruption voltage, UPQC-PV system at t = 0.2 s to t = 0.5 s,

controller to the active shunt filter is unable to maintain the

irradiance = 1000 W/m2 and temperature = 250 C, the value of

average VDC (Fig.7 .f) and VC to remain constant, so an the

the source power (PS) drops to 0 W. The series power (Pse)

average IL also decrease [172] to 6,447 A (Fig. 7.e).

increases by 6000 W and shunt power (PSh) [173] decreased by

-3100 W,[174] and PV power increased by 1300 W,[175] so that the load

power (PL) dropped to 2600 W.

Table 2 and Fig. 12 show that in sag voltage and irradiance levels of 200 W/m2 to 1200 W/m2, the 3P3W system uses UPQC-PV with PI still able to maintain active power above 3714 W. However, in the interruption voltage and same irradiance level, active load power drops to between 2560 W and 2805 W. Table 2 and Fig. 13 also show that in sag voltage and irradiance levels of 200 W/m2 to 1200 W/m2, the 3P3W system uses UPQC-PV with PI still able to generate PV power between 500 W to 920 W. In the scenario of interruption voltage and irraradiation [176] levels with the same sequence, the PV power increases between 1300 W to 1635 W. However, the increase on PV power in interruption voltage has not been able to meet load power so finally drops to 2650 W.

TABLE II. POWER TRANSFER IN UPQC-PV SYSTEM

Irr

Power Transfer (Watt)

Eff

(W/m2

Source

Series

Shunt

Load

PV

)

Power

Power

Power

Power

Power

(%)

Sag Voltage and T= 250 C

200

2700

2800

-1720

3715

680

83.30

400

2455

2550

-1200

3714

920

78.60

600

2455

2550

-1200

3714

920

78.52

800

2534

2620

-1332

3714

810

80.18

1000

2700

2800

-1800

3715

650

85.40

1200

2960

3080

-2250

3715

500

86.59

Interruption

Voltage and

T= 250 C

200

0

4950

-2000

2675

1440

60.93

400

0

4600

-1500

2805

1620

59.43

600

0

4650

-1515

2800

1635

58.70

800

0

4895

-1850

2754

1544

60.01

1000

0

4900

-1900

2650

1300

61.63

1200

0

4850

-1930

2560

1300

59.79

100

(%)

80

PV Efficiency

60

40

-

UPQC

Sag-Voltage

20

Inter-Voltage

0

400

600

800

1000

1200

200

Irradiance Level (W/m2)

Fig. 14. Efficiency[177] of UPQC-PV system under sag and interruption

Fig. 14 shows that in sag voltage and irrradiance[178] level of 200 W/m2 to 1200 W/m2, the 3P3W system using UPQC-PV with PI controller is able to[179] produce a system efficiency of 78.60% to 86.59%. Otherwise, in the interruption voltage and irrradiance[180] increases, the efficiency of UPQC-PV decreases between 58.70% to 61.63%.

IV. CONCLUSSION[181]

The analysis of UPQC-PV[182] system model has been presented in this paper. The PV is connected to a 3P3W distribution system with 380 volts (L-L) and a frequency of 50 hertz, through UPQC-DC link circuit. This system is used to maintain and supply sensitive loads. This research shows that in the sag voltage and irradiance levels of 200 W/m2 to 1200 W/m2, the 3P3W system using UPQC-PV with PI is able to[183] maintain the active load power above 3714 W. However, in the interruption voltage and same irradiance level, the load active power drops to between 2560 W and 2805 W. This paper also shows that in the sag voltage and same irradiance level, the 3P3W system using UPQC-PV with PI is able to[184] generate PV power between 500 W to 920 W. In the scenario of the interruption voltage and same irradiance levels, the power that can be generated by PV increases between 1300 W to 1635 W. However, at 25 0 C and 1000 W/m2, the increase in PV power on interruption voltage has not been able to meet the load power so it finally drops to 2650 W. The increase in PV power close to load power is proposed to overcome this problem.

APPENDIX

Three phase[185] grid: RMS voltage 380 volt (L-L), 50 Hz, line impedance: Rs = 0.1 Ohm Ls = 15 mH; series and shunt active filter: series inductance Lse = 0.015 mH; shunt inductance Lsh = 15 mH; injection transformers: rating 10 kVA, 50 Hz, turn ratio (N1/N2) = 1:1; sensitive load: resistance RL = 60 ohm, inductance LL = 0.15 mH, load impedance Rc = 0.4 ohm and Lc = 15 mH; unbalance load: resistance R1 = 24 ohm, R2 = 12 ohm, and R3 = 6 ohm, capacitance C1,C2, C3 = 2.2 μF; DC-link: voltage VDC = 650 volt and capacitance CDC = 3000 μF; photovoltaic: active power = 0.6 kW temperature = 250 C, irradiance = 1000

W/m2; PI controller: Kp = 0.2, Ki = 1.5; input: error (Vdc) and delta error (ΔVdc); output: instantaneous of R losses¯ .

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1.	an analysis	Determiner Use (a/an/the/this, etc.)	Correctness
2.	the UPQC-PV	Determiner Use (a/an/the/this, etc.)	Correctness
3.	link-.	Improper Formatting	Correctness
4.	proportional-integral	Misspelled Words	Correctness
5.	~~convert~~ → converts	Faulty Subject-Verb Agreement	Correctness
6.	~~reseources~~ → resources	Misspelled Words	Correctness
7.	~~avialable~~ → available	Misspelled Words	Correctness
8.	though,	Comma Misuse within Clauses	Correctness
9.	~~is able to~~ → can	Wordy Sentences	Clarity
10.	~~a number of~~ → several, some, many	Wordy Sentences	Clarity
11.	~~In order to~~ → To	Wordy Sentences	Clarity
12.	~~a number of~~ → several, some, many	Wordy Sentences	Clarity
13.	~~a number~~ → the number	Determiner Use (a/an/the/this, etc.)	Correctness
14.	the source	Determiner Use (a/an/the/this, etc.)	Correctness
15.	the desired	Determiner Use (a/an/the/this, etc.)	Correctness
16.	~~distortion free~~ → distortion-free	Misspelled Words	Correctness
17.	~~i~~ → I	Misspelled Words	Correctness
18.	~~..~~ → ., ...	Closing Punctuation	Correctness
19.	the AC	Determiner Use (a/an/the/this, etc.)	Correctness
20.	the current	Determiner Use (a/an/the/this, etc.)	Correctness

21.	performance-based	Misspelled Words	Correctness
22.	~~auto tuned~~ → auto-tuned	Misspelled Words	Correctness
23.	a control, or the control	Determiner Use (a/an/the/this, etc.)	Correctness
24.	the Phase	Determiner Use (a/an/the/this, etc.)	Correctness
25.	~~Pertub~~ → Perturb	Misspelled Words	Correctness
26.	the mitigation	Determiner Use (a/an/the/this, etc.)	Correctness
27.	~~hysterisis~~ → hysteresis	Misspelled Words	Correctness
28.	~~is able to~~ → can	Wordy Sentences	Clarity
29.	~~three phase~~ → three-phase	Misspelled Words	Correctness
30.	~~phase~~ → phases	Incorrect Noun Number	Correctness
31.	~~drawn~~ → drew, has drawn	Incorrect Verb Forms	Correctness
32.	~~steady state~~ → steady-state	Misspelled Words	Correctness
33.	~~In addition~~ → Also, Besides	Wordy Sentences	Clarity
34.	~~three phase~~ → three-phase	Misspelled Words	Correctness
35.	~~phase~~ → phases	Incorrect Noun Number	Correctness
36.	~~are able to~~ → can	Wordy Sentences	Clarity
37.	~~three phase~~ → three-phase	Misspelled Words	Correctness
38.	~~phase~~ → phases	Incorrect Noun Number	Correctness
39.	the UPQC-BES	Determiner Use (a/an/the/this, etc.)	Correctness
40.	a number, or the number	Determiner Use (a/an/the/this, etc.)	Correctness
41.	the source	Determiner Use (a/an/the/this, etc.)	Correctness

42.	an analysis	Determiner Use (a/an/the/this, etc.)	Correctness
43.	the UPQC-PV	Determiner Use (a/an/the/this, etc.)	Correctness
44.	link-.	Improper Formatting	Correctness
45.	the proposed	Determiner Use (a/an/the/this, etc.)	Correctness
46.	the proposed, or a proposed	Determiner Use (a/an/the/this, etc.)	Correctness
47.	the UPQC-PV	Determiner Use (a/an/the/this, etc.)	Correctness
48.	~~ans~~ → and	Misspelled Words	Correctness
49.	the P	Determiner Use (a/an/the/this, etc.)	Correctness
50.	result in	Wrong or Missing Prepositions	Correctness
51.	the DC-DC	Determiner Use (a/an/the/this, etc.)	Correctness
52.	~~a functions~~ → a function, functions	Determiner Use (a/an/the/this, etc.)	Correctness
53.	the DC-link	Determiner Use (a/an/the/this, etc.)	Correctness
54.	~~a interruption~~ → an interruption	Determiner Use (a/an/the/this, etc.)	Correctness
55.	~~accurs~~ → occurs	Misspelled Words	Correctness
56.	the source	Determiner Use (a/an/the/this, etc.)	Correctness
57.	the source	Determiner Use (a/an/the/this, etc.)	Correctness
58.	the UPQC-PV	Determiner Use (a/an/the/this, etc.)	Correctness
59.	~~mantain~~ → maintain	Misspelled Words	Correctness
60.	power-,	Improper Formatting	Correctness
61.	the efficiency	Determiner Use (a/an/the/this, etc.)	Correctness

62.	the UPQC-PV	Determiner Use (a/an/the/this, etc.)	Correctness
63.	the UPQC-PV	Determiner Use (a/an/the/this, etc.)	Correctness
64.	the simulation	Determiner Use (a/an/the/this, etc.)	Correctness
65.	~~is~~ → are	Faulty Subject-Verb Agreement	Correctness
66.	~~Modelling~~ → Modeling	Mixed Dialects of English	Correctness
67.	a solar, or the solar	Determiner Use (a/an/the/this, etc.)	Correctness
68.	~~which have~~ → that have	Pronoun Use	Correctness
69.	the thermal	Determiner Use (a/an/the/this, etc.)	Correctness
70.	the number	Determiner Use (a/an/the/this, etc.)	Correctness
71.	*pn*	Unknown Words	Correctness
72.	~~solar panels~~ → solar panels	Improper Formatting	Correctness
73.	the intensity	Determiner Use (a/an/the/this, etc.)	Correctness
74.	~~open circuit~~ → open-circuit	Misspelled Words	Correctness
75.	~~open circuit~~ → open-circuit	Misspelled Words	Correctness
76.	the solar, or a solar	Determiner Use (a/an/the/this, etc.)	Correctness
77.	the PV	Determiner Use (a/an/the/this, etc.)	Correctness
78.	~~open circuit~~ → open-circuit	Misspelled Words	Correctness
79.	a series, or the series	Determiner Use (a/an/the/this, etc.)	Correctness
80.	the sensitive	Determiner Use (a/an/the/this, etc.)	Correctness
81.	~~a number of~~ → several, some, many	Wordy Sentences	Clarity

82.	*a number of voltage*	Misuse of Quantifiers	Correctness
83.	~~disturbance~~ → disturbances	Incorrect Noun Number	Correctness
84.	the PCC	Determiner Use (a/an/the/this, etc.)	Correctness
85.	a series, or the series	Determiner Use (a/an/the/this, etc.)	Correctness
86.	~~an unity~~ → a unity	Determiner Use (a/an/the/this, etc.)	Correctness
87.	the amplitude	Determiner Use (a/an/the/this, etc.)	Correctness
88.	~~three phase~~ → three-phase	Misspelled Words	Correctness
89.	the reference	Determiner Use (a/an/the/this, etc.)	Correctness
90.	amplitude~~-~~.	Improper Formatting	Correctness
91.	~~is then~~ → is then	Improper Formatting	Correctness
92.	~~then comparedβ~~ → then comparedβ	Improper Formatting	Correctness
93.	~~comparedβ with~~ → comparedβ with	Improper Formatting	Correctness
94.	~~with sensed~~ → with sensed	Improper Formatting	Correctness
95.	~~sensed load~~ → sensed load	Improper Formatting	Correctness
96.	(~~-~~,	Improper Formatting	Correctness
97.	, ,	Comma Misuse within Clauses	Correctness
98.	a series	Determiner Use (a/an/the/this, etc.)	Correctness
99.	the control	Determiner Use (a/an/the/this, etc.)	Correctness
100.	a series	Determiner Use (a/an/the/this, etc.)	Correctness

101.	the shunt	Determiner Use (a/an/the/this, etc.)	Correctness
102.	the PCC	Determiner Use (a/an/the/this, etc.)	Correctness
103.	the PCC	Determiner Use (a/an/the/this, etc.)	Correctness
104.	~~In order to~~ → To	Wordy Sentences	Clarity
105.	theory ~~theory~~	Misspelled Words	Correctness
106.	~~are~~ → is	Faulty Subject-Verb Agreement	Correctness
107.	a mean	Determiner Use (a/an/the/this, etc.)	Correctness
108.	~~component~~ → components	Incorrect Noun Number	Correctness
109.	the instantaneous, or an instantaneous	Determiner Use (a/an/the/this, etc.)	Correctness
110.	a fluctuating, or the fluctuating	Determiner Use (a/an/the/this, etc.)	Correctness
111.	~~component~~ → components	Incorrect Noun Number	Correctness
112.	~~are~~ → is	Faulty Subject-Verb Agreement	Correctness
113.	~~steady state~~ → steady-state	Misspelled Words	Correctness
114.	the source	Determiner Use (a/an/the/this, etc.)	Correctness
115.	~~abc~~ → ABC	Misspelled Words	Correctness
116.	~~show~~ → shows	Faulty Subject-Verb Agreement	Correctness
117.	*ploss*	Unknown Words	Correctness
118.	~~In order to~~ → To	Wordy Sentences	Clarity
119.	a modulation, or the modulation	Determiner Use (a/an/the/this, etc.)	Correctness
120.	the voltage	Determiner Use (a/an/the/this, etc.)	Correctness

121.	the current	Determiner Use (a/an/the/this, etc.)	Correctness
122.	(-,	Improper Formatting	Correctness
123.	, ,	Comma Misuse within Clauses	Correctness
124.	the IGBT	Determiner Use (a/an/the/this, etc.)	Correctness
125.	the PI	Determiner Use (a/an/the/this, etc.)	Correctness
126.	a shunt	Determiner Use (a/an/the/this, etc.)	Correctness
127.	~~is able to~~ → can	Wordy Sentences	Clarity
128.	the system	Determiner Use (a/an/the/this, etc.)	Correctness
129.	disturbance,	Comma Misuse within Clauses	Correctness
130.	~~an efficiency~~ → the efficiency	Determiner Use (a/an/the/this, etc.)	Correctness
131.	the system	Determiner Use (a/an/the/this, etc.)	Correctness
132.	~~proposes~~ → propose	Faulty Subject-Verb Agreement	Correctness
133.	the efficiency	Determiner Use (a/an/the/this, etc.)	Correctness
134.	the load	Determiner Use (a/an/the/this, etc.)	Correctness
135.	~~distrurbance~~ → disturbance, disturbances	Misspelled Words	Correctness
136.	the sag	Determiner Use (a/an/the/this, etc.)	Correctness
137.	the interruption	Determiner Use (a/an/the/this, etc.)	Correctness
138.	the sensitive, or a sensitive	Determiner Use (a/an/the/this, etc.)	Correctness
139.	a PI	Determiner Use (a/an/the/this, etc.)	Correctness

140.	a DC, or the DC	Determiner Use (a/an/the/this, etc.)	Correctness
141.	the source	Determiner Use (a/an/the/this, etc.)	Correctness
142.	the UPQC-PV	Determiner Use (a/an/the/this, etc.)	Correctness
143.	the disturbance	Determiner Use (a/an/the/this, etc.)	Correctness
144.	disturbances,	Punctuation in Compound/Complex Sentences	Correctness
145.	~~in accordance with~~ → by, following, per, under	Wordy Sentences	Clarity
146.	the value	Determiner Use (a/an/the/this, etc.)	Correctness
147.	~~SourceCurrent~~ → source current	Misspelled Words	Correctness
148.	~~LoadCurrent~~ → load current	Misspelled Words	Correctness
149.	~~linkVoltage~~ → link voltage	Misspelled Words	Correctness
150.	~~LoadCurrent~~ → load current	Misspelled Words	Correctness
151.	*olt*	Unknown Words	Correctness
152.	~~agelt~~ → agent, adult	Misspelled Words	Correctness
153.	~~oaLd~~ → and	Misspelled Words	Correctness
154.	~~verageA~~ → average, averages	Misspelled Words	Correctness
155.	The average	Determiner Use (a/an/the/this, etc.)	Correctness
156.	~~Psource~~ → Source, Resource	Misspelled Words	Correctness
157.	~~Pseries~~ → Series, P-series	Misspelled Words	Correctness
158.	~~Pload~~ → Upload, Preload	Misspelled Words	Correctness
159.	~~PowerTransfer~~ → power transfer	Misspelled Words	Correctness

160.	~~Psource~~ → Source, Resource	Misspelled Words	Correctness
161.	~~PVPower~~ → RAVPower	Misspelled Words	Correctness
162.	~~Pseries~~ → Series, P-series	Misspelled Words	Correctness
163.	~~Pload~~ → Upload, Preload	Misspelled Words	Correctness
164.	the average	Determiner Use (a/an/the/this, etc.)	Correctness
165.	~~is able to~~ → can	Wordy Sentences	Clarity
166.	voltage,	Punctuation in Compound/Complex Sentences	Correctness
167.	the source	Determiner Use (a/an/the/this, etc.)	Correctness
168.	~~interuption~~ → interruption	Misspelled Words	Correctness
169.	a PI	Determiner Use (a/an/the/this, etc.)	Correctness
170.	these conditions	Determiner Use (a/an/the/this, etc.)	Correctness
171.	~~PSh~~ → PCI	Misspelled Words	Correctness
172.	~~decrease~~ → decreases	Faulty Subject-Verb Agreement	Correctness
173.	~~PSh~~ → PCI	Misspelled Words	Correctness
174.	W,	Comma Misuse within Clauses	Correctness
175.	W,	Punctuation in Compound/Complex Sentences	Correctness
176.	~~irraradiation~~ → irradiation	Misspelled Words	Correctness
177.	The efficiency	Determiner Use (a/an/the/this, etc.)	Correctness
178.	~~irrradiance~~ → irradiance	Misspelled Words	Correctness
179.	~~is able to~~ → can	Wordy Sentences	Clarity

180.	~~irrradiance~~ → irradiance	Misspelled Words	Correctness
181.	~~CONCLUSSION~~ → CONCLUSION, CONCLUSIONS	Misspelled Words	Correctness
182.	the UPQC-PV	Determiner Use (a/an/the/this, etc.)	Correctness
183.	~~is able to~~ → can	Wordy Sentences	Clarity
184.	~~is able to~~ → can	Wordy Sentences	Clarity
185.	~~Three phase~~ → Three-phase	Misspelled Words	Correctness
186.	~~Enhanching~~ → Enhancing	Misspelled Words	Correctness
187.	~~Chenni~~ → Chennai, Chen	Misspelled Words	Correctness
188.	~~Ghoshand~~ → Ghosh and	Misspelled Words	Correctness
189.	~~Grid connected~~ → Grid-connected	Misspelled Words	Correctness
190.	, and	Comma Misuse within Clauses	Correctness
191.	, Proc	Improper Formatting	Correctness

Lampiran 2.5

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Power Transfer Analysis Using UPQC-PV System Under Sag and Interruption With Variable Irradiance

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Power Transfer Analysis Using UPQC-PV System Under Sag and Interruption With Variable Irradiance

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***Abstract*— This paper presents an analysis of the Unified Power Quality Conditioner-Photovoltaic (UPQC-PV) system under sag and interruption voltage with variable irradiance. The PV is connected to a three-phase three-wire (3P3W) distribution system with 380 volts (L-L) and a frequency of 50 hertz, through UPQC-DC link. This system is used to maintain and supply sensitive loads. This paper shows that in the sag voltage and irradiance levels of 200 W/m^2 to 1200 W/m^2, the 3P3W system uses UPQC-PV with proportional-integral (PI) still able to maintain the active load power above 3714 W. However, in the interruption voltage and same irradiance level, the load active power drops to between 2560 W and 2805 W. This research also shows that in the sag voltage and same irradiance levels, the 3P3W system uses UPQC-PV with PI still able to generate PV power between 500 W to 920 W. In the interruption voltage and same irradiance levels, the power that can be generated by PV increases between 1300 W to 1635 W. Otherwise, at 25^0 C and 1000 W/m^2, the increase in PV power on interruption voltage has not been able to meet the load active power consumption, so it finally drops to 2650 W. This paper is simulated using Matlab/Simulink.**

Keywords—UPQC, Photovoltaic, Sag, Interruption, Irradiance

I. INTRODUCTION

The decreasing of fossil energy sources and increasing concerns about environmental impacts have caused renewable energy (RE) sources i.e., photovoltaic (PV) and wind, to develop into alternative energy on power generation. Solar or PV generator is one of the most potential RE technologies because it only converts sunlight to generate electricity, where the resources are available in abundant and they are free and relatively clean. Indonesia has a huge energy potential from the sun because it is located in the equator. Almost all regions of Indonesia receive around 10 to 12 hours of sunshine per day, with an average irradiation intensity of 4.5 kWh/m^2 or equivalent to 112.000 GW.

Even though, PV can generate power, this device also has a disadvantage: it results in several voltage and current disturbances, as well as harmonics due to the presence of several types of PV devices and power converters and increasing the number of non-linear loads connected to the source, causing a decrease in power quality (PQ). To overcome this problem and to improve PQ due to the presence of non-linear load and integration of PV into the grid, UPQC is proposed. This device has been a function to compensate for problems of voltage source quality i.e. sag, swell, unbalance, flicker, harmonics, and load current quality problems i.e. harmonics, imbalance, reactive current, and neutral current. UPQC is part of an active power filter consisting of a shunt active filter and series active filter connected in parallel and serving as a superior controller to solve several PQ problems simultaneously [1]. UPQC series component is responsible for reducing the number of disturbances on source side i.e. sag/swell voltage, flicker, unbalanced voltage, and source voltage harmonics. This equipment has served to inject a certain amount of voltage to keep load voltage at desired level so that it returns to balance and distortion-free. UPQC shunt component is responsible for overcoming current quality problems i.e. low power factor, load current harmonics, and unbalanced currents. This equipment has been a function of injection current into the AC system so that the current source becomes a balanced sinusoidal and in phase with source voltage [2]. The design and dynamic performance of integrated PV with UPQC (PV-UPQC) under variable irradiance condition and voltage sag/swell, and load unbalance has been investigated [3]. The proposed system was able to combine both the benefits of distributed generators (DGs) and active power filters. The PV-UPQC combination was also able to reduce harmonics due to nonlinear loads and was able to maintain total harmonics distortion (THD) of grid voltage, load voltage and grid current below the IEEE-519. The system was found to be stable under radiation variations, voltage sag/swell, and load unbalances conditions.

The dynamic performance-based auto-tuned PI for UPQC-PV system has been analyzed [4]. This online optimization methodology is implemented for PV-UPQC to determine the best value of PI gain. The Vector-Proportional Integral (UV-PI) and Proportional Resonant-Response (PR-R) controllers in shunt and series converters significantly increase PV-UPQC performance by reducing convergence time, settling time, switching harmonics, complexity, and dynamic response so that they become more effective. PV-UPQC performance using a control algorithm based on Synchronous Reference Frame (SRF) with the Phase Lock Loop (PLL) mechanism has been presented [5]. Unbalanced load voltage containing harmonics and pure unbalanced pure load voltage has been compensated and balanced so that the load voltage is maintained constant. UPQC was supplied by 64 PV panels using boost converters, PI controllers,

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maximum power point tracking (MPPT) with Perturb and Observer (P and O), and having a momentary reactive power theory (p-q theory) which has been proposed [6]. The system has successfully carried out reactive power compensation and reduced source current and load voltage harmonics. However, this study did not address the mitigation of sag voltage and other disturbances caused by PV penetration.

PV supported by UPQC using Space Vector Pulse Width Modulation (SVPWM) compared to hysteresis control in a three-phase distribution system has been proposed [7]. The system was used to improve PQ and to reduce the burden of 3 phase AC network by supplying power obtained from PV. The UPQC system can supply reactive power needed to increase power factor, reduce voltage and current distortion, and PV helps active injection power into the load. A conceptual study of UPQC on three-phase four-wire (3P4W) system connected to linear and non-linear loads simultaneously has been carried out [8]. The sinusoidal current control strategy drives UPQC in such a way that the supply system has drawn a constant sinusoidal current under steady-state conditions. Besides, the shunt converter also produced reactive power as required by load so that it can improve power factor and reduce THD of source current.

Artificial neural networks based on SRF theory as a control to compensate for PQ problems of 3P3W system through UPQC for various balanced/unbalanced/distorted conditions at load and source have been proposed [9]. The proposed model has successfully mitigated harmonic/reactive currents, unbalanced source and load, and unbalanced current/voltage. Investigation on enhancements PQ including sag and source voltage harmonics on the grid using UPQC provided by PV array connected to DC links using PI compared to FLC has been conducted [10]. The simulation shows that FLC on UPQC and PV could increase THD voltage source better than PI. The improvement of PQ using UPQC on microgrid supplied by PV and wind turbine have been implemented using PI and FLC. Both methods can improve PQ and to reduce distortion in output power [11]. Research on the use of Battery Energy Storage (BES) in UPQC supplied by PV to improve PQ in 3P3W system using FLC validated PI on various disturbances in source and load side has been investigated [12]. The research showed that FLC on the UPQC-Battery Energy Storage (BES) system supplied by PV was able to significantly reduce load current harmonics and source voltage harmonics in the number of disturbances, especially in interruption voltage that occurs on the source bus.

This research presents an analysis of the UPQC-PV system model under sag and interruption voltage with variable irradiance. The PV is connected to a 3P3W system with 380 volts (L-L) and a frequency of 50 hertz, through UPQC-DC link. This system is used to maintain load voltage and load active power constant, as well as to supply sensitive loads. This paper is presented as follows. Section 2 explains the proposed method, UPQC-PV model, parameter simulation, PV model, active filter series and shunt filter control, application of PI, as well as UPQC model efficiency. Section 3 shows results and discussion of load voltage, load current, source active power, load active power, series active power, shunt active power, PV power using PI. In this section, six disturbance scenarios are presented and the results are verified with Matlab/Simulink. Finally, this paper is concluded in Section 4.

II. RESEARCH METHOD

A. Proposed Method

Fig. 1 shows the proposed model in this paper. The PV is connected to a 3P3W distribution system with 380 volts (L-L) and a frequency of 50 hertz, through UPQC-DC link circuit. This system is known as the UPQC-PV system and it is used to maintain and supply sensitive loads. The PV array generates DC power at a constant temperature, variable solar irradiance, and it is connected to DC-link via a DC-DC boost converter. The MPPT method with the P and O algorithm helps PV to generate maximum power, result in an output voltage, which then becomes an input voltage for the DC-DC boost converter. This device has a function to adjust duty cycle value with PV output voltage as an input voltage to produce output voltage according to the DC-link voltage of UPQC. The PV has been a function as an alternative source by injecting power to keep load voltage constant, in the case of an interruption voltage that occurs on the source or points common coupling (PCC) bus.

The analysis of the proposed model is carried out by determining sag and interruption voltage scenarios on the source bus in 3P3W using the UPQC-PV system. The measurement parameters are carried out at fixed temperature (T = 25^0 C) and variable irradiance i.e. 200 W/m^2, 400 W/m^2, 600 W/m^2, 800 W/m^2, 1000 W/m^2 and 1200 W/m^2. Each disturbance scenario at variable irradiance level amounts to 6 disturbance, so the total number of scenarios is 12 disturbances. The UPQC-PV system uses PI to maintain voltage in a series active filter and current in an active shunt filter to keep the voltage at sensitive loads remains constant. The parameters investigated i.e. voltage and current on source bus, voltage and current on load bus, active source power, series active power, shunt active power, load active power, and PV power. The next step is to determine the efficiency value of the UPQC-PV system on sag and interruption voltage scenario in variable irradiance to show the contribution of PV in the mitigation of both voltage disturbances on source bus. Fig. 2 shows power transfer using the UPQC-PV system. Then, the simulation parameters for the proposed model are shown in Appendix Section.

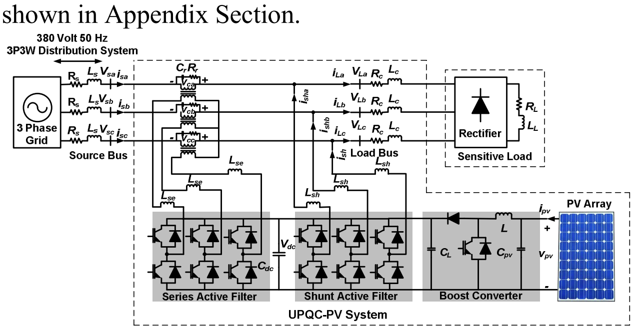

Fig. 1. Proposed model of as UPQC-PV system

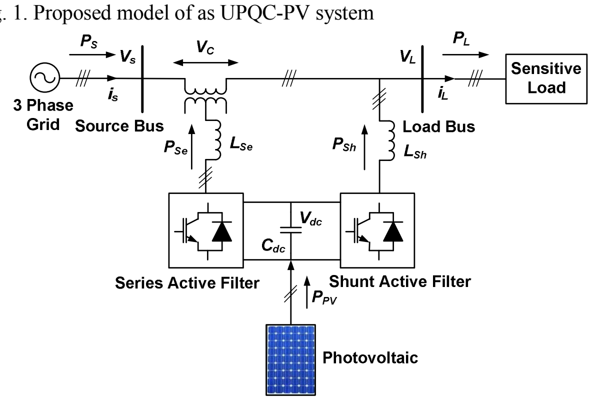

Fig. 2. Power transfer using UPQC-PV system

B. Modeling of PV Array

Fig. 3 shows the equivalent circuit and V-I characteristics of a solar panel. It consists of several PV cells that have external connections in series, parallel, or both combination [13].

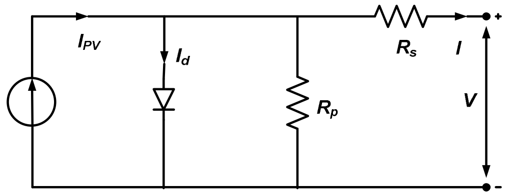

Fig. 3. Equivalent circuit of solar panel

The characteristic of V-I is shown in Eq. (1):

$$I = I_{PV} - I_o\left[exp\left(\frac{V+R_SI}{a\,V_t}\right) - 1\right] - \frac{V+R_SI}{R_P} \quad (1)$$

Where I_{PV} is PV current, I_o is saturated reverse current, $'a'$ is the ideal diode constant, $Vt = N_SKTq^{-1}$ is the thermal voltage, N_S is the number of series cells, q is electron charge, K is Boltzmann constant. T is temperature p-n junction. R_S and R_P are series and parallel resistance of the solar panels. I_{PV} has a linear relationship with the light intensity and also varies with temperature variations. I_o is dependent value on the temperature variations. The value of I_{PV} and I_o are determined using Eq (2) and Eq. (3):

$$I_{PV} = \left(I_{PV,n} + K_I\Delta T\right)\frac{G}{G_n} \quad (2)$$

$$I_o = \frac{I_{SC,n}+K_I\Delta T}{\exp(V_{OC,n}+K_V\Delta T)/aV_t - 1} \quad (3)$$

Where $I_{PV,n}$, $I_{SC,n}$, and $V_{OC,n}$ are PV current, short-circuit current, and open-circuit voltage under standard conditions ($T_n = 25^0C$ and $G_n = 1000\ W/m^2$), respectively. The K_I value is a coefficient of short circuit current to temperature, $\Delta T = T - T_n$ is temperature deviation from standard temperature, G is light intensity and K_V is a coefficient of open-circuit voltage ratio to temperature. Open-circuit voltage, short-circuit current, and voltage-current related to maximum power are three important values of I-V characteristics of a solar panel. These points are changed by variation in atmospheric conditions. By using Eq. (4) and Eq. (5) derived from PV model, short-circuit current, and open-circuit voltage can be calculated under different atmospheric conditions.

$$I_{SC} = (I_{SC} + K_I\Delta T)\frac{G}{G_n} \quad (4)$$

$$V_{OC} = (V_{OC} + K_V\Delta T) \quad (5)$$

C. Control of Series Active Filter

The main function of a series active filter is to protect the sensitive load from several voltage disturbances at the PCC bus. The algorithm of a source voltage and a load voltage control strategy in a series active filter circuit is shown in Fig. 4. This control strategy generates the unit vector template from a distorted input source. Then, the template is expected to be an ideal sinusoidal signal with a unity amplitude. Then, the distorted source voltage is measured and divided by peak the amplitude of base input voltage V_m as stated in Eq. (6) [6].

$$V_m = \sqrt{\frac{2}{3}\left(V_{sa}^2 + V_{sb}^2 + V_{sc}^2\right)} \quad (6)$$

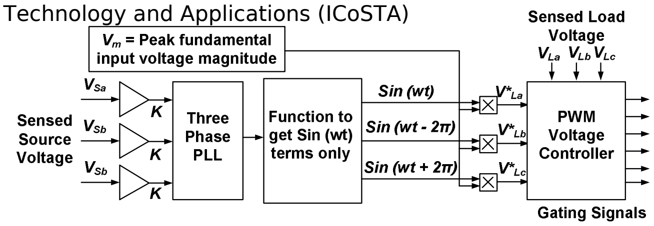

Fig. 4 Series active filter control

A three-phase PLL is used to produce sinusoidal unit vector templates with phase lagging through the use of sine function. The load voltage of the reference signal is determined by multiplying unit vector templates by the peak value of base input voltage amplitude V_m. The load reference voltage $(V_{La}^*, V_{Lb}^*, V_{Lc}^*)$ is then compared with sensed load voltage (V_{La}, V_{Lb}, V_{Lc}) with a PWM controller which is used to generate the desired trigger signal in a series active filter. Fig. 4 shows the control of a series active filter.

D. Control of Shunt Active Filter

The main function of an active shunt filter is to mitigate PQ problems on the load side. The control methodology of a shunt active filter is that the absorbed current from the PCC bus is a balanced positive sequence current including an unbalanced sag voltage on the PCC bus, an unbalanced, or a non-linear load. To obtain satisfactory compensation caused by interference due to non-linear load, many algorithms have been used in some references. This research uses the method of instantaneous reactive power theory or "p-q" theory. The voltages and currents in Cartesian coordinates can be transformed into Cartesian coordinates αβ as stated in Eq. (7) and Eq. (8) [6].

$$\begin{bmatrix} v_\alpha \\ v_\beta \end{bmatrix} = \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} \quad (7)$$

$$\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} = \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} \quad (8)$$

Calculation of real power (p) and imaginary power (q) is shown in Eq. (9). Real and imaginary power are measured power instantaneously and expressed in matrix form. The presence of mean and fluctuating components in an instantaneous component is shown in Eq. (10) [14].

$$\begin{bmatrix} p \\ q \end{bmatrix} = \begin{bmatrix} v_\alpha & v_\beta \\ -v_\beta & v_\alpha \end{bmatrix} \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} \quad (9)$$

$$p = \bar{p} + \tilde{p} \quad ; \quad q = \bar{q} + \tilde{q} \quad (10)$$

Where $\bar{p}$ = the average component of real power, $\tilde{p}$ = the fluctuating component of real power, $\bar{q}$ = the average component of imaginary power, $\tilde{q}$ = the fluctuating component of imaginary power. The total of imaginary power (q) and fluctuating components of real power $(\tilde{p})$ is selected as power references and current references and is utilized through the use of Eq. (10) to compensate for harmonics and reactive power [15]. Fig. 5 shows a shunt active filter control [15].

$$\begin{bmatrix} i_{c\alpha}^* \\ i_{c\beta}^* \end{bmatrix} = \frac{1}{v_\alpha^2 + v_\beta^2} \begin{bmatrix} v_\alpha & v_\beta \\ v_\beta & -v_\alpha \end{bmatrix} \begin{bmatrix} -\tilde{p} + \bar{p}_{loss} \\ -q \end{bmatrix} \quad (11)$$

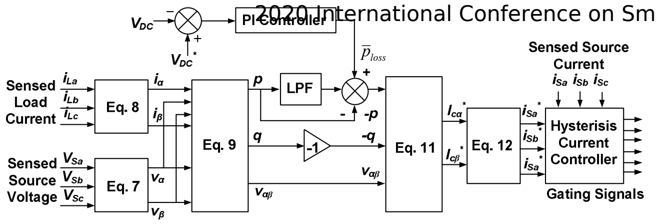

Fig. 5. Shunt active filter control

The $\bar{p}_{loss}$ signal is obtained from the voltage regulator and is used as average real power. It can also be expressed as instantaneous active power associated with resistive losses and switching losses from UPQC. The error is obtained by comparing the actual value of DC-link capacitor voltage with the reference value processed using a PI controller, driven by a closed voltage control to minimize steady-state errors from voltage through DC-link circuit to zero. The compensation current $(i_{c\alpha}^*, i_{c\beta}^*)$ is needed to meet load power demand as shown in Eq. (12). The current is expressed in coordinates $\alpha - \beta$. The compensation current is used to obtain the source phase current by using Eq. (13) for compensation. The source phase current $(i_{sa}^*, i_{sa}^*, i_{sa}^*)$ is expressed in the abc axis obtained from the compensation current in $\alpha - \beta$ coordinates and is presented in Eq. 12 [15] .

$$\begin{bmatrix} i_{sa}^* \\ i_{sb}^* \\ i_{sc}^* \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 0 \\ -1/2 & \sqrt{3}/2 \\ -1/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} i_{c\alpha}^* \\ i_{c\beta}^* \end{bmatrix} \tag{12}$$

To operate properly, The UPQC-PV must have a minimum DC-link voltage (V_{dc}) . The general DC-link voltage value depends on the instantaneous energy that can be generated by UPQC which is defined in Eq.13 [16]:

$$V_{dc} = \frac{2\sqrt{2V_{LL}}}{\sqrt{3}m} \tag{13}$$

Where m is the modulation index and V_{LL} is the voltage of UPQC. Considering the modulation index of 1 and the grid voltage between line-line $(V_{LL} = 380\, V)$, V_{dc} is obtained 620.54 V and chosen as 650 V.

The input of active shunt filter shown in Fig. 6 is DC voltage (V_{dc}) dan DC voltage reference (V_{dc}^*), while the output is P_{loss} using the PI controller. Furthermore, P_{loss} of the input variables produce a reference source current $(i_{sa}^*, i_{sa}^*, i_{sa}^*)$. Then, the reference source current output is compared with the current source (i_{sa}, i_{sb}, i_{sc}) by hysteresis current controller to generate a trigger signal in the IGBT circuit of shunt active filter. In this paper, the PI controller as a DC voltage control algorithm on an active shunt filter, is proposed.

D. Efficiency of UPQC-PV

The research on the use of 3-Phase 4-Leg Unified Series-Parallel Active Filter Systems using Ultra Capacitor Energy Storage (UCES) to mitigate sag and unbalance voltage has been investigated [17]. In this paper, it is found that the implementation of UCES can help the system reduce source current compensation when sag voltage on source bus to keep load voltage constant and balanced. During disturbance, UCES generates extra power flow to load through a series active filter via dc-link and a series active filter to load. Although providing an advantage of sag voltage compensation, the use of UCES in this proposed system is also able to generate losses and to reduce the efficiency of the system. Using the same procedure, the authors propose Eq. (14) for efficiency of UPQC-PV in the formula below.

$$Eff\,(\%) = \frac{P_{Source}+P_{Series}+P_{Shunt}+P_{PV}+P_{BES}}{P_{Load}} \tag{14}$$

III. Result and Discussion

The proposed model analysis is UPQC connected 3P3W (on-grid) system through a DC link supplied by PV known as UPQC-PV system. The system then supplies sensitive voltage devices on the load bus. There are two disturbances scenario i.e. sag voltage (Sag) and interruption voltage (Inter). In the sag voltage scenario, the system is connected to a sensitive load and the source has a 50% sag voltage disturbance for 0.3 s between t = 0.2 s to t = 0.5 s. In the interruption voltage scenario, the system is connected to a sensitive load and the source experiences a 100% source voltage interruption for 0.3 s between t = 0.2 s to t = 0.5 s. The UPQC-PV system uses a PI controller with constant K_P and K_I are 0.2 and 1.5, respectively. PI controller is used as a DC voltage controller on an active filter series and current controller on active shunt filter to keep load voltage constant in case of disturbance voltage happens on the source bus.

The proposed model analysis is carried out by determining sag voltage and interruption voltage on the source bus in 3P3W of the UPQC-PV system. The measurement parameters are carried out at fixed temperature conditions (T = 250 C) and the different radiation i.e. 200 W/m^2, 400 W/m^2, 600 W/ m^2, 800 W/m^2, 1000 W/m^2 and 1200 W/m^2. The disturbance scenarios at the variable irradiance level amounts to 6 disturbances so that the total number of scenarios is 12 interruptions. The UPQC-PV system uses controls mounted on the 3P3W System to keep the voltage at sensitive loads remains constant. Then, using Matlab/Simulink, the model is run following with the scenario that was previously desired to obtain the source voltage curve (V_S), load voltage (V_L), compensation voltage (V_C), source current (I_S), load current (I_L), and DC-Link voltage (V_{DC}). Based on this curve, the average values of source voltage, load voltage, source current and load current are obtained from value of each phase of voltage and current parameters previously obtained. The next research is determining the value of power transfer of active source power, active series power, active shunt power, active load power, PV power contribution, and system efficiency. The measurement of the value of phase voltage, phase current, power transfer, and PV power is determined in one cycle, starting at t = 0.35 s. The results of the average source voltage, source current, load voltage, and load current in the UPQC-PV system model are presented in Table 1.

TABLE I. VOLTAGE AND CURRENT USING UPQC-PV SYSTEM UNDER SAG AND INTERRUPTION WITH VARIABLE IRRADIANCE LEVEL

Irr (W/m^2)	Source Voltage V_S (Volt)				Load Voltage V_L (Volt)				Source Current I_S (Ampere)				Load Current I_L (Ampere)			
	Ph A	Ph B	Ph C	Avg	Ph A	Ph B	Ph C	Avg	Ph A	Ph B	Ph C	Avg	Ph A	Ph B	Ph C	Avg
Sag Voltage and T = 25^0 C																
200	153.9	153.9	153.9	**153.9**	310.1	310.1	310.1	**310.1**	11.77	11.79	11.35	**11.63**	8.590	8.589	8.587	**8.589**
400	154.1	154.1	154.1	**154.1**	310.1	310.1	310.1	**310.1**	10.91	10.98	10.94	**10.94**	8.589	8.590	8.588	**8.589**
600	154.1	154.1	154.1	**154.1**	310.1	310.1	310.1	**310.1**	10.92	10.88	10.98	**10.93**	8.589	8.588	8.589	**8.589**
800	154.0	154.0	154.0	**154.0**	310.1	310.1	310.1	**310.1**	11.45	10.38	11.49	**11.11**	8.588	8.589	8.589	**8.589**
1000	153.8	153.8	153.8	**153.8**	310.1	310.1	310.1	**310.1**	13.39	13.33	13.41	**13.38**	8.589	8.589	8.588	**8.589**
1200	153.8	153.8	153.8	**154.8**	310.1	310.1	310.1	**310.1**	13.69	13.58	13.69	**13.65**	8.589	8.589	8.588	**8.589**
Interuption Voltage and T = 25^0 C																
200	1.229	1.350	1.274	**1.284**	232.8	253.2	247.2	**244.4**	11.65	12.65	12.23	**12.18**	6.561	6.798	6.974	**6.778**
400	1.322	1.416	1.367	**1.368**	245.7	264.2	261.1	**257.0**	12.22	12.66	12.87	**12.51**	6.946	7.051	7.396	**7.131**
600	1.333	1.414	1.363	**1.370**	246.6	263.9	261.8	**257.4**	12.25	12.57	12.85	**12.56**	6.964	7.033	7.406	**7.134**
800	1.304	1.385	1.344	**1.341**	240.1	258.5	255.8	**251.5**	12.13	12.37	12.71	**12.40**	6.788	6.885	7.234	**6.969**
1000	1.190	1.316	1.237	**1.247**	229.2	249.1	242.8	**240.4**	11.31	11.86	11.91	**11.69**	6.443	6.698	6.289	**6.477**
1200	1.227	1.319	1.269	**1.272**	227.5	246.8	243.7	**239.2**	11.50	11.80	12.06	**11.78**	6.433	6.557	6.882	**6.624**

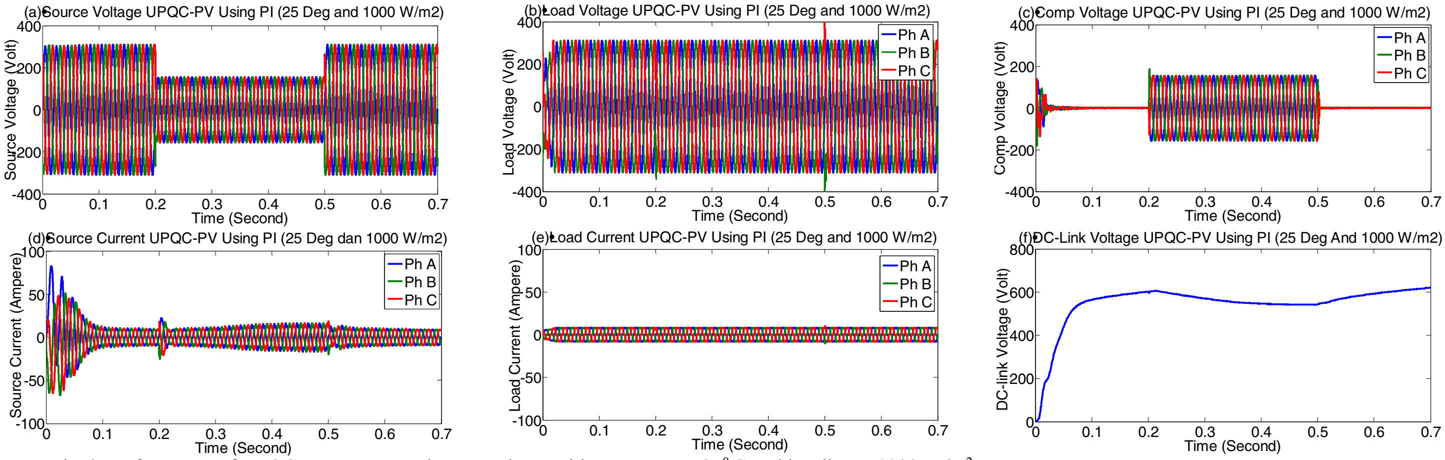

Fig 6. Performance of UPQC-PV system under sag voltage with temperature 25^0C and irradiance 1000 W/m^2

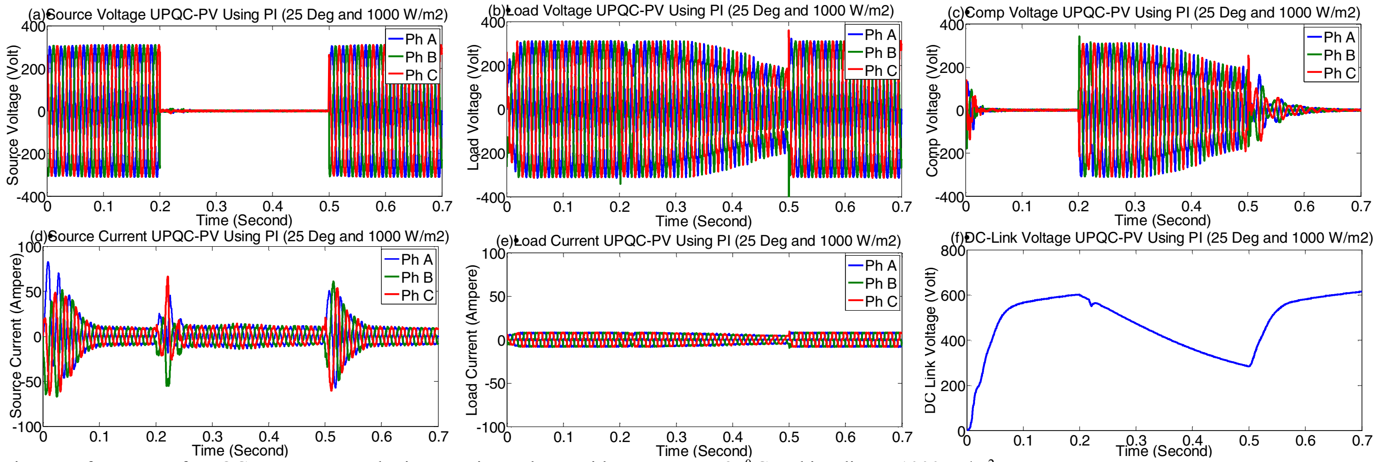

Fig 7. Performance of UPQC-PV system under interruption voltage with temperature 25^0C and irradiance 1000 W/m^2

Fig. 6 shows that in sag voltage, the UPQC-PV system at t = 0.2 s to t = 0.5 s, irradiance = 1000 W/m^2 and temperature = 25^0 using PI control, the average source voltage (V_S) (Fig. 6.a) decreased by 50% from 310.1 V to 153.8 V (Fig. 6.b). During this duration, the average source current (I_S) increases slightly to 13.38 A (Fig. 6.d) because the PV contributes power to the load through a DC-link series active filter by injecting a compensation voltage (V_C) of 156.3 V (Fig. 6.c) through the injection transformer in the active series filter so that an average load voltage (V_L) remains stable at 310.1 V (Fig. 6.b). At the same time, the PI controller on shunt active filter works to keep DC voltage (V_{DC}) stable and the average current source (I_S) increases close to 13.38 A (Fig. 6.d) to keep the average (I_L) stable at 8,589 A (Figure 6.e).

Fig. 7 shows that in the interruption voltage scenario, the UPQC-PV system at t = 0.2 s to t = 0.5 s, irradiation = 1000 W/m2 and temperature = 25^0 using PI controller, the average V_S drops by 100 % to 1.247 V (Fig. 7.a). Under these conditions, the UPQC-PV system is unable to produce maximum power to UPQC DC-link circuit and injects the average V_C (Fig. 7.c) through injection transformer in the active series filter. So at t = 0.2 s to t = 0.5, the average V_L (Fig. 7.b) decreases to 240.4 V. During the interruption period, the application of a PI controller to the active shunt filter is unable to maintain the average V_{DC} (Fig.7.f) and V_C to remain constant, so an average I_L also decreases to 6,447 A (Fig. 7.e).

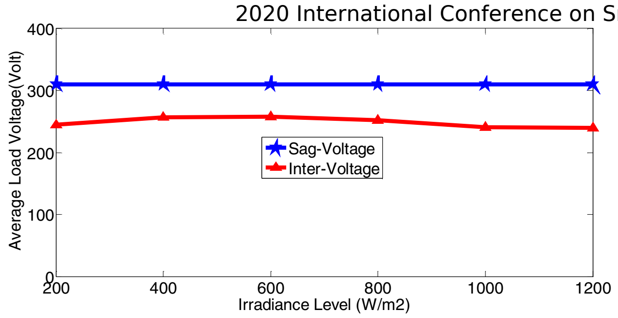

Fig. 8. Average load voltage of UPQC-PV system

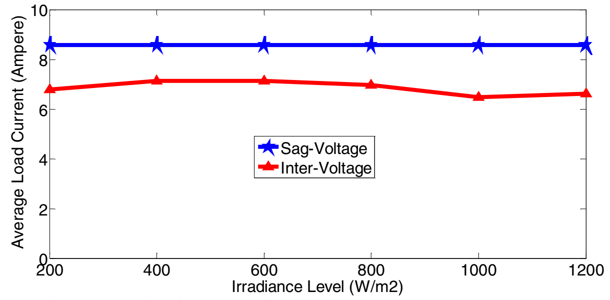

Fig. 9. The average load current of UPQC-PV system

Table 1 and Fig. 8 show that in sag voltage and irradiance level of 200W/m² to 1200 W/m², the 3P3W system using UPQC-PV with PI controller still can maintain the average load voltage $(V_L)$of 310.1 V. However, in the interruption voltage and the irradiance levels, are equally sequential, the average load voltage (V_L)drops to between 239.2 V and 257 V. Table 1 and Fig. 9 also show that in the sag voltage and the irradiance levels of 200 W/m² to 1200 W/m², the 3P3W system uses UPQC-PV with PI controller is still able to maintain the average load current (I_L) of 8.589 A. However, in the scenario of the interruption voltage and same irradiance levels, the average load current (I_L) drops to between 6.624 A and 7.134 A. Thus, the UPQC-PV system can maintain the load voltage (V_L), if there is the sag voltage happens at the source bus. Otherwise, in the interruption voltage scenario, the UPQC-PV system can not maintain load voltage (V_L), and the load current (I_L) remains constant.

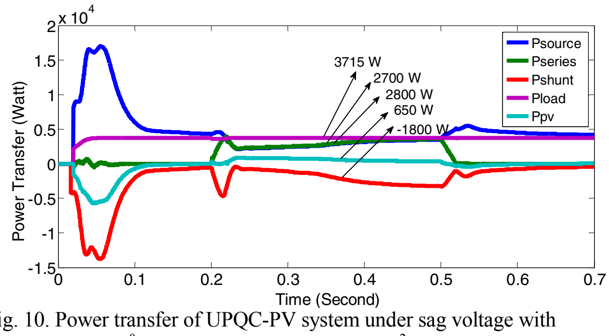

Fig. 10. Power transfer of UPQC-PV system under sag voltage with temperature = 25⁰ C and irradiance = 1000 W/m²

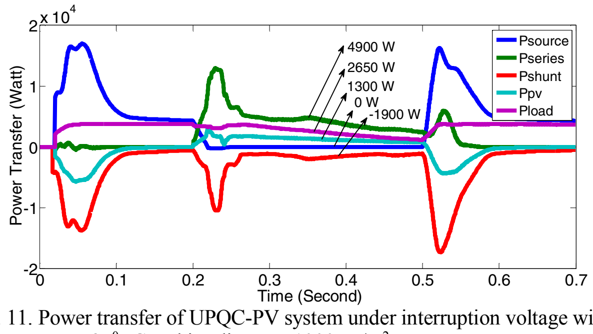

Fig. 11. Power transfer of UPQC-PV system under interruption voltage with temperature = 25⁰ C and irradiance = 1000 W/m²

Fig. 10 shows that in sag voltage, the UPQC-PV system at t = 0.2 s to t = 0.5 s, irradiance = 1000 W/m² and temperature = 25^0 C using PI controller, source power value (P_S) decreases to 2700 W. Series power (P_{Se}) increased by 2800 W and shunt power (P_{Sh}) decreased by -1800 W, PV power by 650 W, so that load power (P_L) value is equal to 3715 W. Fig. 11 shows that in interruption voltage, UPQC-PV system at t = 0.2 s to t = 0.5 s, irradiance = 1000 W/m² and temperature = 25^0 C, the value of the source power (P_S) drops to 0 W. The series power (P_{Se}) increases by 4900 W and shunt power (P_{Sh}) decreases by -1900 W, and PV power (P_{PV}) increases by 1300 W, so that the load power (P_L) dropped to 2650 W.

Table 2 and Fig. 12 show that in sag voltage and irradiance levels of 200 W/m² to 1200 W/m², the 3P3W system uses UPQC-PV with PI still able to maintain active power above 3714 W. However, in the interruption voltage and same irradiance level, active load power (P_L) drops to between 2560 W and 2805 W. Table 2 and Fig. 13 also show that in sag voltage and irradiance levels of 200 W/m² to 1200 W/m², the 3P3W system uses UPQC-PV with PI still able to generate PV power (P_{PV}) between 500 W to 920 W. In the scenario of interruption voltage and irradiance levels with the same condition, the PV power increases (P_{PV}) between 1300 W to 1635 W. However, the increase on PV power (P_{PV}) in interruption, voltage has not been able to meet power on load side so that load power (P_L) Finally it drops to 2650 W.

TABLE II. POWER TRANSFER IN UPQC-PV SYSTEM

Irr (W/m²)	Power Transfer (Watt)					Eff (%)
	Source Power	Series Power	Shunt Power	Load Power	PV Power	
Sag Voltage and T= 25^0 C						
200	2700	2800	-1720	3715	680	83.30
400	2455	2550	-1200	3714	920	78.60
600	2455	2550	-1200	3714	920	78.52
800	2534	2620	-1332	3714	810	80.18
1000	2700	2800	-1800	3715	650	85.40
1200	2960	3080	-2250	3715	500	86.59
Interruption Voltage and T= 25^0 C						
200	0	4950	-2000	2675	1440	60.93
400	0	4600	-1500	2805	1620	59.43
600	0	4650	-1515	2800	1635	58.70
800	0	4895	-1850	2754	1544	60.01
1000	0	4900	-1900	2650	1300	61.63
1200	0	4850	-1930	2560	1300	59.79

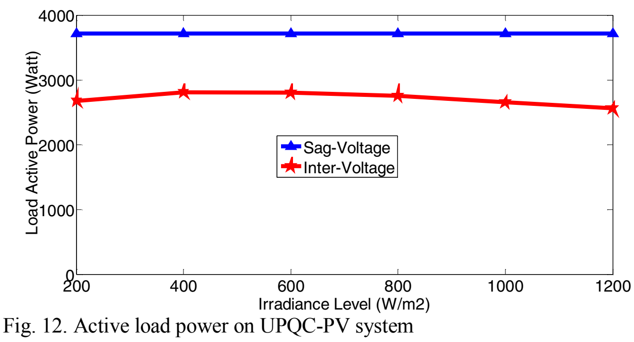

Fig. 12. Active load power on UPQC-PV system

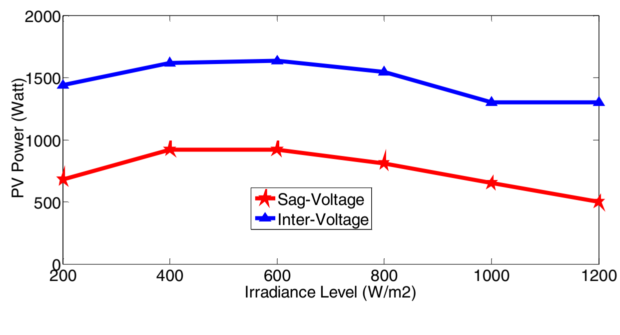

Fig. 13. PV power on UPQC-PV system

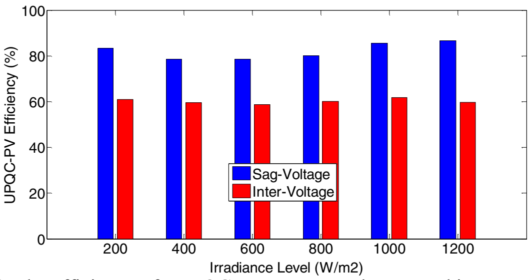

Fig. 14. The efficiency of UPQC-PV system under sag and interruption

Fig. 14 shows that in sag voltage and irradiance level of 200 W/m^2 to 1200 W/m^2, the 3P3W system using UPQC-PV with PI controller can produce a system efficiency of 78.60% to 86.59%. Otherwise, in the interruption voltage and irradiance increases, the efficiency of UPQC-PV decreases between 58.70% to 61.63%.

IV. Conclusion

The analysis of the UPQC-PV system model has been presented in this paper. The PV is connected to a 3P3W distribution system with 380 volts (L-L) and a frequency of 50 hertz, through UPQC-DC link circuit. This system is used to maintain and supply sensitive loads. This research shows that in the sag voltage and irradiance levels of 200 W/m^2 to 1200 W/m^2, the 3P3W system using UPQC-PV with PI can maintain the active load power above 3714 W. However, in the interruption voltage and same irradiance level, the active load power drops to between 2560 W and 2805 W. This paper also shows that in the sag voltage and same irradiance level, the 3P3W system using UPQC-PV with PI can generate PV power between 500 W to 920 W. In the scenario of the interruption voltage and same irradiance levels, the power that can be generated by PV increases between 1300 W to 1635 W. However, at 25^0 C and 1000 W/m^2, the increase in PV power on interruption voltage has not been able to meet the load power so it finally drops to 2650 W. The increase in PV power close to load power is proposed to overcome this problem.

Appendix

Three-phase grid: RMS voltage 380 volt (L-L), 50 Hz, line impedance: R_S = 0.1 Ohm L_S = 15 mH; series and shunt active filter: series inductance L_{Se} = 0.015 mH; shunt inductance L_{Sh} = 15 mH; injection transformers: rating 10 kVA, 50 Hz, turn ratio (N_1/N_2) = 1:1; sensitive load: resistance R_L = 60 ohm, inductance L_L = 0.15 mH, load impedance R_C = 0.4 ohm and L_C = 15 mH; unbalance load: resistance R_1 = 24 ohm, R_2= 12 ohm, and R_3 = 6 ohm, capacitance C_1, C_2, C_3 = 2.2 µF; DC-link: voltage V_{dc} = 650 volt and capacitance C_{dc} = 3000 µF; photovoltaic: active power P_{PV} = 0.6 kW temperature = 25^0 C, irradiance = 1000 W/m^2; PI controller: K_P = 0.2, K_I= 1.5; input: $V_{dc-error}$ and $\Delta V_{dc-error}$; output: instantaneous of power losses ($\bar{p}_{loss}$).

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Lampiran 2.7

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