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(LPPM)
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SURAT KETERANGAN

Nomor: Sket/ 6 /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 jurnal berjudul Load Active Power Transfer Enhancement Using UPQC-PV-BES System With Fuzzy Logic Controller (Amirullah Amirullah, Adiananda Adiananda, Ontoseno Penangsang, dan Adi Soeprijanto) yang telah dipublikasikan di International Journal of Intelligent Engineering and Systems ,Vol.13, No.2, April 2020, pp. 329-349, ISSN: 2185-3118, **Terindeks Scopus Q2.**
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/Pengelola Jurnal

Ubhara Surabaya

Amirullah Ubhara Surabaya <amirullah@ubhara.ac.id>

Submit Paper Amirullah Surabaya Indonesia 26 Nop 2019

1 pesan

Amirullah Ubhara Surabaya <amirullah@ubhara.ac.id> 26 November 2019 pukul 08.53
Kepada: ijies@inass.org
Cc: ijies@inass.org
Bcc: Amirullah Ubhara Surabaya <amirullah@ubhara.ac.id>

Dear Prof. Kei Eguchi,

Here I send you the paper entitled "Power Transfer Enhancement Using UPQC-PV-BES System With Fuzzy Logic Controller" (PDF paper + Cover Letter) to submit in IJIES.

I request USD 150 as publication option.

This is my email and thanks a lot for your respon.

Dr. Amirullah, ST, MT. (Equivalent with B.Eng. M.Eng.)
Lecturer in Electrical Engineering (Power System)
Power Quality Mitigation in Renewable Energy Research Area
Universitas Bhayangkara Surabaya
Jl. Ahmad Yani 114 Surabaya Indonesia
+62-81-949649423 (Mobile)

2 lampiran

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Amirullah Ubhara Surabaya <amirullah@ubhara.ac.id>

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5 pesan

Kei Eguchi <eguti@fit.ac.jp> 26 November 2019 pukul 10.00
Kepada: Amirullah Ubhara Surabaya <amirullah@ubhara.ac.id>

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Sent: Tuesday, November 26, 2019 10:54 AM
To: ijies@inass.org
Subject: Submit Paper Amirullah Surabaya Indonesia 26 Nop 2019

Dear Prof. Kei Eguchi,

Here I send you the paper entitled "Power Transfer Enhancement Using UPQC-PV-BES System With Fuzzy Logic Controller" (PDF paper + Cover Letter) to submit in IJIES.

I request USD 150 as publication option.

This is my email and thanks a lot for your respon.

Dr. Amirullah, ST, MT. (Equivalent with B.Eng. M.Eng.)
Lecturer in Electrical Engineering (Power System)
Power Quality Mitigation in Renewable Energy Research Area
Universitas Bhayangkara Surabaya
Jl. Ahmad Yani 114 Surabaya Indonesia
+62-81-949649423 (Mobile)

Amirullah Ubhara Surabaya <amirullah@ubhara.ac.id> 26 November 2019 pukul 17.03
Kepada: Kei Eguchi <eguti@fit.ac.jp>
Cc: Amirullah Ubhara Surabaya <amirullah@ubhara.ac.id>
Bcc: Amirullah Ubhara Surabaya <amirullah@ubhara.ac.id>

Dear Prof Kei,

Thanks a lot of for your feedback.

Dr. Amirullah, ST, MT.
[Kutipan teks disembunyikan]

Kei Eguchi <eguti@fit.ac.jp> 9 Desember 2019 pukul 07.12
Kepada: Amirullah Ubhara Surabaya <amirullah@ubhara.ac.id>

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Subject: Re: ijies2811: Submit Paper Amirullah Surabaya Indonesia 26 Nop 2019

Dear Prof. Kei Eguchi,

Thanks for your result information.

However I could not understand with this bold statement below:

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University of Bhayangkara Surabaya
Indonesia

Pada tanggal Sen, 9 Des 2019 pukul 07.13 Kei Eguchi <mailto:eguti@fit.ac.jp> menulis:
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Sent: Tuesday, November 26, 2019 12:00 PM
To: Amirullah Ubhara Surabaya <mailto:amirullah@ubhara.ac.id>
Subject: ijies2811: Submit Paper Amirullah Surabaya Indonesia 26 Nop 2019

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IJIES2893: Send Paper Revision Amirullah Surabaya Indonesia 4 Feb 2020

6 pesan

Amirullah Ubhara Surabaya <amirullah@ubhara.ac.id> 3 Februari 2020 pukul 20.34
Kepada: Kei Eguchi <eguti@fit.ac.jp>
Cc: Kei Eguchi <eguti@fit.ac.jp>
Bcc: Amirullah Ubhara Surabaya <amirullah@ubhara.ac.id>

Dear Prof Kei Eguchi,

Here I send you revision of my paper entitled Load Active Power Transfer Enhancement Using UPQC-PV-BES System With Fuzzy Logic Controller (Amirullah Amirullah1* Adiananda Adiananda1 Ontoseno Penangsang2 Adi Soeprijanto2). (Paper ID: Ijies2893).

I also attach you:
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This my email and thanks a lot for your cooperation.

Dr. Amirullah

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Kei Eguchi <eguti@fit.ac.jp> 4 Februari 2020 pukul 06.52
Kepada: Amirullah Ubhara Surabaya <amirullah@ubhara.ac.id>

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Kepada: Kei Eguchi <eguti@fit.ac.jp>
Cc: Amirullah Ubhara Surabaya <amirullah@ubhara.ac.id>
Bcc: Amirullah Ubhara Surabaya <amirullah@ubhara.ac.id>

Dear Prof. Kei Eguchi,

Thanks a lot for your response.

Dr. Amirullah
Universitas Bhayangkara Surabaya
East-Java Province Indonesia
[Kutipan teks disembunyikan]

Kei Eguchi <eguti@fit.ac.jp> 10 Februari 2020 pukul 14.27
Kepada: Amirullah Ubhara Surabaya <amirullah@ubhara.ac.id>

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Cc: Amirullah Ubhara Surabaya <amirullah@ubhara.ac.id>
Bcc: Amirullah Amirullah <amirullah.ubhara.surabaya@gmail.com>

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Kepada: Kei Eguchi <eguti@fit.ac.jp>
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Dear Prof. Dr. Kei Eguchi,

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([1*]Amirullah Amirullah , [1]Adiananda Adiananda, [2]Ontoseno Penangsang, [2]Adi Soeprijanto) *Corresponding author.

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2 pesan

Kei Eguchi <eguti@fit.ac.jp> 13 Februari 2020 pukul 06.46
Kepada: Amirullah Ubhara Surabaya <amirullah@ubhara.ac.id>

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From: Amirullah Ubhara Surabaya <amirullah@ubhara.ac.id>
Sent: Wednesday, February 12, 2020 10:50 PM
To: 江口 啓 <eguti@fit.ac.jp>
Cc: Amirullah Ubhara Surabaya <amirullah@ubhara.ac.id>
Subject: Re: IJIES2893: Send Paper Revision Amirullah Surabaya Indonesia 4 Feb 2020

Dear Prof. Dr. Kei Eguchi,

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The title is Load Active Power Transfer Enhancement Using UPQC-PV-BES System With Fuzzy Logic Controller (1*Amirullah Amirullah , 1Adiananda Adiananda, 2Ontoseno Penangsang, 2Adi Soeprijanto) *Corresponding author.

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Regards,

Dr. Amirullah

Universitas Bhayangkara Surabaya
Jl. Ahmad Yani 114 Surabaya
East Java Indonesia

Pada tanggal Sen, 10 Feb 2020 pukul 14.42 Amirullah Ubhara Surabaya <mailto:amirullah@ubhara.ac.id> menulis:
Dear Prof. Dr. Kei Eguchi,

Thanks a lot for your information. And I would like the paper payment soon.

Dr. Amirullah, ST, MT.

Pada tanggal Sen, 10 Feb 2020 pukul 14.27 Kei Eguchi <mailto:eguti@fit.ac.jp> menulis:
Dear Author(s),

Paper ID: ijies2893

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*Publication fee: USD750 (tentative 20 pages: USD250 + USD50*10, extra 10 pages)
We'd like to discount USD200 from your publication fee.
Therefore, the final publication fee is "USD550".

After we received these documents, the camera-ready version of your paper will be sent to you within a few weeks.
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-----Original Message-----
From: 江口 啓
Sent: Tuesday, February 4, 2020 8:53 AM
To: Amirullah Ubhara Surabaya <mailto:amirullah@ubhara.ac.id>
Subject: RE: IJIES2893: Send Paper Revision Amirullah Surabaya Indonesia 4 Feb 2020

Dear author(s),

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From: Amirullah Ubhara Surabaya <mailto:amirullah@ubhara.ac.id>
Sent: Monday, February 3, 2020 10:34 PM
To: 江口 啓 <mailto:eguti@fit.ac.jp>
Subject: IJIES2893: Send Paper Revision Amirullah Surabaya Indonesia 4 Feb 2020

Dear Prof Kei Eguchi,

Here I send you revision of my paper entitled Load Active Power Transfer Enhancement Using UPQC-PV-BES System With Fuzzy Logic Controller (Amirullah Amirullah1* Adiananda Adiananda1 Ontoseno Penangsang2 Adi Soeprijanto2). (Paper ID: Ijies2893).

I also attach you:
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This my email and thanks a lot for your cooperation.

Dr. Amirullah

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Amirullah Ubhara Surabaya <amirullah@ubhara.ac.id> 13 Februari 2020 pukul 09.17
Kepada: Kei Eguchi <eguti@fit.ac.jp>
Cc: Amirullah Ubhara Surabaya <amirullah@ubhara.ac.id>
Bcc: Amirullah Amirullah <amirullah.ubhara.surabaya@gmail.com>

Dear Prof Dr. Kei Eguchi,

Thanks a lot for sending me the official receipt and acceptance letter of IJIES 2893 paper.

Regards,

Dr. Amirullah, ST, MT.
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Lampiran 2

Bukti Pendukung

Lampiran 2.1

Naskah Makalah Submitted

Received: January 1, 20191

International Journal of
Intelligent Engineering & Systems

http://www.inass.org/

Power Transfer Enhancement Using UPQC-PV-BES System With Fuzzy Logic Controller

Amirullah Amirullah[1]* **Adiananda Adiananda[1]**

[1]*Electrical Engineering Study Program Faculty of Engineering,*
Universitas Bhayangkara Surabaya, Surabaya, Indonesia
* Corresponding author's Email: amirullah@ubhara.ac.id

Abstract: This paper presents enhancement of active power transfer using Unified Power Quality Conditioner - Photovoltaic-Battery Energy Storage (UPQC-PV-BES) system that is connected to a three phase three wire (3P3W) system with a voltage of 380 volts (L-L) and a frequency of 50 hertz. The proposed model is also compared with UPQC and UPQC-PV respectively. The parameters investigated i.e. load voltage, load current, active load power, and efficiency of proposed model. BES functions to store excess energy generated by PV, distribute it to the load if necessary, prevent interruption voltage, and regulate the charging process and energy usage in battery. The Fuzzy Logic Controller (FLC) is proposed and compared with Proportional Integral (PI) method to control DC voltage variable and input DC reference voltage to produce a reference current source on hysteresis current controller on active shunt filter in 12 disturbance scenarios. In scenarios 1 to 5, the 3P3W system uses three combinations of UPQC with PI controller and FLC, still maintains load voltage and load current above 300 V and 8 A. Whereas in scenario 6, only the UPQC-PV-BES with FLC is able to maintain load voltage and load current higher compared to other two UPQC combinations as 304.1 V and 8.421 A, respectively. In scenarios 1 to 5, the 3P3W system uses three combinations of UPQC with PI controller and FLC, capable of producing active load power above 3600 W. Whereas in scenario 6, only a combination of UPQC-PV-BES with PI controller and FLC are able to produce a load voltage of 3720 W and 3700 W, respectively. In scenarios 1 to 6, UPQC-PV-BES results in lower efficiency compared to using UPQC and UPQC-PV. However, in scenario 6, UPQC-PV-BES with FLC is able to produce load voltage, load current, and active load power higher than UPQC-PV and UPQC. Thus the UPQC-PV-BES model using FLC is able to compensate load voltage and load current, as well as to enhance active load power in case an interruption voltage occurs on source bus.

Keywords: Power Transfer, UPQC, PV, BES, FLC, Disturbance Scenarios.

1. 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,

Received: January 1, 20192

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 Standard. The system was found to be stable under irradiation variations from 1000 $W/m2$ to 600 $W/m2$.

The dynamic performance of the proposed JAYA based auto tuned PI controller for PV-UPQC systems has been analyzed [4]. Online JAYA optimization methodology is implemented for PV-UPQC to determine the best value of PI controller 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 kept constant by PV-UPQC.

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 three-phase AC network by supplying power obtained from PV array. 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]. A 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 controller 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. Table 1 shows abbreviation in this paper.

Received: January 1, 20193

Table 1. Abbreviation

Symbol	Description
UPQC	Unified Power Quality Conditioner
PV	Photovoltaic
BES	Battery Energy Storage
RE	Renewable Energy
DG	Distributed Generation
FLC	Fuzzy Logic Controller
PI	Proportional Integral
NL	Non Linear Load
MPPT	Maximum Power Point Tracking
3P3W	Three Phase Three Wire
3P4W	Three Phase Four Wire
PCC	Point Common Coupling
P and O	Perturb and Observe
FIS	Fuzzy Inference System
CB	Circuit Breaker

The study proposes enhancement of active power transfer using UPQC-PV-BES system that is connected to a three phase three wire (3P3W) distribution system with a voltage of 380 volts (L-L) and a frequency of 50 hertz. The effectiveness of proposed model is validated with two other combinations, UPQC and UPQC-PV respectively. BES functions to store excess energy generated by PV, distribute it to the load if necessary, prevent interruption voltage, and regulate the charging process and energy usage in batteries. BES is also expected to be able to save excess power generated by PV and use it as a backup power. The FLC is proposed and compared with PI method to control DC voltage variable and input DC reference voltage to produce a reference current source on hysteresis current controller on active shunt filter in 12 disturbance scenarios. The FLC is proposed and compared with PI, because the it has a weakness in determining proportional and integral gain constants that still use trial and error method. The parameters observed i.e. voltage and current on source bus, voltage and current on load bus, active source power transfer, series active power transfer, active shunt power transfer, active load power transfer, PV power, and BES power. The next step is to determine efficiency value of each UPQC combination to show the circuit that has a higher performance in enhanching active power transfer and in maintaining load voltage and load current.

This paper is presented as follow. Section 2 explains proposed method, UPQC-PV-BES system model, parameter simulation, PV circuit model, active series and shunt filter control, application of PI controller and FLC, as well as UPQC efficiency for proposed model. 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, BES power using FLC validated with PI controller. In this section, six disturbance scenarios are presented and the results are verified with Matlab/Simulink. Finally, this paper is concluded in Section 4.

2. Research Method

2.1. Proposed Method

Fig. 1 shows the proposed model of PV connected to a 3P3W distribution system with 380 volts (L-L) and a frequency of 50 hertz, through a series of DC links UPQC and BES. The PV array generator generates DC power at a constant temperature and solar radiation level and is connected to BES through DC/DC boost converter circuit. The MPPT method with P and O algorithm helps PV to produce maximum power, generating an output voltage, which then becomes an input voltage for DC/DC boost converter. The boost converter functions to adjust duty cycle value with PV generator output voltage as an input voltage to produce an output voltage according to DC-link voltage of UPQC. BES connected to the DC-link circuit UPQC DC functions as energy storage and is expected to inject power to maintain load voltage and load active power in case of an interuption voltage from source bus.

Analysis of the proposed model is carried out on three UPQC combinations connected to 3P3W (on-grid) system via a DC link circuit. The three combinations are UPQC, UPQC-PV, and UPQC-PV-BES. Two single phase circuit breakers (CBs) are used to connect and disconnect PV and BES to UPQC DC-link. Each combination of circuit in each condition consists of six disturbance scenarios are NL, Unba-NL, Dis-NL, Sag-NL, Swell-NL, and Inter-NL. FLC is used as DC voltage control on shunt active filter to improve PQ in each fault scenario and the results are validated with PI control. Each scenario uses UPQC with PI and FLC controller so that there are a total of 12 disturbances. The parameters are voltage and current on the source bus, voltage and current on the load bus, source active power, series active power transfer, shunt active power, load active power, PV power, and BES power. The next step is to determine nominal of efficiency of each UPQC combination to show the circuit that has superior performance in maintain load voltage, load current, and active load power as part of power quality problems under six disturbance scenarios. Fig. 2 shows active power transfer using UPQC-PV-BES. Appendix shows simulation parameters for proposed model.

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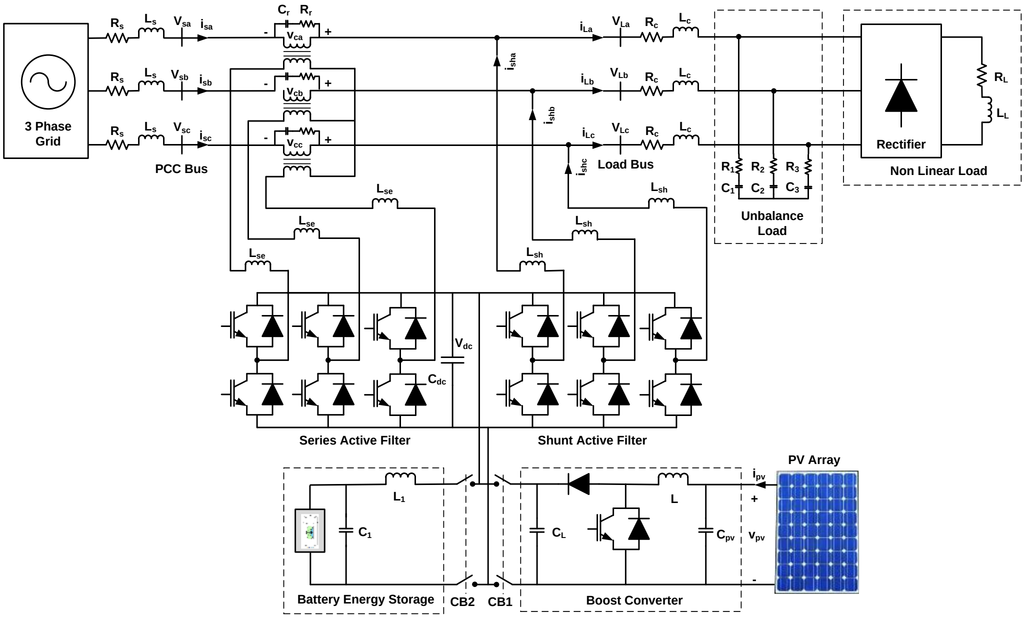

Figure 1. Proposed model using UPQC-PV-BES

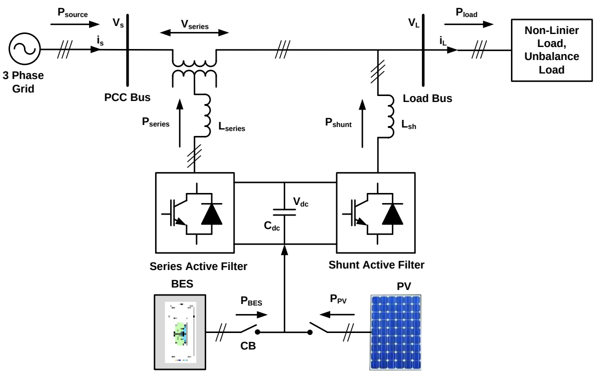

Figure 2. Active power transfer using UPQC-PV-BES.

2.2. 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].

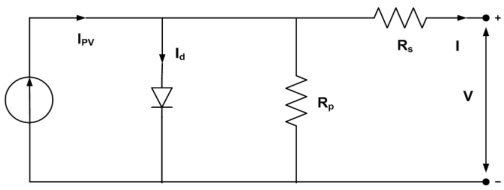

Figure 3. Equivalent circuit of solar panel

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

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

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):

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

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

Where I_{PV}, n, I_{SC}, 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.

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

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

2.3. Series Active Filter Control

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. Furthermore, the template is expected to be an ideal sinusoidal signal with an unity amplitude. Then, the distorted source voltage is measured and divided by the peak amplitude of base input voltage V_m as stated in Eq. (6) [6].

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

A three phase lock loop (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.

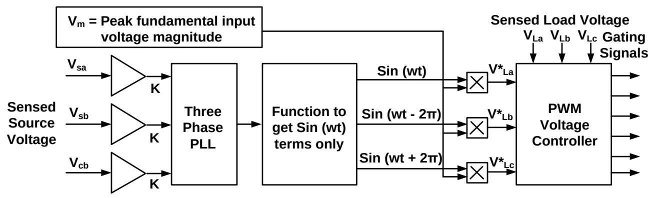

Figure 4 Series active filter control

2.3. Shunt Active Filter Control

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 they 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 DC-link capacitor voltage with the reference value processed using a FLC, 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

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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].

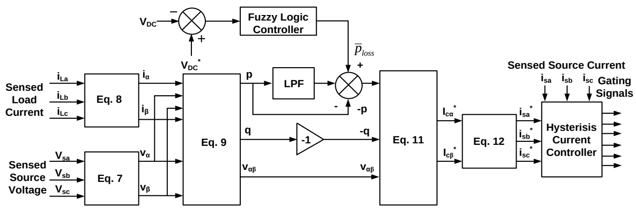

Figure 5. Shunt active filter control

In order to operate properly, UPQC-PV-BES 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]:

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

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, FLC as a DC voltage control algorithm on shunt active filter is proposed and compared with PI controller. FLC is able to reduce oscillations and produce calculations with rapid convergence during interference. This method is also used to overcome the weaknesses of PI controller in determining proportional gain constants (K_p) and integral gain constants (K_i) that still use trial and error method.

2.4. Fuzzy Logic Controller

This research begins by determining $\bar{p}_{loss}$ as an input variable, to produce a reference source current on the hysteresis current control and generate a trigger signal on the shunt active IGBT filter circuit from UPQC with PI control (K_p = 0.2 and K_i = 1.5). By using the same procedure, $\bar{p}_{loss}$ is also determined using FLC. This method has been widely used in industrial processes today because it has heuristic properties, simpler, more effective, and has multi-rule-based variables in both linear and non-linear system. The FLC components are fuzzification, decision making (rulebase, database, reason mechanism) and defuzzification in Fig. 6.

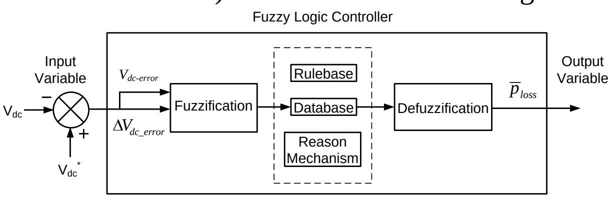

Figure 6. Block diagram of FLC

The fuzzy rules algorithm collects a number of fuzzy control rules in a particular order. These rules are used to control the system so that it meets the desired performance requirements and they are designed from a number of intelligent control system knowledge. Fuzzy inference system (FIS) in FLC uses Mamdani Method with a max-min composition relationship. FIS consists of three parts i.e. rule base, database, and reason-mechanism [17]. Fuzzy logic control method is applied by determining input variables V_{dc} ($V_{dc\text{-error}}$) and delta V_{dc} ($\Delta V_{dc\text{-error}}$), seven fuzzy linguistic pairs, fuzzy operating system blocks (fuzzification, fuzzy rulebase and defuzzification), $V_{dc\text{-error}}$ and $\Delta V_{dc\text{-error}}$ during seven fuzzy linguistic sets, fuzzy operating system blocks (fuzzification, fuzzy rulebase and defuzzification), $V_{dc\text{-error}}$ and $\Delta V_{dc\text{-error}}$ during fuzzification process, fuzzy rule base table, crips value to determine $\bar{p}_{loss}$ in the defuzzification phase.

The value of $\bar{p}_{loss}$ is one of the input variables to get the compensation current ($i_{c\alpha}^*$, $i_{c\beta}^*$) in Equation (16). During the fuzzification process, a number of input variables are calculated and converted to linguistic variables based on a subset called the membership function. The V_{dc} error ($V_{dc\text{-error}}$) and delta error V_{dc} ($\Delta V_{dc\text{-error}}$) are proposed as input variables with $\bar{p}_{loss}$ system output variables. In order to translate these variables, each input and output variable is designed using seven membership functions i.e. Negative Big (NB), Negative Medium (NM), Negative Small (NS), Zero (Z), Positive Small (PS), Positive Medium (PM))) and Positive Big (PB). The membership functions of input and output crips are presented with triangular and trapezoidal membership functions. The $V_{dc\text{-error}}$ ranges from -650 to 650, , $\Delta V_{dc\text{-error}}$ from -650 to 650, and $\bar{p}_{loss}$ from -100 to 100. The input and output MFs are shown in Fig. 7, Fig. 8, and Fig. 9.

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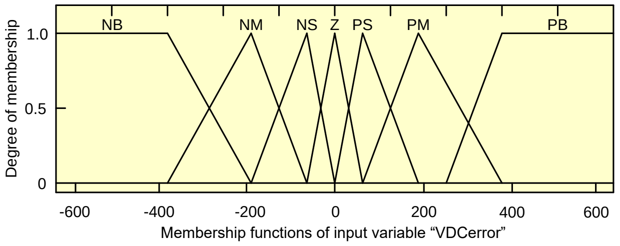

Figure 7. Input MFs of $V_{dc\text{-}error}$

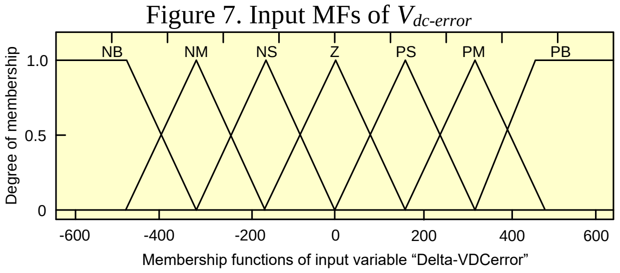

Figure 8. Input MFs of $\Delta V_{dc\text{-}error}$

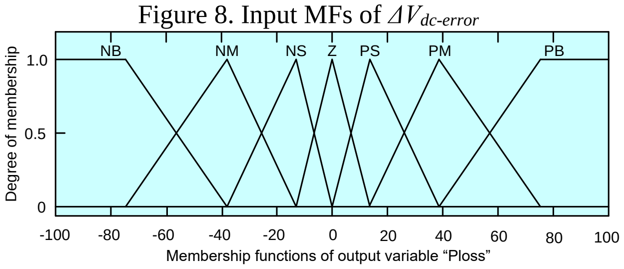

Figure 9. Output MFs of $\bar{p}_{loss}$

Table 2. Fuzzy Rule Base

$V_{dc\text{-}error}$ / $\Delta V_{dc\text{-}error}$	NB	NM	NS	Z	PS	PM	PB
PB	Z	PS	PS	PM	PM	PB	PB
PM	NS	Z	PS	PS	PM	PM	PB
PS	NS	NS	Z	PS	PS	PM	PM
Z	NM	NS	NS	Z	PS	PS	PM
NS	NM	NM	NS	NS	Z	PS	PS
NM	NB	NM	NM	NS	NS	Z	PS
NB	NB	NB	NM	NM	NS	NS	Z

After *Vdc-error* and *ΔVdc-error* are obtained, two input MFs are subsequently converted to linguistic variables and used as input function for FLC. The output MF is generated using inference block and basic rules of FLC as shown in Table 2. Then, defuzzification block finally operates to change $\bar{p}_{loss}$ output generated from the linguistic variable to numeric again. The value of $\bar{p}_{loss}$ then becomes the input variable for current hysteresis control to produce a trigger signal in the IGBT circuit of UPQC shunt active filter to reduce source current harmonics and load voltage harmonics. Simultaneously, it also improves PQ of 3P3W system under six disturbance scenarios of three combination model i.e. UPQC, UPQC-PV, and UPQC-PV-BES, respectively.

2.5. UPQC-PV-BES Eficiency

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 [18]. 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-BES.

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

3. Result and Discussion

The proposed model is determined through on three UPQC combinations connected to 3P3W system (on-grid) via a DC link circuit. The three combinations are UPQC, UPQC-PV, and UPQC-PV-BES. Two single phase circuit breakers are used to connect and disconnect PV and BES circuit to UPQC-DC link circuit. Each combination of sequences of each condition consists of six disturbance scenarios, i.e. NL, Unba-NL, Dis-NL, Sag-NL, Swell-NL, and Inter-NL. In Scenario 1, the system is connected to non-linear loads with R and L values of 60 Ohms and 0.15 mH, respectively. In skenario 2, the system is connected to non-linear loads for 0.3 s since t = 0.2 s to t = 0.5 s and also connected to three phase unbalanced load with values R_1, R_2, and R_3 of 6, 12, and 24 Ohm respectively and C_1, C_2 and C_3 of 2.2 µF. In scenario 3, the system is connected to non-linear load and distorted voltage sources which results 5^{th} and 7^{th} harmonics with individual harmonics distortion values of 5% and 2%, respectively. In Scenario 4, the system is connected to a non-linear load and the source experiences a 50% sag voltage disturbance for 0.3 s between t = 0.2 s to t = 0.5 s. In Scenario 5, the system is connected to a non-linear load and the source experiences a 50% swell voltage disturbance for 0.3 s between t = 0.2 s to t = 0.5 s. In Scenario 6, the system is connected to a non-linear load and the source experiences a 100% interuption voltage for 0.3 s between t = 0.2 s to t = 0.5 s. Each combination uses an UPQC control with a FLC validated by PI control so that totally is 12 scenarios.

Then, by using Matlab/Simulink, each combination model is run according to the desired scenario to get the curve of source voltage (V_S), load voltage (V_L), compensation voltage (V_C), source

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current (V_S), load current (V_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 based on the value of each phase voltage and current parameters previously obtained. The next process is determining value of power transfer of active source power, series active power transfer, active shunt power, load active power, PV active power, and BES power. The measurement of nominal of voltage and current on source and load bus, UPQC power transfer, PV power, and BES are determined in one cycle start at t = 0.35 s. The results of the average source voltage, source current, load voltage, and load current on three proposed UPQC combinations are presented in Table 3, Table 4, and Table 5.

Table 3. Voltage and current of 3P3W system using UPQC

Scenarios	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
PI Controller																
1. NL	309.5	309.5	309.5	**309.5**	310.0	310.0	310.0	**310.0**	8.741	8.728	8.751	**8.740**	8.585	8.586	8.586	**8.586**
2. Unba-NL	309.5	309.5	309.5	**309.5**	310.1	310.0	310.0	**310.0**	8.733	8.750	8.749	**8.744**	8.588	8.586	8.585	**8.586**
3. Dist-NL	309.5	309.5	309.5	**309.5**	309.1	312.6	310.1	**310.6**	8.855	8.772	8.801	**8.809**	8.539	8.769	8.595	**8.634**
4. Sag-NL	153.4	153.4	153.4	**153.4**	310.1	310.1	310.1	**310.1**	16.42	16.39	16.42	**16.41**	8.588	8.588	8.588	**8.588**
5. Swell-NL	464.6	464.6	464.6	**464.6**	309.9	309.9	309.9	**309.9**	8.380	8.388	8.380	**8.383**	8.585	8.585	8.584	**8.585**
6. Inter-NL	1.017	0.9814	1.014	**1.004**	173.5	161.2	169.5	**168.1**	9.479	9.353	9.027	**9.286**	4.866	4.465	4.404	**4.578**
Fuzzy Logic Controller																
1. NL	309.5	309.5	309.5	**309.5**	310.0	310.0	310.0	**310.0**	8.679	8.721	8.720	**8.706**	8.587	8.587	8.585	**8.586**
2. Unba-NL	309.5	309.5	309.5	**309.5**	310.0	310.0	310.0	**310.0**	8.713	8.687	8.700	**8.700**	8.586	8.587	8.588	**8.587**
3. Dist-NL	309.5	309.5	309.5	**309.5**	308.9	311.6	310.5	**310.4**	8.816	8.703	8.703	**8.741**	8.533	8.734	8.603	**8.623**
4. Sag-NL	153.4	153.4	153.4	**153.4**	310.1	310.1	310.1	**310.1**	16.39	16.38	16.41	**16.39**	8.588	8.588	8.588	**8.588**
5. Swell-NL	464.6	464.7	464.7	**464.7**	310.0	310.0	310.0	**310.0**	8.356	8.353	8.357	**8.355**	8.587	8.587	8.586	**8.587**
6. Inter-NL	1.135	1.377	1.299	**1.270**	141.4	172.2	167.4	**160.4**	10.22	12.23	13.27	**11.91**	3.718	4.438	4.855	**4.337**

Table 4. Voltage and current of 3P3W system using UPQC-PV

Scenarios	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
PI Controller																
1. NL	309.5	309.5	309.5	**309.5**	310.0	310.0	310.0	**310.0**	8.828	8.838	8.858	**8.841**	8.586	8.586	8.585	**8.586**
2. Unba-NL	309.5	309.5	309.5	**309.5**	310.0	310.0	310.0	**310.0**	8.756	8.774	8.745	**8.758**	8.585	8.588	8.585	**8.586**
3. Dist-NL	309.5	309.5	309.5	**309.5**	308.5	312.1	310.5	**310.5**	8.936	8.863	10.73	**9.510**	8.522	8.757	8.601	**8.627**
4. Sag-NL	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**
5. Swell-NL	464.4	464.4	464.4	**464.4**	310.1	310.1	310.1	**310.1**	8.457	8.468	8.460	**8.462**	8.558	8.590	8.558	**8.587**
6. Inter-NL	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**
Fuzzy Logic Controller																
1. NL	309.5	309.5	309.5	**309.5**	310.1	310.1	310.0	**310.1**	8.769	8.738	8.811	**8.773**	8.578	8.588	8.587	**8.584**
2. Unba-NL	309.5	309.5	309.5	**309.5**	310.0	310.0	310.0	**310.1**	8.674	8.682	8.674	**8.677**	8.587	8.587	8.588	**8.587**
3. Dist-NL	309.4	309.5	309.5	**309.5**	309.6	312.1	309.9	**310.5**	8.938	8.820	8.916	**8.891**	8.552	8.766	8.586	**8.635**
4. Sag-NL	153.8	153.8	153.8	**153.8**	310.1	310.0	310.1	**310.1**	13.52	13.46	13.56	**13.51**	8.558	8.587	8.589	**8.578**
5. Swell-NL	464.4	464.7	464.7	**464.7**	310.1	310.1	310.1	**310.1**	8.353	8.371	8.365	**8.363**	8.591	8.588	8.587	**8.589**
6. Inter-NL	1.259	1.285	1.530	**1.358**	209.9	193.7	242.7	**215.4**	13.28	11.49	14.07	**12.95**	6.459	5.003	6.299	**5.921**

Table 4. Voltage and current of 3P3W system using UPQC-PV-BES

Scenarios	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
PI Controller																
1. NL	309.6	309.6	309.6	**309.6**	307.6	307.8	307.7	**307.7**	7.766	7.793	7.759	**7.773**	8.528	8.529	8.533	**8.530**
2. Unba-NL	309.6	309.6	309.6	**309.6**	307.8	307.9	307.9	**307.9**	7.787	7.801	7.779	**7.789**	8.531	8.533	8.537	**8.534**
3. Dist-NL	309.6	309.6	309.6	**309.6**	313,8	314.3	317.4	**317.4**	7.897	7.919	7.867	**7.895**	8.748	8.704	8.785	**8.746**
4. Sag-NL	154.5	154.5	154.5	**154.5**	307.1	307.3	307.3	**307.2**	7.235	7.276	7.226	**7.246**	8.509	8.514	8.510	**8.511**
5. Swell-NL	464.7	464.7	464.7	**464.7**	308.6	308.7	308.6	**308.6**	7.979	7.980	7.964	**7.975**	8.550	8.553	8.554	**8.553**
6. Inter-NL	0.5359	1.385	0.8501	**0.9238**	310.2	259.8	290.2	**286.7**	7.392	12.67	6.045	**8.703**	8.707	7.747	7.637	**8.031**
Fuzzy Logic Controller																
1. NL	309.5	309.5	309.5	**309.5**	307.7	307.9	307.7	**307.8**	8.420	8.426	8.416	**8.421**	8.527	8.532	8.531	**8.530**
2. Unba-NL	309.5	309.5	309.5	**309.5**	307.9	308.0	307.9	**307.9**	8.402	8.403	8.401	**8.402**	8.535	8.539	8.536	**8.537**
3. Dist-NL	309.6	309.5	309.5	**309.5**	313.4	312.9	315.9	**314.1**	8.516	8.565	8.496	**8.526**	8.741	8.677	8.736	**8.718**
4. Sag-NL	154.4	154.4	154.4	**154.4**	307.3	307.3	307.2	**307.3**	8.563	8.560	8.561	**8.561**	8.514	8.517	8.512	**8.515**
5. Swell-NL	464.6	464.6	464.6	**464.6**	308.6	308.8	308.6	**308.7**	8.396	8.389	8.389	**8.392**	8.552	8.556	8.554	**8.554**
6. Inter-NL	0.4467	0.3918	0.3801	**0.4062**	314.0	293.4	304.9	**304.1**	4.024	3.778	3.608	**3.804**	8.874	8.195	8.193	**8.421**

Table 3 shows that in scenario 1 to 5, the 3P3W system using UPQC with PI control is still able to maintain an average load voltage between 309.9 to 310.6 V. But in scenario 6, average load voltage drops to 169.1 V. In the same system and scenarios 1 to 5 using FLC control, average load voltage rises slightly from 310.0 to 310.4 V. But in scenario 6, an average load voltage drops to 160.4 V. Table 3 also shows that in scenarios 1 to 5, the 3P3W system using UPQC with PI control is still able to maintain an average load current between 8,585 to 8,634 A.

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But in scenario 6, the average load current drops to 4,578 A. On the same system and scenario 1 to 5 using FLC control, the average load current rises slightly from 8,587 to 8,623 A. But in scenario 6, an average load current drops slightly to 4,337 A.

Table 4 shows that in scenarios 1 to 5, the 3P3W system using UPQC-PV with PI control is still able to maintain an average load voltage between 310.0 to 310.5 V. However, in scenario 6, the average load voltage drops to 240.4 V. On the system and with scenario 1 through 5 using FLC control, an average load voltage rises slightly from 310.1 to 310.5 V. But in scenario 6, an average load voltage drops to 215.4 V. Table 3 also shows that in scenario 1 to 5, the 3P3W system using UPQC with PI control is still able to maintain an average load current of 8,586 to 8,627 A. But in scenario 6, the average load current drops to 6,477 A. In the same system and scenario 1 to 5 using FLC control, the average load current rises slightly from 8,578 to 8,635 A. But in scenario 6, an average load current drops significantly to 5,921 V.

Fig. 10 and Fig. 11 show performance of load voltage and load current of 3P3W system using three UPQC combinations in six disturbance scenarios with PI control and FLC.

Fig. 10 shows that in disturbance scenario 1 to 5, the 3P3W system uses three combinations of UPQC with PI control and FLC, able to maintain load voltage above 300 V. Whereas in scenario 6, only a combination of UPQC-PV-BES with FLC is able to produce load voltage is 304.1 V. Fig. 11 shows that in disturbance scenario 1 to 5, the 3P3W system uses three combinations of UPQC with PI controller and FLC, able to maintain load current above 8 A. Whereas in scenario 6, only UPQC-PV-BES combination with PI control and FLC capable to generate load current of 8.031 and 8.421 respectively. Therefore, in scenario 6, combination of UPQC-PV-BES with FLC is able to provide load voltage and load current performance better than the other two UPQC combinations.

Fig. 12. shows performance of 3P3W system using (a) UPQC, (b) UPQC-PV, (c) (UPQC-PV-BES with FLC in Scenario 6 (Inter-NL).

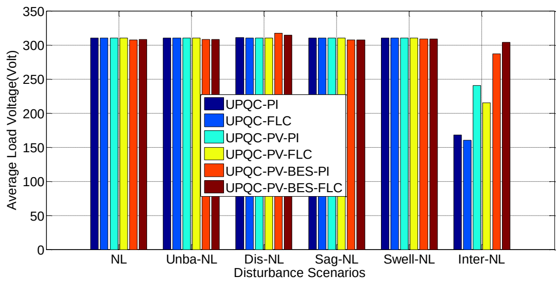


Figure 10. Performance of load voltage using three UPQC combinations in six fault scenarios

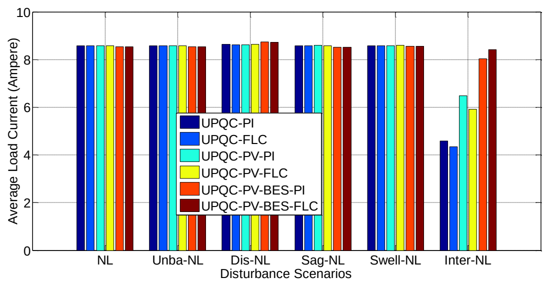
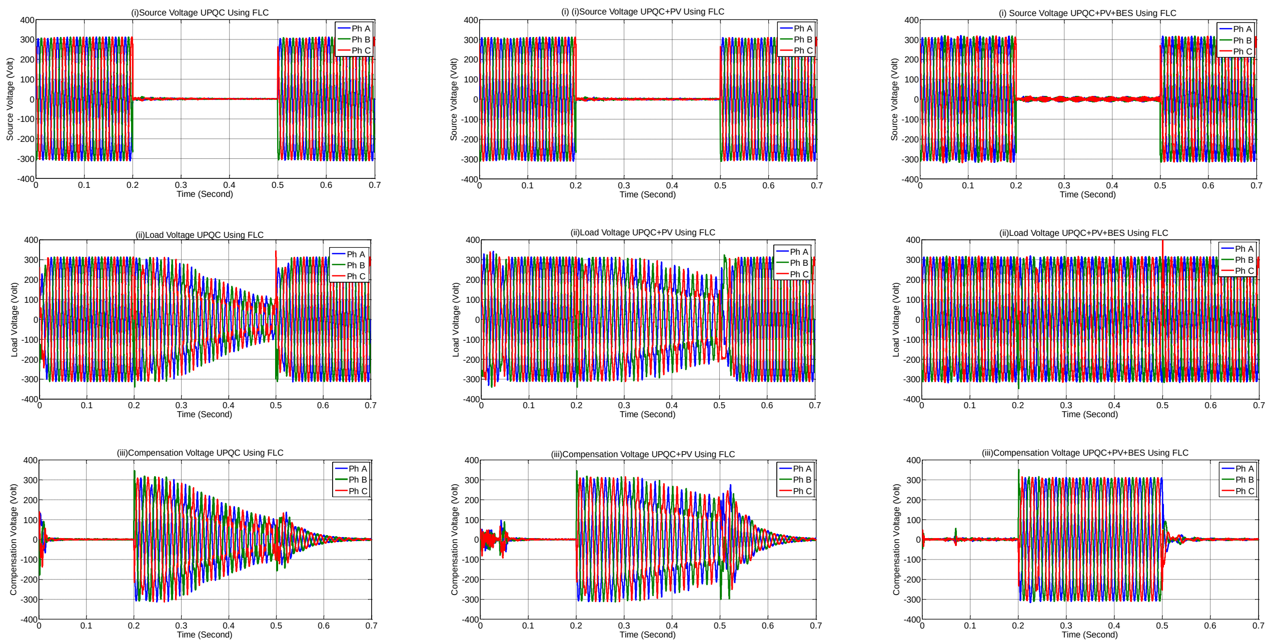


Figure 11. Performance of load current using three UPQC combinations in six fault scenarios



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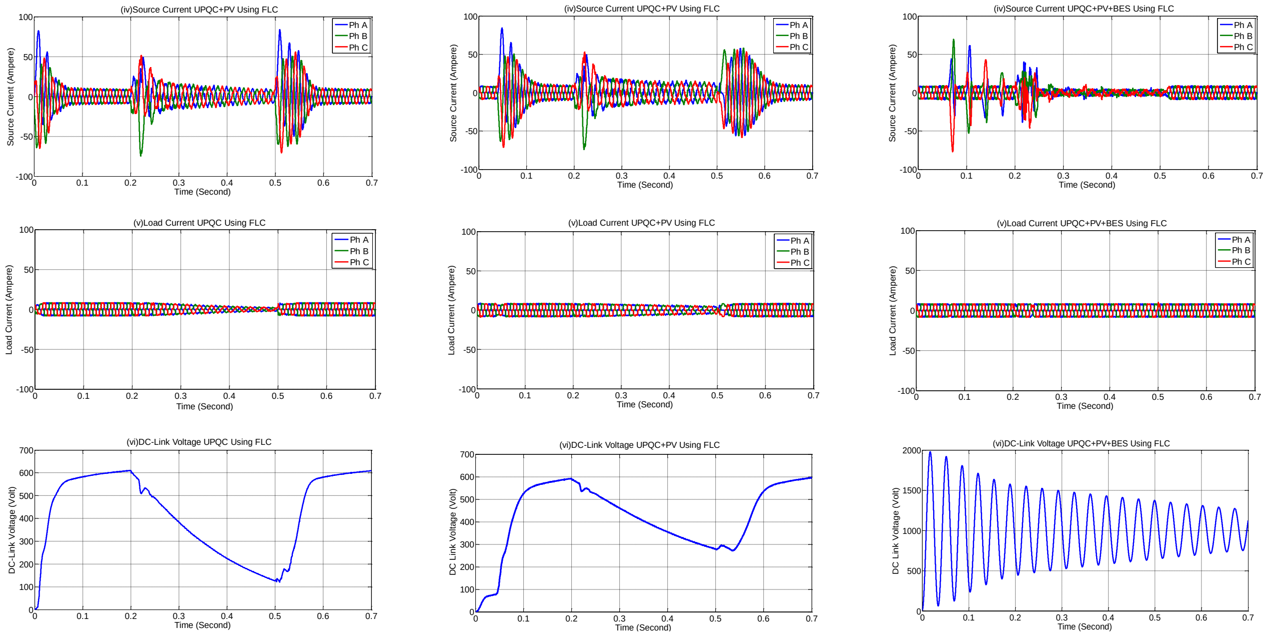

(a) UPQC (b) UPQC-PV (c) UPQC-PV-BES

Figure 12. Performance of 3P3W system on three UPQC combinations with FLC in Scenario 6 (Swell-NL)

Fig. 12.a.i shows that in scenario 6, UPQC at t = 0.2 s to t = 0.5 sec, the average V_S drops by 100% to 1,270 V. Under these condition, the capacitor in UPQC DC-link do not able to produce maximum power and inject average V_C (Fig. 12.a.iii) through an injection transformer in series active filter. So at t = 0.2 s to t = 0.5, an average V_L in Fig. 13.a.ii decreases to 160.4 V. During interruption period, implementation of the FLC to shunt active filter is unable to maintain V_{DC} (Fig. 12.a.vi) and an average V_C to keep it constant, causing an average I_L to also decrease to 4.337 A (Fig. 12.bv).

Fig. 12.b.i shows that in scenario 6, UPQC-PV combination at t = 0.2 s to t = 0.5 s, an average V_S drops by 100% to 1,358 V. Under these condition, UPQC-PV does not able to generate maximum power to UPQC DC link and inject and average V_C in Fig. 12.a.iii through an injection transformer in series active filter. So at t = 0.2 s to t = 0.5 s, an average V_L in Fig. 12.b.ii decreases to 215.4 V. During interruption period, application of FLC to shunt active filter is unable to maintain V_{DC} (Fig.12.b.vi) and an average V_C to remain constant, causing an average I_L is also decrease to 5,921 A (Figure 12.bv).

Fig. 12.c.i shows that in UPQC-PV-BES combination at t = 0.2 s to t = 0.5 s, an average V_S also drops 100% to 0.4062 V. During the interruption period, UPQC-PV-BES is able to generate power to UPQC DC-link and inject an average V_C (Fig.12.c.iii) through injection transformer in series active filter so that an average V_L remains stable at 304.1 V (Fig. 12.c.ii). During interruption period, even though an average I_S drop to 3.804 A, UPQC-PV-BES combination is able to generate power, store excess energy from PV, and allow current to load through shunt active filter so that I_L remains constant at 8,421 A (Figure 12. c.vi).

Fig. 2 shows an active power transfer of a single phase circuit using UPQC-PV-BES. Table 6, Table 7, and Table 8 show active power transfer in a the combination of circuit: (a) UPQC, (b) UPQC-PV, and (c) UPQC-PV-BES using PI controller and FLC in six disturbance scenarios. Table 9 shows DC power transfer UPQC-PV and UPQC-PV-BES.

Table 6. Active Power Transfer on UPQC

Skenarios	**Active Power Transfer (Watt)**			
	Source Power	**Series Power**	**Shunt Power**	**Load Power**
Proportional Integral Controller				
1. NL	4000	22	-260	3712
2. Unba-NL	4000	20	-270	3712
3. Dis-NL	4080	32	-280	3760
4. Sag-NL	3675	3820	-3670	3714
5. Swell-NL	5760	-1850	0	3712
6. Inter-NL	0	2850	-1200	1400
Fuzzy Logic Controller				
1. NL	4000	22	-240	3714
2. Unba-NL	4010	25	-260	3714
3. Dis-NL	4020	20	-228	3750
4. Sag-NL	3700	3850	-3730	3714
5. Swell-NL	5735	-1850	0	3713
6. Inter-NL	0	3800	-2300	1420

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Table 7. Active Power Transfer on UPQC-PV

Skenarios	**Active Power Transfer (Watt)**			
	Source Power	**Series Power**	**Shunt Power**	**Load Power**
Proportional Integral Controller				
1. NL	4000	20	-280	3715
2. Unba-NL	4000	20	-290	3712
3. Dist-NL	4000	25	-250	3750
4. Sag-NL	2700	2800	-1800	3715
5. Swell-NL	6000	-1700	0	3715
6. Inter-NL	0	4900	-1900	2650
Fuzzy Logic Controller				
1. NL	4000	20	-230	3714
2. Unba-NL	4000	20	-240	3714
3. Dist-NL	4000	25	-250	3760
4. Sag-NL	2800	2860	-1840	3715
5. Swell-NL	6000	-1700	0	3715
6. Inter-NL	0	6000	-3100	2600

Table 8. Active Power Transfer on UPQC-PV-BES

Skenarios	**Active Power Transfer (Watt)**			
	Source Power	**Series Power**	**Shunt Power**	**Load Power**
Proportional Integral Controller				
1. NL	3600	15	150	3690
2. Unba-NL	3600	15	135	3690
3. Dist-NL	3700	80	120	3850
4. Sag-NL	1700	1750	300	3680
5. Swell-NL	5500	-1700	0	3600
6. Inter-NL	0	-1100	5000	3720
Fuzzy Logic Controller				
1. NL	3830	15	-80	3690
2. Unba-NL	3830	10	-85	3690
3. Dist-NL	3900	100	-100	3850
4. Sag-NL	2000	2000	-150	3680
5. Swell-NL	5725	-1850	0	3700
6. Inter-NL	0	-900	4700	3700

Fig. 13 shows performance of active power transfer in a combination of circuits: (a) UPQC, (b) UPQC-PV, and (c) UPQC-PV-BES using PI controller and FLC in six disturbance scenarios.

Fig. 14 shows active power transfer in a combination of circuit are (a) UPQC, (b) UPQC-PV, and (c) UPQC-PV-BES using FLC in disturbance scenario 6 (Inter -NL).

Table 9. DC Power Transfer on UPQC-PV and UPQC-PV-BES

Scenarios	**DC Power(Watt)**		
	PV	**PV-BES**	
	PV Power	**PV Power**	**BES Power**
Proportional Integral Controller			
1. NL	120	0	400
2. Unba-NL	110	0	400
3. Dist-NL	125	0	390
4. Sag-NL	650	0	410
5. Swell-NL	-560	0	380
6. Inter-NL	1300	0	490
Fuzzy Logic Controller			
1. NL	130	0	520
2. Unba-NL	125	0	520
3. Dist-NL	120	0	520
4. Sag-NL	650	0	530
5. Swell-NL	-550	0	500
6. Inter-NL	1300	0	600

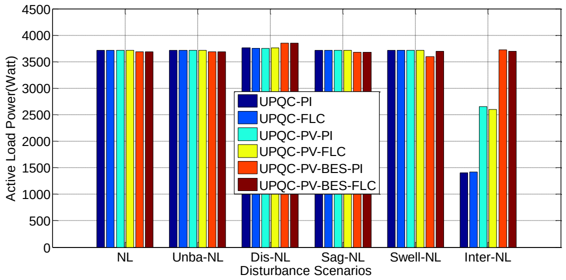
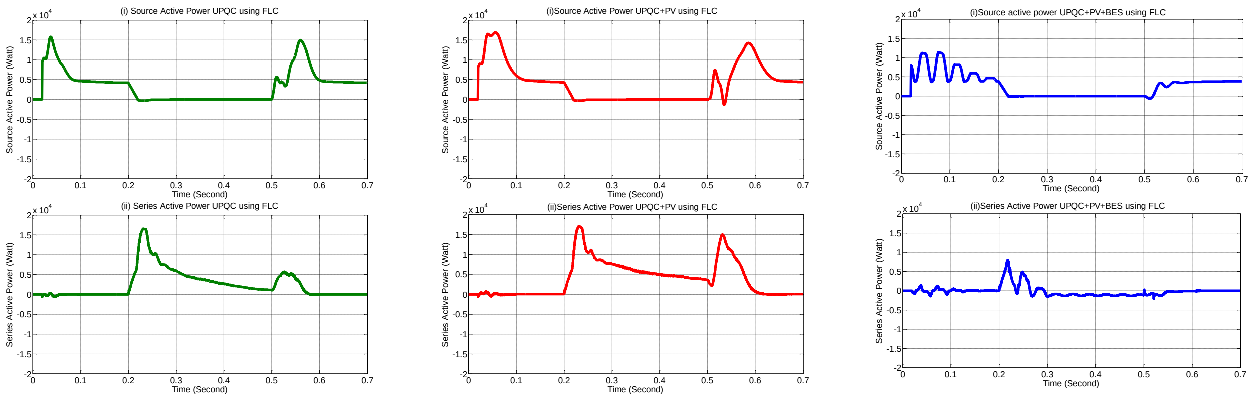


Figure 13. Active power transfer performance on three UPQC combinations in six scenarios

Fig. 13 shows that in disturbance scenario 1 to 5, the 3P3W system uses three combinations of UPQC with PI control and FLC is able to produce active load power above 3600 W. Whereas in scenario 6, only UPQC-PV-BES combination with PI control and FLC which is capable of producing active load power of 3720 W and 3700 W respectively. In the same scenario, UPQC combination using PI control and FLC can only produce a active load power of 1420 W and 1400 W respectively. Whereas if using a UPQC-PV combination using both control, active load power rose slightly to 2650 W and 2600 W respectively.



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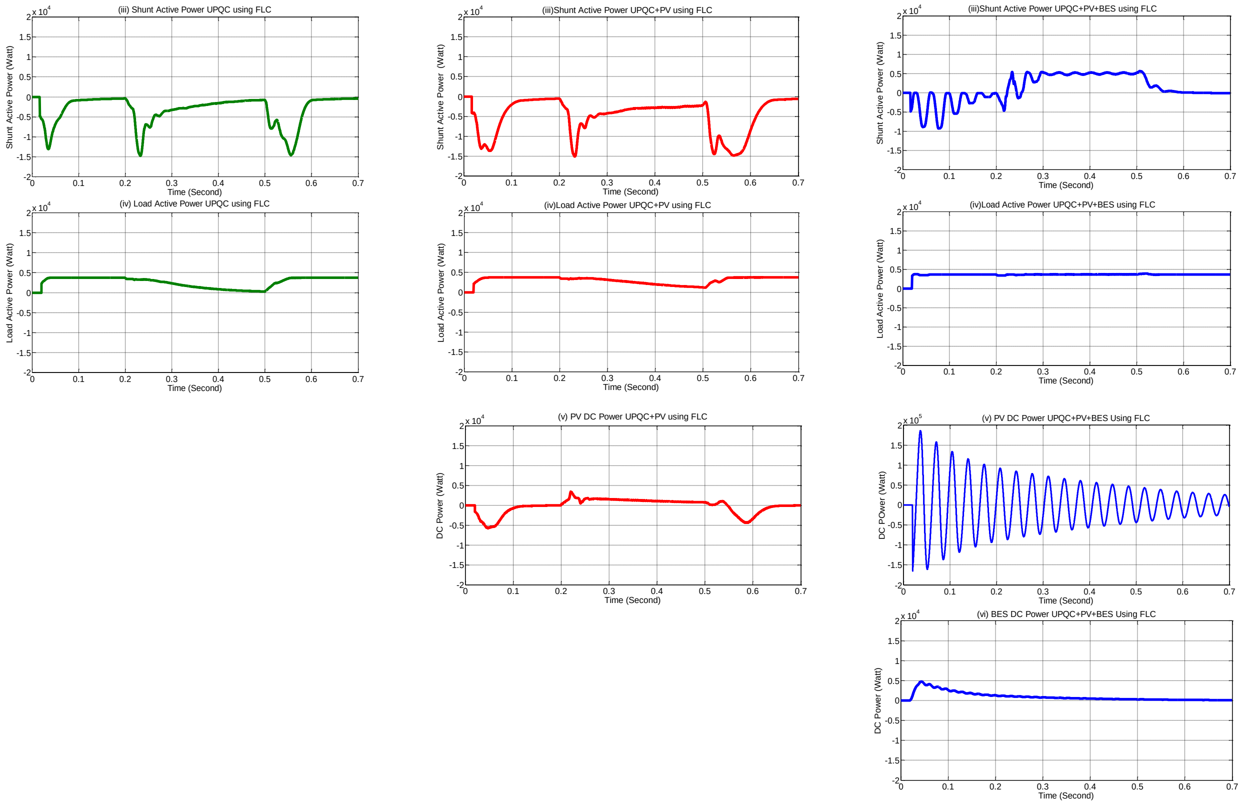

(a) UPQC (b) UPQC-PV (c) UPQC-PV-BES

Figure 14. Active power transfer performance in three UPQC combinations use FLC in scenario 6 (Inter-NL)

Fig. 14.a.i shows that in scenario 6, UPQC at t = 0.2 s to t = 0.5 s using FLC, the source active power (P_S) drops to 0 W. The series active power (P_{Se}) (Fig. 14. a.ii) increases by 3800 W and shunt active power (P_{Sh}) decreases by -2300 W (Fig. 14.a.iii), so that load active power (P_L) (Fig. 14.a.iv) decreases of 1420 W.

Fig. 14.b.i shows that in scenario 6, UPQC-PV combination at t = 0.2 s to t = 0.5 s using FLC, the nominal of source active power (P_S) drops to 0 W. The series active power (P_{Se}) (Fig. 14.b.ii) increases by 6000 W and shunt active power (P_{Sh}) decreases by -3100 W (Fig. 14.a.iii), PV power (Fig. 15.b.v) roses by 1300 W, so that load active power (PL) (Fig.14.b.iv) decreases of 2600 W.

Fig. 14.c.i shows that in scenario 6, UPQC-PV-BES at t = 0.2 s to t = 0.5 s using FLC, the value of source active power (P_S) drops to 0 W. The series active power (P_{Se}) (Fig. 15.c.ii) decrease by -900 W and shunt power (P_{Sh}) increases by 4700 W (Fig. 15.c.iii), PV power (Fig. 15.c.v) by 0 W, and BES power (Fig. 14. c.vi) of 600 W, so that load active power (PL) (Fig. 14.c.iv) becomes of 3700 W.

The next step is to determine efficiency of each combination i.e. (a) UPQC, (b) UPQC-PV, (c) UPQC-PV-BES using PI control and FLC. The efficiency of circuit combination is determined using Eq. 18 [6] and showed in Table 10 and Fig.15

Table 10 and Fig. 15 show that in scenarios 1 to 6, the combination of UPQC-PV and UPQC-PV-BES respectively results in lower efficiency compared to using only UPQC. In scenarios 4 and 6, the UPQC-PV-BES combination produces a higher efficiency than UPQC-PV combination. In scenario 4 using FLC, UPQC-PV-BES combination produces efficiency of 84.02% compared to UPQC-PV combination of 83.11%. In scenario 6 using FLC, UPQC-PV-BES model produces efficiency of 84.10% compared to UPQC-PV of 61.91%.

Table 10. Efficiency of UPQC combinations

Scenarios	Efficiency (%)		
	UPQC	**UPQC-PV**	**UPQC-PV-BES**
Proportional Integral Controller			
1. NL	98.67	96.25	88.59
2. Unba-NL	98.98	96.67	88.92
3. Dist-NL	98.12	96.16	89.74
4. Sag-NL	97.09	85.40	88.46
5. Swell-NL	94.94	99.34	86.12
6. Inter-NL	84.85	61.63	84.74
Fuzzy Logic Controller			
1. NL	98.20	94.75	86.12
2. Unba-NL	98.38	95.10	86.32
3. Dist-NL	98.37	96.54	87.11
4. Sag-NL	97.23	83.11	84.02
5. Swell-NL	95.57	99.07	84.57
6. Inter-NL	94.67	61.91	84.10

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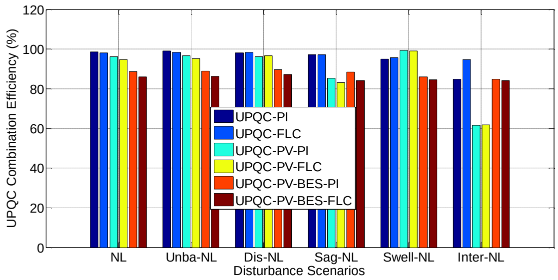

Figure 15. Efficiency of UPQC combinations

4. Conclussions

The implementation of UPQC-PV-BES in 3P3W system has been presented. In disturbance scenarios 1 to 5, the 3P3W system uses three combinations of UPQC with PI control and FLC, still maintains load voltage and load current above 300 V and 8 A. Whereas in scenario 6, only the UPQC-PV-BES combination with FLC is able to maintain load voltage and load current higher compared to other two UPQC combinations as 304.1 V and 8.421 A respectively. In disturbance scenarios 1 to 5, the 3P3W system uses three combinations of UPQC with PI controller and FLC, capable of producing active load power above 3600 W. Whereas in scenario 6, only a combination of UPQC-PV-BES with PI controller and FLC are able to produce a load voltage of 3720 W and 3700 W, respectively. In scenarios 1 to 6, the combination of UPQC-PV-BES results in lower efficiency compared to using UPQC and UPQC-PV. However, in scenario 6, the combination of UPQC-PV-BES with FLC is able to produce load voltage, load current, and active load power higher than UPQC-PV and UPQC. Thus the UPQC-PV-BES model using FLC is able to compensate load voltage and load current, and to enhance load active power in case an interruption voltage occurs on source bus.

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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; non linear 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; battery energe storage: type = nickel metal hybrid, DC voltage = 650 volt, rated capacity = 200 Ah, initial SOC = 100%, inductance L_1 = 6 mH, capacitance C_1 = 200 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; fuzzy model: method = mamdani, composition = max-min; input membership function: error (V_{dc}) = trapmf, trimf, delta error (ΔV_{dc}) = trapmf, trimf; output membership function: instantaneous power loss $\bar{p}_{loss}$ = trapmf, trimf.

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Lampiran 2.2

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Paper Title	**Power Transfer Enhancement Using UPQC-PV-BES System With Fuzzy Logic Controller**
Co-author(s)	**Adiananda Adiananda**
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Lampiran 2.3

Hasil Review Makalah Major

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Paper ID	Ijies2811
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Recommendation for Publication

~~□(Evaluation A:) Accept~~ ~~□(Evaluation B:) Accept after Minor Revision~~

~~□(Evaluation C:) Accept after Major Revision~~ □(Evaluation D:) Reject

Comments from reviewers 1 & 2:

This is well written and organized paper. It is scientifically sound and contains sufficient interest. However, English presentation of this paper is so poor. I recommend to resubmit this paper after the improvement of presentation.

1. English presentation should be further polished. There are many editing problems (spacing problems) in English. e.g. "compared to other two", "active load power in case", "performance of load voltage and load current", etc.
2. English presentation should be further polished. There are many grammatical and editing problems in English. e.g. "it only convert sunlight", "where the reseources are avialable", "quality problems i.e.. low power factor", "compared to hysterisis control", "This reserch showed", "in enhanching active power transfer", "in case of an interuption voltage", "there are a total of 12 disturbances.", "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", "with an unity amplitude", "instantaneous reactive power theory theory or", "produce a reference source current) $(i^*_{sa}, i^*_{sa}, i^*_{sa}$.", "UPQC-PV-BES Eficiency", "the authors proposes Eq. (14)", "a 100% interuption voltage", "Under these condition", "in a the combination of circuit", etc……… Give Up.
3. The problem definition of this work is not clear. In Sect.1, the drawbacks of each conventional technique should be described clearly. You should emphasize the difference with other methods to clarify the position of this work further.
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7. The font size of Table 4 & 5 is small. Besides, the width of these tables is too wide.

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Lampiran 2.4

Hasil Review Makalah Minor

Intelligent Networks and Systems Society

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International Journal of Intelligent Engineering and Systems (IJIES)

Paper ID	Ijies2893
Paper Title	Load Active Power Transfer Enhancement Using UPQC-PV-BES System With Fuzzy Logic Controller

Recommendation for Publication	
~~□(Evaluation A:) Accept~~	□(Evaluation B:) Accept after Minor Revision
~~□(Evaluation C:) Accept after Major Revision~~	~~□(Evaluation D:) Reject~~

Comments from reviewers 1 & 2:

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1. English presentation should be further polished. There are so many grammatical and editing problems in English. e.g. In Sect. 1, "the resources are avialable", "This device have been a function", "This model is used to improve PQ and reduce the burden", "Artificial neural network (ANN) 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", "UPQC applied to 3P4W system..", "Both researchs show", "BES is also expected to be able to save surplus power generated by PV and use it", "because the it has", "load actice power transfer", etc……. There are so many errors in your manuscript. Check it by yourself. You must improve your English presentation. It's so terrible.
2. The problem definition of this work is not clear. In Sect.1, the drawbacks of each conventional technique should be described clearly. You should emphasize the difference with other methods to clarify the position of this work further.
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   [1] R. Ruskone, S. Airault, and O. Jamet, "Vehicle Detection on Aerial Images", *International Journal of Intelligent Engineering and Systems*, Vol.1, No.1, pp.123-456, 2009.

   (In the case of Journal Papers)

   [2] R. Ruskone, L. Guigues, S. Airault, and O. Jamet, "Vehicle Detection on Aerial Images", In: *Proc. of International Conf. On Pattern Recognition*, Vienna, Austria, pp.900-904, 1996.

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Presentation & English	□Satisfactory □Needs improvement □Poor	
Overall organization	□Satisfactory □Could be improved □Poor	

Lampiran 2.5

Response Letter

Ijies2893 Reply Form:

Paper ID	**Ijies2893**
Paper Title	**Load Active Power Transfer Enhancement Using UPQC-PV-BES System With Fuzzy Logic Controller**

Reviewer comment to the authors:

1. English presentation should be further polished. There are somany grammatical and editing problems in English. e.g. In Sect. 1, “the resources are avialable”, “This device have been a function”, “This model is used to improve PQ and reduce the burden”, “Artificial neural network (ANN) 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”, “UPQC applied to 3P4W system..”, “Both researchs show”, “BES is also expected to be able to save surplus power generated by PV and use it”, “because the it has”, “load actice power transfer”, etc……. There are so many errors in your manuscript. Check it by yourself. You must improve your English presentation. It’s so terrible.

Answer:

Thank you for your comment.

i. I have revised false phrases that you mentioned i.e.

a. Abstract Section.

Whereas in Scn 6, only a combination of UPQC-PV-BES with PI controller and FLC “are” able to produce a load voltage….**revised to** Whereas in Scn 6, only a combination of UPQC-PV-BES with PI controller and FLC “is” able to produce a load voltage….(abtract-red font).

b. Introduction section (Section 1)

i. the resources are “avialable” in abundant…. **revised to** the resources are “available” in abundant…..(Page 1, Column 1, Red Font).

ii. This device “have” been a function **revised to** This device “has” been a function (Page 2, Column 1, Red Font).

iii. This model is used to improve PQ and “reduce” the burden… **revised to** This model is used to improve PQ and “to reduce” the burden (Page 2, Column 2, Paragraph 1, Red Font).

iv. Artificial neural network (ANN) 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 **revised to** Artificial neural network (ANN) 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 “has” been proposed (Page 2, Column 2, Paragraph 2, Red Font).

v. ….UPQC applied to “3P4W” system **revised to**….UPQC applied to “three phase four wire (3P4W)” system (Page 3, Column 1, Red Font).

vi. Both researchs “show” **revised to** Both researchs “showed” (Page 3, Column 1, Paragraph 1, Red Font).

vii. BES is also expected to be able to save surplus power generated by PV and “use” it as a backup power **revised to** BES is also expected to be able to save surplus power generated by PV and “be used” as a backup power (Page 3, Column 1, Paragraph 2, Red Font).

viii. ….because “the it” has **revised to** because “it” has…..(Page 3, Column 1, Paragraph 2, Red Font).

ix. ….load “actice” power transfer **revised to** ….load “active” power transfer (Page 3, Column 2, Paragraph 1, Red Font).

x. ….a weakness in determining proportional and integral gain constants “that still use” trial and error method **revised to**….a weakness in determining proportional and integral gain constants “which remain using” trial and error method. (Page 3, Column 1, Paragraph 2, Red Font).

xi. This device has a function of “injection” current **revised to** This device has a function of “injecting” current into AC system (Page 2, Column 1, Paragraph 2, Red Font).

xii. so that source current becomes a balanced sinusoidal and “it is in phase” with source voltage **revised to** so that source current becomes a balanced sinusoidal and “in phase” with source voltage (Page 2, Column 1, Paragraph 2, Red Font).

xiii. The PV-UPQC combination was also able to reduce harmonics due to nonlinear loads and “is” able to keep total harmonics distortion (THD) **revised to** The PV-UPQC combination was also able to reduce harmonics due to nonlinear loads and “was” able to keep total harmonics distortion (THD) (Page 2, Column 1, Paragraph 2, Red Font).

xiv. 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 **revised to** 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 “show that they became” more effective (Page 2, Column 1, Paragraph 3, Red Font).

xv. Unbalanced load voltage “contains” harmonics and “pure unbalanced pure load voltage”….**revised to** Unbalanced load voltage containing harmonics and “pure unbalanced load voltage”….(Page 2, Column 1, Paragraph 3, Red Font).

xvi. …..and having a momentary reactive power theory (p-q theory) “has been” proposed **revised to**….and having a momentary reactive power theory (p-q theory) “which has been” proposed. (Page 2, Column 2, Paragraph 1, Red Font).

xvii. The system “has been able to carry” out reactive power compensation and “reduce” source current and load voltage harmonics **revised to** The system “has succesfully to carried out” reactive power compensation and “reduced” source current and load voltage harmonics. (Page 2, Column 2, Paragraph 1, Red Font).

xviii. The UPQC system was able to supply reactive power needed to increase power factor, reduce voltage and current distortion, and help “to inject” active power by PV into the load **revised to** The UPQC system was able to supply reactive power needed to increase power factor, reduce voltage and current distortion, and help “inject” active power by PV into the load. (Page 2, Column 2, Paragraph 1, Red Font).

xix. The proposed model “has been able to mitigate”….. **revised to** The proposed model has “succesfully mitigated”….. (Page 2, Column 2, Paragraph 2, Red Font).

xx. ……by PV array connected to DC links using PI compared to FLC has been “carried out” **revised to**…..by PV array connected to DC links using PI compared to FLC has been “conducted”. (Page 2, Column 2, Paragraph 2, Red Font).

xxi. Both methods “were” able to improve PQ and “reduce” distortion in output power **revised to** Both methods “are” able to improve PQ and “to reduce” distortion in output power (Page 2, Column 2, Paragraph 3, Red Font).

xxii. “The research” on the use of BES in UPQC “is supplied” by PV to improve PQ in three phase 3P3W distribution systems using FLC validated PI controller on various disturbances in source and load side “have” been investigated **revised to** “Research” on the use of BES in UPQC “supplied” by PV to improve PQ in three phase 3P3W distribution systems using FLC validated PI controller on various disturbances in source and load side “has” been investigated (Page 2, Column 2, Paragraph 3, Red Font).

xxiii. “This” research showed that FLC on UPQC-BES supplied by PV was able to significantly….**revised to** “The” research showed that FLC on UPQC-BESsupplied by PV was able to significantly….(Page 2, Column 2, Paragraph 3, Red Font).

xxiv. ….. that the topology “has” the capacity to compensate for network disturbances, inject power generated by PV panels under different operating conditions, and “able to” compensate THD voltage on load bus and THD current on source bus **revised to** …..that the topology “had” the capacity to compensate for network disturbances, inject power generated by PV panels under different operating conditions, and “was able to” compensate THD voltage on load bus and THD current on source bus. (Page 3, Column 1, Paragraph 1, Red Font).

xxv. “The Research” on biogeography-based optimization with harmonic elimination techniques for modification of UPQC connected to smartgrid has been carried out **revised to** “Research” on biogeography-based optimization with harmonic elimination techniques for modification of UPQC connected to smartgrid has been carried out. (Page 3, Column 1, Paragraph 1, Red Font).

xxvi. The firing angle of shunt-series converter is obtained in real-time from an angle “that is already” stored in the microcontroller memory **revised to** The firing angle of shunt-series converter is obtained in real-time from an angle “already” stored in the microcontroller memory. (Page 3, Column 1, Paragraph 1, Red Font).

xxvii. The effectiveness of “proposed” model is validated with UPQC and UPQC-PV, respectively revised to The effectiveness of “the proposed model” is validated with UPQC and UPQC-PV, respectively. (Page 3, Column 1, Paragraph 2, Red Font).

xxviii. …….a weakness in determining proportional and integral gain constants “that still use” trial and error method **revised by**…..a weakness in determining proportional and integral gain constants “which remain using” trial and error method. (Page 3, Column 1, Paragraph 2, Red Font).

xxix. The next step is to determine efficiency value of each UPQC combination to show “the circuit which it has a higher” performance….. **revised to** The next step is to determine efficiency value of each UPQC combination to show “which circuit has higher” performance…..(Page 3, Column 1, Paragraph 2, Red Font).

xxx. Section 3 shows results and “discussions” of load voltage….**revised to** Section 3 shows results and “discussion” of load voltage….(Page 3, Column 2, Paragraph 1, Red Font).

xxxi. Table 1 shows “abbreviation” in this paper **revised to** Table 1 shows “the abbreviations used” in this paper (Page 3, Column 2, Paragraph 1, Red Font).

c. Research Method Section (Section 2)

i. The PV generator raises DC power at a constant temperature and solar radiation level (1000 W/m^2 and 25^0 C) and “it is” connected to BES through DC/DC boost converter circuit **revised to** The PV generator raises DC power at a constant temperature and solar radiation level (1000 W/m^2 and 25^0 C) and “is” connected to BES through DC/DC boost converter circuit. (Page 3, Column 2, Paragraph 2, Red Font).

ii. BES is connected to the DC-link and “it has a function as” energy storage and “it is” expected to inject power to keep load voltage and load active power especially for an interruption voltage from source bus **revised to** BES is connected to the DC-link and “which serves as” energy storage and “is” expected to inject power to keep load voltage and load active power, especially for an interruption voltage from source bus. (Page 4, Column 1, Paragraph 2, Red Font).

iii. The next step is to determine nominal of efficiency of each UPQC combination to show the circuit that has superior performance in “maintain” load voltage…. **revised to** The next step is to determine nominal of efficiency of each UPQC combination to show the circuit that has superior performance in “maintaining” load voltage….(Page 4, Column 2, Paragraph 1, Red Font).

iv. Simulation parameters for “proposed” model is “showed” in appendix section **revised to** Simulation parameters for “the proposed” model is “shown” in appendix section (Page 4, Column 2, Paragraph 1, Red Font).

v. The equivalent circuit of solar panel is “showed” in Fig. 3 **revised to** The equivalent circuit of solar panel is “shown” in Fig. 3. (Page 5, Column 1, Paragraph 1, Red Font).

vi. I_o is dependent value on the temperature variation. Eq. (2) and Eq. (3) are "calculation" of I_{PV} and I_o values: **revised to** I_o is dependent value on the temperature variation. Eq. (2) and Eq. (3) are "the calculation" of I_{PV} and I_o values: (Page 5, Column 1, Paragraph 2, Red Font).

vii. Where $I_{PV,n}$, $I_{SC,n}$, and $V_{OC,n}$ "is" the photovoltaic current, short circuit current, and open circuit voltage under standard conditions ($T_n = 25^0 C$ and $G_n = 1000\ W/m^2$), respectively **revised to** Where $I_{PV,n}$, $I_{SC,n}$, and $V_{OC,n}$ "are" the photovoltaic current, short circuit current, and open circuit voltage under standard conditions ($T_n = 25^0 C$ and $G_n = 1000\ W/m^2$), respectively. (Page 5, Column 1, Paragraph 3, Red Font).

viii. …..with a pulse width modulation (PWM) controller which "it is used" to raise the desired trigger signal in series active filter **revised to**…..with a pulse width modulation (PWM) controller which "is used" to raise the desired trigger signal in series active filter. (Page 5, Column 2, Paragraph 2, Red Font).

ix. The total imaginary power (q) and fluctuating section of real power are selected as power and current references and "are they are" utilized through the use of Eq.11 **revised to** The total imaginary power (q) and fluctuating section of real power are selected as power and current references and "are" utilized through the use of Eq.11(Page 6, Column 1, Paragraph 2, Red Font).

x. The general DC-link voltage value depends on the instantaneous energy that can be generated by UPQC which "it is" defined in Eq.13 **revised to** The general DC-link voltage value depends on the instantaneous energy that can be generated by UPQC which "is" defined in Eq.13 (Page 6, Column 2, Paragraph 1, Red Font).

xi. FLC is able to reduce oscillations and "produce"……..**revised to** FLC is able to reduce oscillations and "to produce"……….. (Page 6, Column 2, Paragraph 2, Red Font).

xii. This method is also used to overcome the weaknesses of PI controller in determining proportional gain constants (K_P) and integral gain constants(K_I), "that still use" trial and error method **revised to** This method is also used to overcome the weaknesses of PI controller in determining proportional gain constants (K_P) and integral gain constants(K_I), "which remain using the" trial and error method. (Page 6, Column 2, Paragraph 2, Red Font).

xiii. This research starts by determining $\bar{p}_{loss}$ as an input variable, to produce a reference source current on the hysteresis current control and “generate” a trigger signal…..**revised to** This research starts by determining $\bar{p}_{loss}$ as an input variable, to produce a reference source current on the hysteresis current control and “to generate” a trigger signal…..(Page 6, Column 2, Paragraph 3, Red Font).

xiv. “By using” the same procedure, $\bar{p}_{loss}$ is also determined using FLC **revised to** “Using” the same procedure, $\bar{p}_{loss}$ is also determined using FLC…..(Page 6, Column 2, Paragraph 3, Red Font).

xv. …….because it has heuristic properties, “simpler more effective”, and has multi-rule-based variables in both linear and non-linear system **revised to** ……...because it has heuristic properties, “is simpler and more effective”, and has multi-rule-based variables in both linear and non-linear system. (Page 6, Column 2, Paragraph 3, Red Font).

xvi. The FLC sections “are” fuzzification…. **revised to** The FLC sections “comprise” fuzzification….(Page 6, Column 2, Paragraph 3, Red Font).

xvii. The value of $\bar{p}_{loss}$ is one of the input variables to “get” the compensation current........**revised to** The value of $\bar{p}_{loss}$ is one of the input variables to “obtain” the compensation current…..(Page 7, Column 1, Paragraph 1, Red Font).

xviii. During the fuzzification process, a number of input variables are calculated and converted “to” linguistic variables…..**revised to** During the fuzzification process, a number of input variables are calculated and converted “into” linguistic variables…..(Page 7, Column 1, Paragraph 1, Red Font).

xix. After $V_{dc-error}$ and $\Delta V_{dc-error}$ are obtained, two input MFs are subsequently converted “to” linguistic variables….. **revised to** After $V_{dc-error}$ and $\Delta V_{dc-error}$ are obtained, two input MFs are subsequently converted “into” linguistic variables…..(Page 7, Column 2, Paragraph 1, Red Font).

xx. 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 **revised to** In this paper, it “is” found that the implementation of UCES “is” able to help system reduce source current compensation when sag voltage “is on source bus” to keep load voltage constant and balanced. (Page 7, Column 2, Paragraph 2, Red Font).

xxi. Although “it provides” an advantage of sag voltage compensation…. **revised to** Although “providing” an advantage of sag voltage compensation…..(Page 7, Column 2, Paragraph 2, Red Font).

xxii. “By using” the same procedure, the authors propose Eq. (14) for efficiency of UPQC-PV-BES “is formulated” below **revised to** “Using” the same procedure, the authors propose Eq. (14) for efficiency of UPQC-PV-BES “in the formula” below. (Page 7, Column 2, Paragraph 2, Red Font).

d. Results and Discussion (Section 3)

i. Results and “Discussions” in Section 3 **revised to** Results and “Discussion” (Subtitle Section 3, Page 8).

ii. The proposed model is determined “through on” UPQC combinations….. **revised to** The proposed model is determined “using” three UPQC combinations….(Page 8, Column 1, Paragraph 1, Red Font).

iii. …..which results “5^{th} and 7^{th}“ harmonics….. **revised to**…..which results “in 5^{th} and 7^{th}“ harmonics……..(Page 8, Column 1, Paragraph 1, Red Font).

iv. …..the source experiences “100% an interruption” voltage….revised to …..the source experiences “a 100% interruption” voltage……..(Page 8, Column 1, Paragraph 1, Red Font).

v. ……”so that totally is 12 scns” **revised to** ……”so that there are 12 scns in total”. (Page 8, Column 1, Paragraph 1, Red Font).

vi. Then, “by using” Matlab/Simulink, each combination model is run according to the desired scn to “get” …. **revised to** Then, “using” Matlab/Simulink, each combination model is run according to the desired scn to “obtain” …. (Page 8, Column 1, Paragraph 2, Red Font).

vii. The next process is determining “value” of power transfer….**revised to** The next process is determining “the value” of power transfer…..(Page 8, Column 1, Paragraph 2, Red Font).

viii. …..and BES are determined in one cycle “start” at t = 0.35 s. **revised to**…..and BES are determined in one cycle “starts” at t = 0.35 s. (Page 8, Column 1, Paragraph 2, Red Font).

ix. The results of the average source voltage, source current, load voltage, and load current on “three” proposed UPQC combinations….**revised to** The results of the average source voltage, source current, load voltage, and load current on “the three” proposed UPQC combinations…. (Page 8, Column 1, Paragraph 2, Red Font).

x. "An average" **revised to** "The average" (Page 8, Column 2, Paragraph 1, Red Font).

xi. "An average" **revised to** "The average" (Page 8, Column 2, Paragraph 2, Red Font).

xii. "An average" **revised to** "The average" (Page 8, Column 2, Paragraph 3, Red Font).

xiii. "However", in the same system and "with Scn 1 to 6" using FLC control **revised to** "In" the same system and "Scn 1 to 6" using FLC control (Page 8, Column 2, Paragraph 3, Red Font).

xiv. …..load current "roses" slightly from 8,421 to 8,718 A **revised to**….load current "rises" slightly from 8,421 to 8,718 A. (Page 8, Column 2, Paragraph 3, Red Font).

xv. Fig. 10 shows that in Scn 1 to 5 the 3P3W system "uses" three combinations of UPQC with PI control and FLC "able to" maintain load voltage above 300 V **revised to** Fig. 10 shows that in Scn 1 to 5, the 3P3W system "using" three combinations of UPQC with PI control and FLC "is able to" maintain load voltage above 300 V. (Page 9, Column 1, Paragraph 2, Red Font).

xvi. …..only a combination of UPQC-PV-BES with FLC is able to "result" load voltage of 304.1 V **revised to**. …..only a combination of UPQC-PV-BES with FLC is able to "generate" load voltage of 304.1 V. (Page 9, Column 1, Paragraph 2, Red Font).

xvii. Whereas in Scn 6, only "UPQC-PV-BES" combination with PI control and FLC "capable to" generating load current….. **revised to** Whereas in Scn 6, only "the UPQC-PV-BES" combination with PI control and FLC "is capable" of generating load current…..(Page 9, Column 1, Paragraph 2, Red Font).

xviii. Therefore, in Scn 6, "combination" of UPQC-PV-BES with FLC "is able to provide" better load voltage and load current performance than both "UPQC and UPQC-PV" combination **revised to** Therefore, in Scn 6, "the combination" of UPQC-PV-BES with FLC "provides" better load voltage and load current performance than both "the UPQC and UPQC-PV" combination. (Page 9, Column 1, Paragraph 2, Red Font).

xix. "An average" **revised to** "The average" (Page 9, Column 1, Paragraph 3, Red Font).

xx. Fig. 12 shows "performance"…**revised to** Fig. 12 shows "the performance"….. (Page 9, Column 1, Paragraph 3, Red Font).

xxi. Fig. 12.a.i shows "in Scn 4" the UPQC combination….**revised to** Fig. 12.a.i shows "in Scn 4 of" the UPQC combination….(Page 9, Column 1, Paragraph 3, Red Font).

xxii. ….in load power and "maintain"….**revised to**……in load power and "to maintain"…. (Page 9, Column 1, Paragraph 3, Red Font).

xxiii. …..to maintain an average current (I_L) "remained" stable at 8.588 A (Fig. 12.a.v).

revised to …..to maintain an average current (I_L) “remain” stable at 8.588 A (Fig. 12.a.v). (Page 9, Column 1, Paragraph 3, Red Font).

xxiv. “An average” **revised to** “The average” (Page 9, Column 2, Paragraph 1, Red Font).

xxv. Fig. 12.b.i shows that “in Scn 4”, UPQC-PV combinationat t = 0.2 s to t = 0.5 **revised to** Fig. 12.b.i shows that “in Scn 4 of the” UPQC-PV combinationat t = 0.2 s to t = 0.5 s,…. (Page 9, Column 2, Paragraph 1, Red Font).

xxvi. …..load current (I_L) “remained” stable at 8.578 A (Fig. 12.b.v) **revised to**…..load current (I_L) “remain” stable at 8.578 A (Fig. 12.b.v) (Page 9, Column 2, Paragraph 1, Red Font).

xxvii. Fig. 12.c.i, “in Scn 4, UPQC-PV-BES combination also shows the same performance in terms on an average” V_C, V_L, and I_L ……..**revised to** Fig. 12.c.i “also shows that the UPQC-PV-BES combination in Scn 4 indicates almost the same performance on the average” V_C, V_L, and I_L ………..(Page 9, Column 2, Paragraph 2, Red Font).

xxviii. “An average” **revised to** “The average” (Page 9, Column 2, Paragraph 2, Red Font).

xxix. Fig. 13 shows “performance” of UPQC combinations using FLC in Scn 6 (Inter-NL) **revised to** Fig. 13 shows “the performance” of UPQC combinations using FLC in Scn 6 (Inter-NL). (Page 9, Column 2, Paragraph 3, Red Font).

xxx. Fig. 13.a.i shows that “in scn 6”, UPQC at t = 0.2 s to t = 0.5 sec…**revised to** Fig. 13.a.i shows that “in scn 6 of” UPQC at t = 0.2 s to t = 0.5 sec…. (Page 9, Column 2, Paragraph 3, Red Font).

xxxi. Under this condition, the capacitor in UPQC DC-link “is not able” to produce maximum power….**revised to** Under this condition, the capacitor in UPQC DC-link “is unable” to produce maximum power…(Page 9, Column 2, Paragraph 3, Red Font).

xxxii. …..and “an” average V_C “to keep it constant”, “causes an average” I_L to also decrease to 4.337 A (Fig. 13.a.v) **revised to** …..and the average V_C “constantly”, “causes the average” I_L to also decrease to 4.337 A (Fig. 13.a.v) …(Page 9, Column 2, Paragraph 3, Red Font).

xxxiii. “An average” **revised to** “The average” (Page 9, Column 2, Paragraph 3, Red Font).

xxxiv. Fig. 13.b.i shows that “in Scn 6,” UPQC-PV combination at t = 0.2 s to t = 0.5 s…. **revised to** Fig. 13.b.i shows that ” in Scn 6 of” UPQC-PV combination at t = 0.2 s to t = 0.5 s….(Page 9, Column 2, Paragraph 4, Red Font).

xxxv. Under this condition, UPQC-PV “does not able” to generate maximum….. **revised to** Under this condition, UPQC-PV “is unable” to generate maximum…..(Page 9, Column 2, Paragraph 4, Red Font).

xxxvi. “An average” **revised to** “The average” (Page 9, Column 2, Paragraph 4, Red Font).

xxxvii. “Fig. 13.c.i shows that in UPQC-PV-BES combination at t = 0.2 s to t = 0.5 s an average V_S also drops 100% to 0.4062 V” **revised to** Fig. 13.c.i shows that the average V_S also drops 100% to 0.4062 V in the UPQC-PV-BES combination at t = 0.2 s to t = 0.5 s. (Page 10, Column 1, Paragraph 1, Red Font).

xxxviii. During “the interruption” period, “UPQC-PV-BES” is able to generate…. **revised to** During “interruption” period, “the UPQC-PV-BES” is able to generate….(Page 10, Column 1, Paragraph 1, Red Font). (Page 10, Column 1, Paragraph 1, Red Font).

xxxix. During “the” interruption period, even though “an” average I_S drops to 3.804 A, UPQC-PV-BES is able to generate power….**revised to** Even though “the” average I_S drops to 3.804 A during interruption period, the UPQC-PV-BES is able to generate power….(Page 10, Column 2, Paragraph 1, Red Font).

xl. “An average” **revised to** “The average” (Page 10, Column 2, Paragraph 1, Red Font).

xli. Fig. 14.a.i shows that in Scn 4, “UPQC”…. **revised to** Fig. 14.a.i shows that in Scn 4 “of UPQC”…. (Page 17, Column 1, Paragraph 2, Red Font).

xlii. …source active power….shunt active power….load active power…**revised to** …”the” source active power….”the” shunt active power….”the” load active power… (Page 17, Column 1, Paragraph 2, Red Font).

xliii. Fig. 14.b.i shows that in Scn 4, “UPQC-PV”…. **revised to** Fig. 14.b.i shows that in Scn 4 “of UPQC-PV”…. (Page 17, Column 1, Paragraph 3, Red Font).

xliv. ….”roses”…. **revised to**….”increases”….. (Page 19, Column 1, Paragraph 3, Red Font).

xlv. Fig. 14.c.i shows that in Scn 4, “UPQC-PV-BES”…. **revised to** Fig. 14.c.i shows that in Scn 4 “of UPQC-PV_BES”…. (Page 17, Column 1, Paragraph 4, Red Font).

xlvi. ….”equal as”…. **revised to**….”equal to”….. (Page 17, Column 2, Paragraph 1, Red Font).

xlvii. Fig. 15.a.i shows that in Scn 6, “UPQC”…. **revised to** Fig. 15.a.i shows that in Scn 6 of UPQC…..(Page 17, Column 2, Paragraph 2, Red Font).

xlviii. …..”decrease of”….**revised to**….”decrease to”….(Page 17, Column 2, Paragraph 2, Red Font).

xlix. Fig. 15.b.i shows that in Scn 6, “UPQC-PV”…. **revised to** Fig. 15.b.i shows that in Scn 6 of UPQC-PV…..(Page 17, Column 2, Paragraph 2, Red Font).

l. …..”decrease of”….**revised to**….”decrease to”….(Page 19, Column 2, Paragraph 3, Red Font).

li. Fig. 15.c.i shows that in Scn 6, “UPQC-PV-BES”…. **revised to** Fig. 15.b.i shows that in Scn 6 of UPQC-PV-BES…..(Page 17, Column 2, Paragraph 3, Red Font).

lii. …..”becomes of”….**revised to**….”becomes”….(Page 17, Column 2, Paragraph 4, Red Font).

liii. The next step is to determine “efficiency”…. **revised to** The next step is to determine “the efficiency”….(Page 18, Column 2, Paragraph 1, Red Font).

liv. The efficiency of “circuit” combination is determined using Eq. 14 and showed in Table 10 and Fig.17….. **revised to** The efficiency of “each circuit” combination is determined using Eq. 14 and “shown” in Table 10 and Fig.17 (Page 18, Column 2, Paragraph 1, Red Font).

e. Conclussion (Section 4)

i. ……the 3P3W system “uses” three combinations of UPQC of UPQC with PI control and FLC “maintains” load voltage and load current “above” 300 V and 8 A **revised to** ……the 3P3W system “using” three combinations of UPQC of UPQC with PI control and FLC “is still able to maintain” load voltage and load current to be above 300 V and 8 A. (Page 19, Column 1, Paragraph 1, Red Font).

ii. Whereas in Scn 6, only the UPQC-PV-BES combination with FLC is able to maintain “load” voltage and load current “higher than other two UPQC combinations as” 304.1 V and 8.421 A **revised to** Whereas in Scn 6, only the UPQC-PV-BES combination with FLC is able to maintain “the load” voltage and load current “to be higher than the other two UPQC combinations of” 304.1 V and 8.421 A. (Page 19, Column 1, Paragraph 1, Red Font).

iii. In disturbance scns 1 to 5, the 3P3W system “uses” three combinations of UPQC with PI controller and FLC “capable of producing” load active…. **revised to** In disturbance scns 1 to 5, the 3P3W system “using” three combinations of UPQC with PI controller and FLC “is capable of producing” load active….(Page 19, Column 1, Paragraph 1, Red Font).

iv. Whereas in Scn 6, only “a” combination of UPQC-PV-BES with PI controller and FLC “are” able to produce…. **revised to** Whereas in Scn 6, only “the” combination of UPQC-PV-BES with PI controller and FLC “is” able to produce……..(Page 19, Column 1, Paragraph 1, Red Font).

v. However, In Scn 6, the combination of UPQC-PV-BES with FLC is able to produce load voltage, load current, and load active power “higher compared than” UPQC-PV and UPQC **revised to** In Scn 6, however, the combination of UPQC-PV-BES with FLC is able to produce “higher” load voltage, load current, and load active power “compared to” UPQC-PV and UPQC. (Page 19, Column 1, Paragraph 1, Red Font).

vi. Thus, the UPQC-PV-BES model using FLC is able to compensate to “load voltage” and load current, and to enhance “load active power”….. **revised to** Thus, the UPQC-PV-BES model using FLC is able to compensate to “the load voltage” and load current, and to enhance “the load active power”….. (Page 19, Column 1, Paragraph 1, Red Font).

f. Acknowlegment (Section 5)

i. …..”Directorate” General of Research…..**revised to**…..”the Directorate” General of Research…..(Page 19, Column 2, Paragraph 1, Red Font).

ii. ……through Fundamental Research “base on” the Decree Letter Number….**revised to**……through Fundamental Research “accordance with” the Decree Letter Number….(Page 19, Column 2, Paragraph 1, Red Font).

Reviewer comment to the authors:

2. The problem definition of this work is not clear. In Sect.1, the drawbacks of each conventional technique should be described clearly. You should emphasize the difference with other methods to clarify the position of this work further.

   Answer:

   Thank you for your comment.

   a. I have described the problem definition of this paper in Page 3, Paragraph 2, Column 1, Red Font i.e. "The previous research on UPQC-PV which has been carried out aims to compensate for sag/swell voltage on source bus, to reduce THD caused by distorted supply and non-linear loads, as well as to mitigate unbalanced loads. However, this combination has several disadvantages. This system is unable to overcome voltage interruption in source bus if PV power connected to UPQC DC-link circuit is insufficient to meet load power and the duration of interruption (momentary) exceeds 3 seconds base on limit IEEE 1159-1995 Standard".
   b. I use Fuzzy Logic Controller (FLC) as the method on this paper because the fuzzy rules algorithm collects a number of fuzzy control rules in a particular order. These rules are used to control the system so that it meets the desired performance requirements and they are designed from a number of intelligent control system knowledge. FLC is simple designed depend on input and input membership functions (MFs) as well as table fuzzy rules which authors are determined before. (Page 6, Column 2, Paragraph 3, Red Font).
   c. This method also has advantages because it requires faster time in determining output than another artificial intelligence methods e.g. Neural Network (NN). Because the weakness of NN requires time for learning (training) and testing process, so that it produces longer control responses when determining output variables. (Page 2, Column 2, Paragraph 2, Red Font).

Reviewer comment to the authors:

3. In figures/equations, mathematical expressions must be Italic font.Unify the font style.

   Answer:

   Thank you for your comment.

3. I have revised mathematical expressions in Italic font for the figures/equations i.e.

   a. Research Method (Section 2)

   i. Mathematical expressions in Fig. 3. i.e. I_{PV} , R_S, R_P, I, V, I_d have been in Italic font. (Page 5 Column 1).
   ii. Mathematical expressions in Eq. (1) have been in Italic font. (Page 5 Column 1).
   iii. Mathematical expressions in Paragraph 2 i.e. I_{PV} , I_O , R_S, R_P, etc….., have been in Italic font. (Page 5 Column 1).
   iv. Mathematical expressions in Eq. (2) and Eq. (3) have been in Italic font. (Page 5 Column 1).
   v. Mathematical expressions in Paragraph 3 i.e. $I_{PV,n}$, $I_{SC,n}$, and $V_{OC,n}$, etc…., have been in Italic font. (Page 5 Column 1).
   vi. Mathematical expressions in Eq. (4) and Eq. (5) have been in Italic font. (Page 5 Column 1).
   vii. Mathematical expressions in Paragraph 1, Paragraph 2, and Paragraph 3 i.e. $(V_{La}^*, V_{Lb}^*, V_{Lc}^*)$, (V_{La}, V_{Lb}, V_{Lc}), V_m , $\alpha\beta$ have been in Italic font. (Page 5 Column 2).
   viii. Mathematical expressions in Eq. (6) have been in Italic font. (Page 5 Column 2).
   ix. Mathematical expressions in Fig. 4. i.e. $(V_{La}^*, V_{Lb}^*, V_{Lc}^*)$, (V_{La}, V_{Lb}, V_{Lc}), V_m , etc….., have been in Italic font. (Page 5 Column 2).
   x. Mathematical expressions in Eq. (7) have been in Italic font. (Page 5 Column 2).
   xi. Mathematical expressions in Eq. (8), Eq. (9), Eq. (10), Eq. (11), and Eq. (12), have been in Italic font. (Page 6 Column 1).
   xii. Mathematical expressions in Paragraph 1, Paragraph 2, and Paragraph 3 i.e. (p), (q) $\bar{p}_{loss}$ $(i_{c\alpha}^*, i_{c\beta}^*)$ $(i_{sa}^*, i_{sa}^*, i_{sa}^*)$, etc,……have been in Italic font. (Page 6 Column 1).
   xiii. Mathematical expressions in Fig. 5. i.e. $(i_{sa}^*, i_{sa}^*, i_{sa}^*)$, (i_{sa}, i_{sb}, i_{sc}), (V_{sa}, V_{sb}, V_{sc}), etc….., have been in Italic font. (Page 6 Column 1).
   xiv. Mathematical expressions in Eq. (13) have been in Italic font. (Page 6 Column 2).
   xv. Mathematical expressions in Paragraph 1, Paragraph 2, and Paragraph 3 i.e. (V_{dc}) (V_{dc}^*) $(i_{sa}^*, i_{sa}^*, i_{sa}^*)$. (i_{sa}, i_{sb}, i_{sc}) (K_I) (K_P) , etc,……have been in Italic font. (Page 6 Column 2).

xvi. Mathematical expressions in Fig. 6. i.e. $V_{dc-error}$, $\Delta V_{dc-error}$, $\bar{p}_{loss}$ etc,….. have been in Italic font. (Page 7 Column 1).

xvii. Mathematical expressions in Paragraph 1 and Paragraph 2 i.e. $V_{dc-error}$ $\Delta V_{dc-error}$, $\bar{p}_{loss}$ etc,……have been in Italic font. (Page 7 Column 1).

xviii. Mathematical expressions in Fig. 7, Fig. 8, and Fig. 9 i.e. $V_{dc-error}$, $\Delta V_{dc-error}$, $and\ \bar{p}_{loss}$ have been in Italic font. (Page 7 Column 1 and Column 2).

xix. Mathematical expressions in Paragraph 1 i.e. $V_{dc-error}$ $\Delta V_{dc-error}$, $and\ \bar{p}_{loss}$ have been in Italic font. (Page 7 Column 2).

xx. Mathematical expressions in Eq. (14) have been in Italic font. (Page 7 Column 2).

b. Results and Discussion Section (Section 3)

i. Mathematical expressions in Paragraph 1 and Paragraph 2 i.e. R_1, R_1 , R_3 , C_1, C_2, C_3, (V_S), (V_L), (V_C), (I_S), (I_L), (V_{dc}), etc……have been in Italic font. (Page 8 Column 1).

ii. Mathematical expressions in Paragraph 1, Paragraph 2, and Paragraph 3 i.e. $(V_L)\ and\ (I_L)$ have been in Italic font. (Page 8 Column 2).

iii. Mathematical expressions in Paragraph 2 and Paragraph 3 i.e. V_S , V_L , I_S , I_L , V_C , and, V_{dc} have been in Italic font. (Page 9 Column 1).

iv. Mathematical expressions in Paragraph 1, Paragraph 2, Paragraph 3, and Paragraph 4 i.e. V_S , V_L , I_S , I_L , $V_C and$, V_{dc} have been in Italic font. (Page 9 Column 2).

v. Mathematical expressions in Paragraph 1 i.e. V_S , V_L , I_S , I_L , $V_C and$, V_{dc} have been in Italic font. (Page 10 Column 1 and Column 2).

vi. Mathematical expressions in Paragraph 2, Paragraph 3, and Paragraph 4 i.e. (P_S) , (P_{Se}) , (P_{Sh}), (P_L) , $(P_{PV}) and\ (P_{BES})$ have been in Italic font. (Page 17 Column 1).

vii. Mathematical expressions in Paragraph 1, Paragraph 2, Paragraph 3, and Paragraph 4 i.e. (P_S) , (P_{Se}) , (P_{Sh}), (P_L) , $(P_{PV}) and\ (P_{BES})$ have been in Italic font. (Page 17 Column 2).

c. Appendix Section

i. Mathematical expressions in Appendix Section i.e. $R_{S,}$ L_S, L_{Se}, L_{Sh}, etc……………………$(V_{dc-error})$, $(\Delta V_{dc-error})$ $and\ \bar{p}_{loss}$ have been in Italic font. (Page 19 Column 2).

Reviewer comment to the authors:

4. In Tables 3-5, the width is too wide. Improve the presentation of these tables.

   Answer:

   Thank you for your comment.

   a. I have revised width and font of Tables 3-5 depend on IJIES format (10 pt) below:
      i. Table 3. Voltage and current of 3P3W system using UPQC
      ii. Table 4. Voltage and current of 3P3W system using UPQC-PV
      iii. Table 5. Voltage and current of 3P3W system using UPQC-PV-BES

Reviewer comment to the authors:

5. Please improve the reference format. This is very important for indexing service. If you did not follow the following format, your paper will be rejected automatically.

   *Do not use “et al.” in author names. e.g.

   [1] R. Ruskone, S. Airault, and O. Jamet, “Vehicle Detection on Aerial Images”, *International Journal of Intelligent Engineering and Systems*, Vol.1, No.1, pp.123-456, 2009. (In the case of Journal Papers)

   [2] R. Ruskone, L. Guigues, S. Airault, and O. Jamet, “Vehicle Detection on Aerial Images”, In: *Proc. of International Conf. On Pattern Recognition*, Vienna, Austria, pp.900-904, 1996. (In the case of Conference Proceedings)

   *Note: e.g. In the case of the author name:"John Doe", express as "J. Doe". ("John" is the first name and "Doe" is the family name.)

   Answer:

   Thank you for your comment.

   The reference format has been improved below i.e.

   Note: The revision is highlighted by red font.

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Adding Revision by the authors:

6. Future work of this paper i.e.

   This research uses BES with 100% state of charge (SoC) or fully charged. The use of BES with varying SoC (0% to 99%) is proposed as future work to find out load active power transfer performance of UPQC-PV-BES system in unfully charged BES condition. (Conclussion, Page 20, Column 1, Paragraph 2, Red Font)

**) For Reviewer 1 and Reviewer 2:

1. Thanks a lot for your constructive comments.
2. We are appreciate for your kind guidance and valuable advices.

Lampiran 2.6

Hasil Revisi Makalah

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Load Active Power Transfer Enhancement Using UPQC-PV-BES System With Fuzzy Logic Controller

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Abstract: This paper presents enhancement of load active power transfer using Unified Power Quality Conditioner-Photovoltaic-Battery Energy Storage (UPQC-PV-BES) system. This system is connected to a three phase three wire (3P3W) system with a voltage of 380 V (line to line) and 50 hertz. The proposed model is also compared with UPQC and UPQC-PV respectively. The parameters investigated are load voltage, load current, load active power, and efficiency. BES functions to save excess energy generated by PV, distribute it to the load, avoid interruption voltage, and regulate the charging process and energy utilization. The fuzzy logic controller (FLC) is proposed and compared with proportional integral (PI) method to control DC voltage variable and input DC reference voltage, to produce a reference current source on hysteresis current controller on shunt active filter in 12 disturbance scenarios (scns). In Scenario (Scn) 1 to 5, the 3P3W system uses three combinations of UPQC with PI controller and FLC, still keeps load voltage and load current above 300 V and 8 A. Whereas in Scn 6, only the UPQC-PV-BES with FLC is able to maintain load voltage and load current higher compared to UPQC and UPQC-PV combinations as 304.1 V and 8.421 A, respectively. In Scn 1 to 5, the 3P3W system uses three combinations of UPQC with PI controller and FLC, capable of producing load active power above 3600 W. Whereas in Scn 6, only a combination of UPQC-PV-BES with PI controller and FLC is able to produce a load voltage of 3720 W and 3700 W, respectively. In Scn 1 to 6, UPQC-PV-BES results in lower efficiency compared to using UPQC and UPQC-PV. However, in Scn 6, UPQC-PV-BES with FLC is able to produce load voltage, load current, and load active power higher than UPQC-PV and UPQC. Thus, the UPQC-PV-BES model using FLC is able to compensate load voltage and load current, as well as to enhance load active power, especially for an interruption on source bus. This research is simulated using Matlab/Simulink.

Keywords: : Load Active Power Transfer, UPQC, PV, BES, FLC, Disturbance Scns

1. Introduction

The degradation 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 radiation intensity of 4.5 kWh/m^2 or equivalent to 112.000 GW.

Although, PV is able to generate power, this equipment also has disadvantage: it results in a number of voltage and current interferences, 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 was proposed. This device

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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 was 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 section was 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 section was responsible for overcoming current quality problems e.g. low power factor, load current harmonics, and unbalanced current. This device has a function of injecting current into AC system so that source current 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 radiation 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 keep 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 of the proposed model based auto tuned PI controller for PV-UPQC systems has been analyzed [4]. Online model optimization methodology was implemented for PV-UPQC to determine the best value of PI controller 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 show that they became 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 load voltage had been compensated and balanced so that the load voltage was kept constant by PV-UPQC.

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 succesfully to 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 hysteresis control in a 3P3W distribution system has been proposed [7]. This model is used to improve PQ and to reduce the burden of three-phase AC network by supplying power obtained from PV array. The UPQC system was able to supply reactive power needed to increase power factor, reduce voltage and current distortion and help inject active power by PV 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]. A 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 produced reactive power as required by load so that it could improve an input power factor and reduce THD of source current.

Artificial neural network (ANN) 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 has been proposed [9]. The proposed model has succesfully mitigated harmonics/reactive currents, unbalanced source and load, and unbalanced current/voltage. The weakness of neural network (NN) requires time for learning (training) and testing process, so that it produces longer control responses when determining output variables. Investigation on PQ 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 has been conducted [10]. The simulation showed that FLC on UPQC and PV can improve THD voltage source better than PI.

The improvement of PQ using UPQC on microgrid supplied by PV and wind turbine has 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 BES in UPQC supplied by PV to improve PQ in 3P3W distribution systems using FLC validated PI controller on various disturbances in source and load side has been investigated [12]. The research

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showed that FLC on UPQC-BES supplied by PV was able to significantly reduce source current harmonics and load voltage harmonics in number of disturbances, especially in interruption voltage disturbance on source bus. The grid-connected UPQC combined with a PV generator was proposed by [13] using a converter topology and by [14] using dual UPQC applied to three phase four wire (3P4W) system. Both researchs showed that the topology had the capacity to compensate for network disturbances, inject power generated by PV panels under different operating conditions, and was able to compensate THD voltage on load bus and THD current on source bus. Research on biogeography-based optimization with harmonic elimination techniques for modification of UPQC connected to smartgrid has been carried out [15]. Low-order harmonics are eliminated by choosing the right switching angle and at the same time high-order harmonics are suppressed by injecting the same harmonics magnitude but opposite the phase by other converters. Excitation from the UPQC converter modification is obtained from the PV panel. The firing angle of shunt-series converter is obtained in real-time from an angle already stored in the microcontroller memory.

The previous research on UPQC-PV which has been carried out aims to compensate for sag/swell voltage on source bus, to reduce THD caused by distorted supply and non-linear loads, as well as to mitigate unbalanced loads. However, this combination has several disadvantages. This system is unable to overcome voltage interruption in source bus if PV power connected to UPQC DC-link circuit is insufficient to meet load power and the duration of interruption (momentary) exceeds 3 seconds base on limit IEEE 1159-1995 Standard. This research proposes enhancement of load active power transfer using UPQC-PV-BES system that is connected to a 3P3W system with a voltage of 380 V (line to line) and 50 hertz. The effectiveness of the proposed model is validated with UPQC and UPQC-PV, respectively. BES functions to store excess energy generated by PV, distribute it to the load if necessary, prevent interruption voltage, and regulate the charging process and energy utilization. BES is also expected to be able to save surplus power generated by PV and be used as a backup power. The FLC is proposed and compared with PI method to control DC voltage variable and input DC reference voltage to produce a reference current source on hysteresis current controller on active shunt filter in 12 disturbance scns. The FLC is proposed and compared with PI, because it has a weakness in determining proportional and integral gain constants which remain using trial and error method. The parameters observed are voltage and current on source bus, voltage and current on load bus, source active power, series active power transfer, shunt active power, load active power, PV power, and BES power. The next step is to determine efficiency value of each UPQC combination to show which circuit has a higher performance in enhancing of load active power transfer and in maintaining of load voltage and load current.

This paper is presented as follow. Section 2 explains proposed method, UPQC-PV-BES system model, parameter simulation, PV circuit model, active series and shunt filter control, application of PI controller and FLC, as well as UPQC efficiency for proposed model. Section 3 shows results and discussion of load voltage, load current, source active power transfer, load active power transfer, series active power transfer, shunt active power transfer, PV power, BES power using FLC validated with PI controller. In this section, six disturbance scns are presented and the results are verified with Matlab/Simulink. Finally, this paper is concluded in Section 4. Table 1 shows the abbreviations used in this paper.

Table 1. Abbreviation

Symbol	Description
UPQC	Unified Power Quality Conditioner
PV	Photovoltaic
BES	Battery Energy Storage
RE	Renewable Energy
DG	Distributed Generation
FLC	Fuzzy Logic Controller
PI	Proportional Integral
NL	Non Linear Load
MPPT	Maximum Power Point Tracking
3P3W	Three Phase Three Wire
3P4W	Three Phase Four Wire
P and O	Perturb and Observe
CBs	Circuit Breakers
FIS	Fuzzy Inference System
MFs	Membership Functions
Scn	Scenario

2. Research Method

2.1. Proposed Method

Fig. 1 shows the proposed model of PV connected to a 3P3W with 380 V (line-line) and 50 hertz, through a series of DC links UPQC and BES. The PV generator raises DC power at a constant temperature and solar radiation level (1000 W/m^2 and 25^0 C) and is connected to BES through DC/DC boost converter circuit. The MPPT method with P and O algorithm helps PV to produce peak power, generate an output voltage, which then become an

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input voltage for DC/DC boost converter. The boost converter functions to adjust duty cycle value with PV output voltage as an input voltage to result an output voltage according to DC-link voltage. BES is connected to the DC-link which serves as energy storage and is expected to inject power to keep load voltage and load active power, especially for an interruption voltage from source bus.

Investigation of the proposed model is carried out on three UPQC combinations connected to 3P3W (on-grid) system via a DC link circuit. The three combinations are UPQC, UPQC-PV, and UPQC-PV-BES. Two single phase circuit breakers (CBs) are used to connect and disconnect PV and BES to UPQC DC-link. Each combination of circuit in each condition consists of six disturbance scns i.e. NL (Non-Linear Load), Unbalance-NL (Unba-NL), Distorted-NL (Dis-NL), Sag-NL, Swell-NL, and Interruption-NL (Inter-NL). FLC is used as DC voltage control on shunt active filter to fix PQ in each fault scn and the results are validated with PI control. Each scn in UPQC uses PI and FLC controller so that the total number of disturbances are 12. The measured parameters are voltage and current on the source bus, voltage and current on the load bus, source active power, series active power transfer, shunt active power, load active power, PV power, and BES power. The next step is to determine nominal of efficiency of each UPQC combination to show the circuit that has superior performance in maintaining load voltage, load current, and load active power under six disturbance scns. Fig. 2 shows active power transfer using UPQC-PV-BES. Simulation parameters for the proposed model is shown in appendix section.

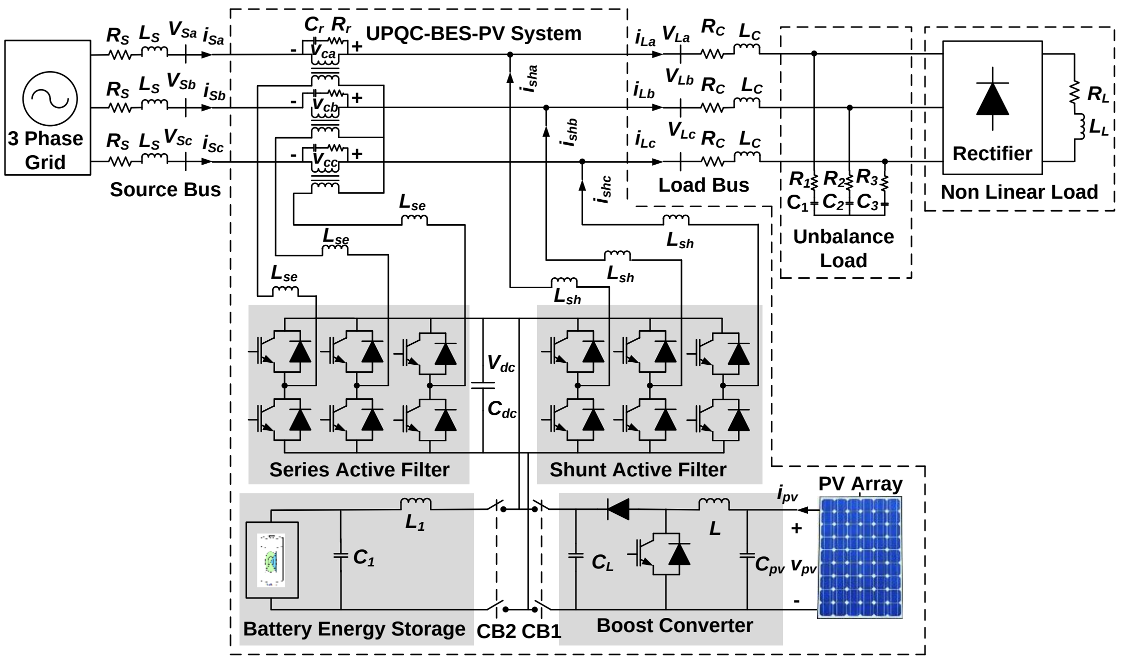

Figure 1. Proposed model using UPQC-PV-BES

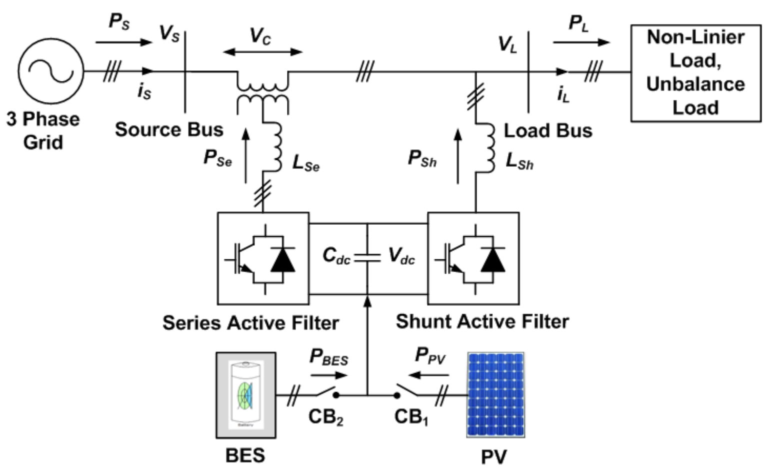

Figure 2. Active power transfer using UPQC-PV-BES system

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2.2. Modelling of Photovoltaic

The equivalent circuit of solar panel is shown in Fig. 3. It consists of several PV cells which have external connections in series, parallel, or series-parallel [16].

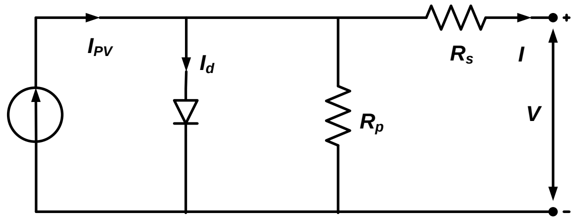

Figure 3. Equivalent circuit of solar panel

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

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

Where I_{PV} is PV current, I_o is saturated re-serve current, 'a' is the ideal diode constant, $Vt = N_S K T q^{-1}$ is thermal voltage, N_S is number of series cells, q is electron charge, K is Boltzmann constant, T is 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 variation. Eq. (2) and Eq. (3) are the calculation of I_{PV} and I_o values:

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

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

Where $I_{PV,n}$, $I_{SC,n}$, and $V_{OC,n}$ are the photovoltaic 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 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.

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

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

2.3. Series Active Filter Control

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

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

The 3 phase lock loop (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. Then, the load reference voltage $(V_{La}^*, V_{Lb}^*, V_{Lc}^*)$ is compared with sensed load voltage (V_{La}, V_{Lb}, V_{Lc}) with a pulse width modulation (PWM) controller which is used to raise the desired trigger signal in series active filter. Fig. 4 shows control of series active filter.

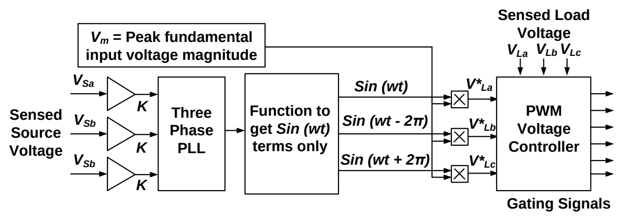

Figure 4. Series active filter control

2.4. Shunt Active Filter Control

The shunt active filter has the main function 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 NL, many algorithms have been used in some literatures. This research uses the method of instantaneous reactive power theory or "p-q theory". The voltages and currents modeled in Cartesian coordinates can be transformed into Cartesian coordinates $\alpha\beta$ in Eq. (7) and Eq. (8) [6].

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

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

Eq. (9) shows calculation of real power (p) and imaginary power (q). The real and imaginary power are determined in instantaneously power and expressed in matrix form. Eq. (10) shows instantaneous section (mean and fluctuating) [17].

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

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

Where $\bar{p}$ = the average section of real power, $\tilde{p}$ = the fluctuating section of real power, $\bar{q}$ = the average section of imaginary power, $\tilde{q}$ = the fluctuating section of imaginary power. The total imaginary power (q) and fluctuating section of real power are selected as power and current references and are utilized through the use of Eq. (10) to compensate harmonics and reactive power [18].

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

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 FLC, 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. (11). The current is expressed in coordinates α-β. The compensation current is used to obtain source phase current by using Eq. (12) 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 [17]. Fig. 5 show shunt active filter control [18].

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

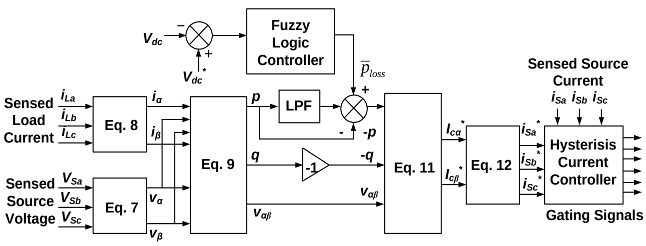

Figure 5. Shunt active filter control

The UPQC-PV-BES system must have a minimum DC-link (V_{dc}) voltage in order to operate properly. The general DC-link voltage value depends on the instantaneous energy that can be generated by UPQC which is defined in Eq.13 [19]:

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

Where m is the modulation index and V_{LL} is the voltage of UPQC. Considering 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 source current reference $(i_{sa}^*, i_{sa}^*, i_{sa}^*)$. Then, the reference of 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, FLC as a DC voltage control algorithm on shunt active filter is proposed and compared with PI controller. FLC is able to reduce oscillations and to produce calculations with rapid convergence during interference. This method is also used to overcome the weaknesses of PI controller in determining proportional gain constants (K_P) and integral gain constants(K_I), which remain using the trial and error method.

2.5. Fuzzy Logic Controller

This research starts by determining $\bar{p}_{loss}$ as an input variable, to produce a reference source current on the hysteresis current control and to generate a trigger signal on the shunt active IGBT filter circuit from UPQC with PI control $(K_P = 0.2$ and and $(K_I = 0.2)$. Using the same procedure, $\bar{p}_{loss}$ is also determined using FLC. This method has been widely used in industrial processes today because it has heuristic properties, is simpler and more effective, and has multi-rule-based variables in both linear and non-linear system. The FLC sections comprise fuzzification, decision making (rulebase, database, reason mechanism) and defuzzification in Fig. 6. The fuzzy rules algorithm collects a number of fuzzy control rules in a particular order. These rules are used to control the system so that it meets the desired performance requirements and they are designed from a number of intelligent control system knowledge. Fuzzy inference system (FIS) in FLC uses Mamdani Method with a max-min composition relationship. FIS consists of three parts i.e. rulebase, database, and reason-mechanism [20].

The FLC method is applied by determining input variables i.e. V_{dc} error $(V_{dc-error})$, delta V_{dc} error $(\Delta V_{dc-error})$, seven fuzzy linguistic pairs, fuzzy operating system blocks, $V_{dc-error}$ and $\Delta V_{dc-error}$ during seven fuzzy linguistic sets, fuzzy operating system blocks, $V_{dc-error}$ and $\Delta V_{dc-error}$ during fuzzification process, fuzzy rule base, as well as crips value to determine $\bar{p}_{loss}$ in defuzzification.

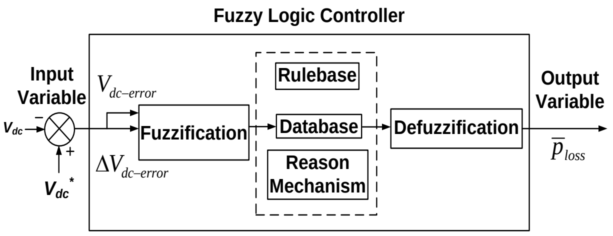

Figure 6. Block diagram of FLC

The value of $\bar{p}_{loss}$ is one of the input variables to obtain the compensation current $(i^{*}_{c\alpha}, i^{*}_{c\beta})$ in Equation (16). During the fuzzification process, a number of input variables are calculated and converted into linguistic variables based on a subset called the membership function. The $V_{dc-error}$ and $\Delta V_{dc-error}$ are proposed as input variables with $\bar{p}_{loss}$ system output variables. In order to translate these variables, each input and output variable is designed using seven membership functions (MFs) i.e. Negative Big (NB), Negative Medium (NM), Negative Small (NS), Zero (Z), Positive Small (PS), Positive Medium (PM) and Positive Big (PB). The membership functions of input and output crips are presented with triangular and trapezoidal membership functions. The $V_{dc-error}$ ranges from -650 to 650, $\Delta V_{dc-error}$ from -650 to 650, and $\bar{p}_{loss}$ from -100 to 100. The input and output MFs are shown in Fig. 7, Fig. 8, and Fig. 9.

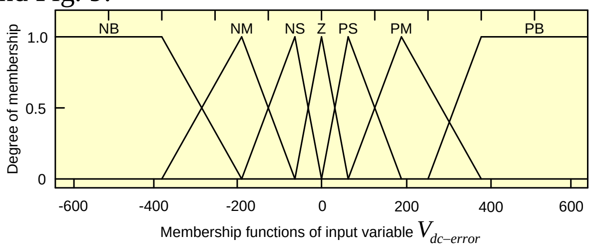

Figure 7. Input MFs of $V_{dc-error}$

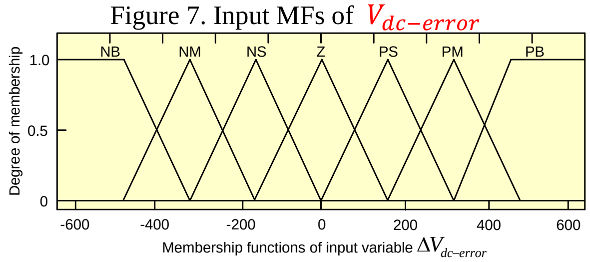

Figure 8. Input MFs of $\Delta V_{dc-error}$

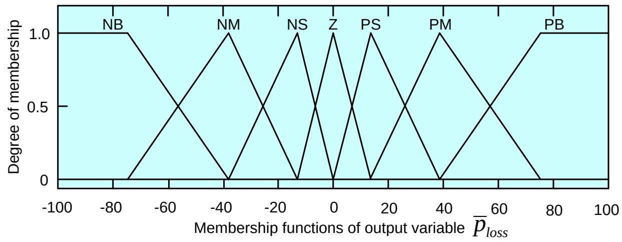

Figure 9. Output MFs of $\bar{p}_{loss}$

Table 2. Fuzzy Rule Base

$V_{dc-error}$ / $\Delta V_{dc-error}$	NB	NM	NS	Z	PS	PM	PB
PB	Z	PS	PS	PM	PM	PB	PB
PM	NS	Z	PS	PS	PM	PM	PB
PS	NS	NS	Z	PS	PS	PM	PM
Z	NM	NS	NS	Z	PS	PS	PM
NS	NM	NM	NS	NS	Z	PS	PS
NM	NB	NM	NM	NS	NS	Z	PS
NB	NB	NB	NM	NM	NS	NS	Z

After $V_{dc-error}$ and $\Delta V_{dc-error}$ are obtained, two input MFs are subsequently converted into linguistic variables and used as input function for FLC. The output MF is generated using inference block and basic rules of FLC as shown in Table 2. Then, defuzzification block finally operates to change $\bar{p}_{loss}$ output generated from the linguistic variable to numeric again. The value of $\bar{p}_{loss}$ then becomes the input variable for current hysteresis control to produce a trigger signal in the IGBT circuit of UPQC shunt active filter to reduce source current harmonics and load voltage harmonics. Simultaneously, it also improves PQ of 3P3W system under six disturbance scns of three combination model i.e. UPQC, UPQC-PV, and UPQC-PV-BES, respectively.

2.6. UPQC-PV-BES Efficiency

The 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 [21]. In this paper, it is found that the implementation of UCES is able to help system reduce source current compensation when sag voltage is 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 capable of generating losses and efficiency system. Using the same procedure, the authors propose Eq. (14) for efficiency of UPQC-PV-BES in the formula below.

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

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3. Results and Discussion

The proposed model is determined using three UPQC combinations connected to 3P3W system (on-grid) via a DC link circuit. The three combinations are UPQC, UPQC-PV, and UPQC-PV-BES. Two single phase CBs are used to connect and disconnect PV and BES circuit to UPQC-DC link circuit. Each combination of sequences of each condition consists of six disturbance scns, i.e. NL, Unba-NL, Dis-NL, Sag-NL, Swell-NL, and Inter-NL. In Scn 1, the system is connected to non-linear loads with R and L values of 60 Ohms and 0.15 mH, respectively. In Scn 2, the system is connected to non-linear loads for 0.3 s since t = 0.2 s to t = 0.5 s and also connected to three phase unbalanced load with values R_1, R_2 and R_3 of 6, 12, and 24 Ohm respectively and C_1, C_2 and C_3 of 2.2 μF. In Scn 3, the system is connected to non-linear load and distorted voltage sources which results in 5th and 7th harmonics with individual harmonics distortion values of 5% and 2%, respectively. In Scn 4, the system is connected to a non-linear load and the source experiences a 50% sag voltage disturbance for 0.3 s between t = 0.2 s to t = 0.5 s. In Scn 5, the system is connected to a non-linear load and the source experiences a 50% swell voltage disturbance for 0.3 s between t = 0.2 s to t = 0.5 s. In Scn 6, the system is connected to a non-linear load and the source experiences 100% an interruption voltage for 0.3 s between t = 0.2 s to t = 0.5 s. Each combination uses an UPQC control with a FLC validated by PI so that there are 12 scns in total.

Then, using Matlab/Simulink, each combination model is run according to the desired scn to obtain the curve of source voltage (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 based on the value of each phase voltage and current parameters previously obtained. The next process is determining the value of power transfer of source active power (P_S), series active power (P_{Se}), shunt active power (P_{Sh}), load active power (P_L) PV power (P_{PV}), and BES power (P_{BES}). The measurement of nominal of voltage and current on source and load bus, UPQC power transfer, PV power, and BES are determined in one cycle starts at t = 0.35 s. The results of the average source voltage, source current, load voltage, and load current on the three proposed UPQCs are presented in Table 3, Table 4, and Table 5.

Table 3 shows that in Scn 1 to 5, the 3P3W system using UPQC with PI control is still able to maintain the average load voltage (V_L) between 309.9 to 310.6 V. But in Scn 6, average load voltage drops to 169.1 V. In the same system and scns 1 to 5 using FLC control, average load voltage rises slightly from 310.0 to 310.4 V. But in Scn 6, the average load voltage drops to 160.4 V. Table 3 also shows that in scns 1 to 5, the 3P3W system using UPQC with PI control is still able to maintain the average load current (I_L) between 8,585 to 8,634 A. But in Scn 6, the average load current drops to 4,578 A. On the same system and Scn 1 to 5 using FLC control, the average load current rises slightly from 8,587 to 8,623 A. But in Scn 6, the average load current drops slightly to 4,337 A.

Table 4 shows that in Scn 1 to 5, the 3P3W system using UPQC-PV with PI control is still able to keep the average load voltage (V_L) between 310.0 to 310.5 V. However, in Scn 6, the average load voltage drops to 240.4 V. In the system and with Scn 1 through 5 using FLC control, the average load voltage rises slightly from 310.1 to 310.5 V. But in Scn 6, the average load voltage drops to 215.4 V. Table 4 also shows that in Scn 1 to 5, the 3P3W system using UPQC with PI control is still able to maintain the average load current (I_L) of 8,586 to 8,627 A. But in Scn 6, the average load current drops to 6,477 A. In the same system and Scn 1 to 5 using FLC control, the average load current rises slightly from 8,578 to 8,635 A. But in Scn 6, the average load current drops significantly to 5,921 A.

Table 5 shows that in Scn 1 to 5, the 3P3W system using UPQC-PV-BES with PI control is still able to maintain the average load voltage (V_L) between 307.2 to 308.2 V. However, in Scn 6, the average load voltage drops to 286.7 V. In the same system and Scn 1 to 6 using FLC control, the average load voltage rises slightly from 304.1 to 314.1 V. Table 5 also shows that in Scn 1 to 6, the 3P3W system using UPQC with PI control is still able to maintain the average load current (I_L) of 8,031 to 8,746 A. In the same system and Scn 1 to 6 using FLC, the average load curren rises slightly from 8,421 to 8,718 A.

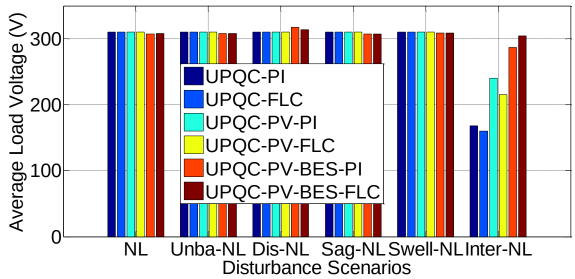

Figure 10. Performance of load voltage using three UPQC combinations in six fault scns

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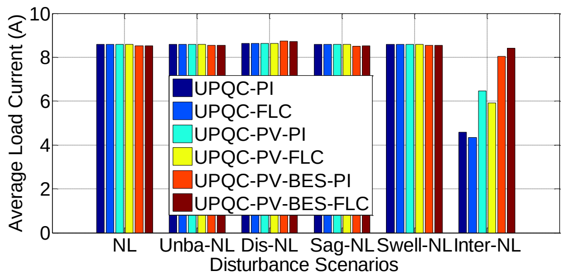

Figure 11. Performance of load current using three UPQC combinations in six fault scns

Fig. 10 shows performance of load voltage and Fig. 11 shows performance of load current from the 3P3W system using three UPQC combinations in six disturbance scns with PI control and FLC.

Fig. 10 shows that in Scn 1 to 5, the 3P3W system using three combinations of UPQC with PI control and FLC is able to maintain load voltage (V_L) above 300 V. Whereas in Scn 6, only a combination of UPQC-PV-BES with FLC is able to generated load voltage (V_L) is 304.1 V. Fig. 11 shows that in Scn 1 to 5, the 3P3W system uses three combinations of UPQC with PI controller and FLC is able to maintain load current (I_L) above 8 A. Whereas in Scn 6, only the UPQC-PV-BES combination with PI control and FLC is capable of generating load current (I_L) of 8.031 A and 8.421 A, respectively. Therefore, in Scn 6, the combination of UPQC-PV-BES with FLC provides better load voltage (V_L) and load current (I_L) performance than both the UPQC and UPQC-PV combination.

Fig. 12 shows the performance of UPQC combinations using FLC: (a) UPQC, (b) UPQC-PV, (c) (UPQC-PV-BES in Scn 4 (Sag-NL). Fig. 13 shows same performance of UPQC combinations using FLC: (a) UPQC, (b) UPQC-PV, (c) (UPQC-PV-BES using FLC but in Scn 6 (Inter-NL). Fig. 12.a.i shows in Scn 4 of the UPQC combination at t = 0.2 s to t = 0.5 s, the average source voltage (V_S) drops by 50% from 310.1 V to 153.4 V. During sag period, the average source current (I_S) increases to 16.39 A (Fig. 12.a.iv) to compensate for reduction in load power and to maintain the average load voltage (V_L) of 310.1 (Fig. 12.a.ii). The series active filter then supplies power to the load through the UPQC DC-link circuit and injects a compensation voltage (V_C) of 156.7 V (Fig. 12.a.iii) through the injection transformer. At the same time, FLC of an active shunt filter works to keep the DC voltage (V_{dc}), stable the average current source (V_{dc}), increases approach to 16.39 A (Fig. 12.a.iv.) to maintain the average current (I_L) remain stable at 8.588 A (Fig. 12.a.v).

Fig. 12.b.i shows in Scn 4 of the UPQC-PV combination at t = 0.2 s to t = 0.5 s, the average source voltage (V_S) drops by 50% from 310.1 V to 153.8 V. During sag period, the average source current increases slightly to 13.51 A (Fig. 12.b.iv) because PV generates power to the load through DC-link of an series active filter by injecting voltage compensation voltage (V_C) of 153.8 V (Fig. 12.b.iii) through an injection transformer in series active filter so that the average load voltage (V_L) remains stable at 310.1 V (Fig. 12.b.ii). At the same time, FLC on an active shunt filter works to keep DC voltage (V_{dc}), stable and the average current source (I_S), increases close to 13.51 A (Fig. 12.b.iv.) to maintain the average load current (I_L) remain stable at 8.578 A (Fig. 12.b.v).

Fig. 12.c.i also shows that the UPQC-PV-BES combination in Scn 4 indicates almost the same performance on an average V_C, V_L, and I_L values as presented in Fig. 12.c.iii, Fig. 12.c.ii, and Fig. 12.c.v The difference is that the average I_S slightly decreases to 8,561 A (Fig. 12.c.iv) because part of reduction in load power has been compensated by power transfer from PV-BES combination to the load through DC-link of series active filter and from an shunt active filter towards the load. The use of BES is able to prove that in addition to being able to store excess power from PV, this combination is also able to inject current into the load through the DC-link (Fig. 12.c.vi) to produce the average I_L remaining stable at 8.515 A (Fig. 12.c.v).

Fig. 13 shows the performance of UPQC combinations using FLC in Scn 6 (Inter-NL). Fig. 13.a.i shows that in Scn 6 of UPQC at t = 0.2 s to t = 0.5 sec, the average V_S drops by 100% to 1,270 V. Under this condition, the capacitor in UPQC DC-link is unable to produce maximum power and inject average V_C (Fig. 13.a.iii) through an injection transformer in series active filter. So at t = 0.2 s to t = 0.5, the average V_L in Fig. 13.a.ii decreases to 160.4 V. During interruption period, implementation of the FLC to shunt active filter is unable to maintain V_{dc} (Fig. 13.a.vi) and the average V_C constantly, which causes the average I_L to also decrease to 4.337 A (Fig. 13.a.v).

Fig. 13.b.i shows that in Scn 6 of UPQC-PV combination at t = 0.2 s to t = 0.5 s, the average V_S drops by 100% to 1,358 V. Under this condition, UPQC-PV is unable to generate maximum power to UPQC DC link and inject and average V_C in Fig. 13.a.iii through an injection transformer in series active filter so at t = 0.2 s to t = 0.5 s, the average V_L in Fig. 13.b.ii decreases to 215.4 V. During interruption, application of FLC to shunt active filter

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is unable to maintain V_{dc} (Fig.13.b.vi) and the average V_C to remain constant, so an average I_L is also decrease to 5,921 A (Fig. 13.b.v).

Fig. 13.c.i shows that the average V_S also drops 100% to 0.4062 V in the UPQC-PV-BES combination at t = 0.2 s to t = 0.5 s. During interruption period, the UPQC-PV-BES is able to generate power to UPQC DC-link and to inject the average V_C (Fig.13.c.iii) through injection transformer in series active filter so that the average V_L remains stable at 304.1 V (Fig. 13.c.ii). Even though the average I_S drop to 3.804 A during interruption period, the UPQC-PV-BES combination is able to generate power, store excess energy from PV, and allow current to load through shunt active filter so that I_L remains constant at 8,421 A (Fig. 13. c.v).

Table 3. Voltage and current of 3P3W system using UPQC

Scn	Source Voltage V_S (Volt)				Load Voltage V_L (Volt)				Source Current I_S (Ampere)				Load Current I_L (Ampere)			
	A	B	C	Avg	A	B	C	Avg	A	B	C	Avg	A	B	C	Avg
PI Controller																
1	309.5	309.5	309.5	**309.5**	310.0	310.0	310.0	**310.0**	8.741	8.728	8.751	**8.740**	8.585	8.586	8.586	**8.586**
2	309.5	309.5	309.5	**309.5**	310.1	310.0	310.0	**310.0**	8.733	8.750	8.749	**8.744**	8.588	8.586	8.585	**8.586**
3	309.5	309.5	309.5	**309.5**	309.1	312.6	310.1	**310.6**	8.855	8.772	8.801	**8.809**	8.539	8.769	8.595	**8.634**
4	153.4	153.4	153.4	**153.4**	310.1	310.1	310.1	**310.1**	16.42	16.39	16.42	**16.41**	8.588	8.588	8.588	**8.588**
5	464.6	464.6	464.6	**464.6**	309.9	309.9	309.9	**309.9**	8.380	8.388	8.380	**8.383**	8.585	8.585	8.584	**8.585**
6	1.017	0.982	1.014	**1.004**	173.5	161.2	169.5	**168.1**	9.479	9.353	9.027	**9.286**	4.866	4.465	4.404	**4.578**
Fuzzy Logic Controller																
1	309.5	309.5	309.5	**309.5**	310.0	310.0	310.0	**310.0**	8.679	8.721	8.720	**8.706**	8.587	8.587	8.585	**8.586**
2	309.5	309.5	309.5	**309.5**	310.0	310.0	310.0	**310.0**	8.713	8.687	8.700	**8.700**	8.586	8.587	8.588	**8.587**
3	309.5	309.5	309.5	**309.5**	308.9	311.6	310.5	**310.4**	8.816	8.703	8.703	**8.741**	8.533	8.734	8.603	**8.623**
4	153.4	153.4	153.4	**153.4**	310.1	310.1	310.1	**310.1**	16.39	16.38	16.41	**16.39**	8.588	8.588	8.588	**8.588**
5	464.6	464.7	464.7	**464.7**	310.0	310.0	310.0	**310.0**	8.356	8.353	8.357	**8.355**	8.587	8.587	8.586	**8.587**
6	1.135	1.377	1.299	**1.270**	141.4	172.2	167.4	**160.4**	10.22	12.23	13.27	**11.91**	3.718	4.438	4.855	**4.337**

Table 4. Voltage and current of 3P3W system using UPQC-PV

Scn	Source Voltage V_S (Volt)				Load Voltage V_L (Volt)				Source Current I_S (Ampere)				Load Current I_L (Ampere)			
	A	B	C	Avg	A	B	C	Avg	A	B	C	Avg	A	B	C	Avg
PI Controller																
1	309.5	309.5	309.5	**309.5**	310.0	310.0	310.0	**310.0**	8.828	8.838	8.858	**8.841**	8.586	8.586	8.585	**8.586**
2	309.5	309.5	309.5	**309.5**	310.0	310.0	310.0	**310.0**	8.756	8.774	8.745	**8.758**	8.585	8.588	8.585	**8.586**
3	309.5	309.5	309.5	**309.5**	308.5	312.1	310.5	**310.5**	8.936	8.863	10.73	**9.510**	8.522	8.757	8.601	**8.627**
4	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**
5	464.4	464.4	464.4	**464.4**	310.1	310.1	310.1	**310.1**	8.457	8.468	8.460	**8.462**	8.558	8.590	8.558	**8.587**
6	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**

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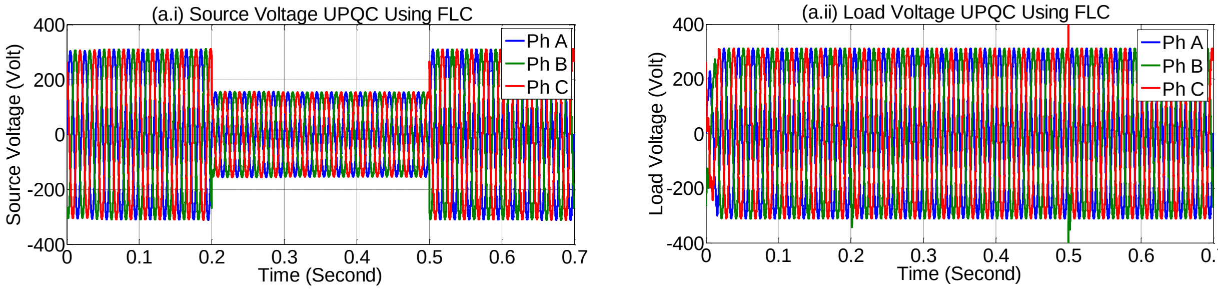
Table 4. Voltage and current of 3P3W system using UPQC-PV (Continue)

Fuzzy Logic Controller																
1	309.5	309.5	309.5	**309.5**	310.1	310.1	310.0	**310.1**	8.769	8.738	8.811	**8.773**	8.578	8.588	8.587	**8.584**
2	309.5	309.5	309.5	**309.5**	310.0	310.0	310.0	**310.1**	8.674	8.682	8.674	**8.677**	8.587	8.587	8.588	**8.587**
3	309.4	309.5	309.5	**309.5**	309.6	312.1	309.9	**310.5**	8.938	8.820	8.916	**8.891**	8.552	8.766	8.586	**8.635**
4	153.8	153.8	153.8	**153.8**	310.1	310.0	310.1	**310.1**	13.52	13.46	13.56	**13.51**	8.558	8.587	8.589	**8.578**
5	464.4	464.7	464.7	**464.7**	310.1	310.1	310.1	**310.1**	8.353	8.371	8.365	**8.363**	8.591	8.588	8.587	**8.589**
6	1.259	1.285	1.530	**1.358**	209.9	193.7	242.7	**215.4**	13.28	11.49	14.07	**12.95**	6.459	5.003	6.299	**5.921**

Table 5. Voltage and current of 3P3W system using UPQC-PV-BES

Scn	**Source Voltage V_S (Volt)**				**Load Voltage V_L (Volt)**				**Source Current I_S (Ampere)**				**Load Current I_L (Ampere)**			
	A	**B**	**C**	**Avg**	**A**	**B**	**C**	**Avg**	**A**	**B**	**C**	**Avg**	**A**	**B**	**C**	**Avg**
PI Controller																
1	309.6	309.6	309.6	**309.6**	307.6	307.8	307.7	**307.7**	7.766	7.793	7.759	**7.773**	8.528	8.529	8.533	**8.530**
2	309.6	309.6	309.6	**309.6**	307.8	307.9	307.9	**307.9**	7.787	7.801	7.779	**7.789**	8.531	8.533	8.537	**8.534**
3	309.6	309.6	309.6	**309.6**	313,8	314.3	317.4	**317.4**	7.897	7.919	7.867	**7.895**	8.748	8.704	8.785	**8.746**
4	154.5	154.5	154.5	**154.5**	307.1	307.3	307.3	**307.2**	7.235	7.276	7.226	**7.246**	8.509	8.514	8.510	**8.511**
5	464.7	464.7	464.7	**464.7**	308.6	308.7	308.6	**308.6**	7.979	7.980	7.964	**7.975**	8.550	8.553	8.554	**8.553**
6	0.5359	1.385	0.8501	**0.9238**	310.2	259.8	290.2	**286.7**	7.392	12.67	6.045	**8.703**	8.707	7.747	7.637	**8.031**
Fuzzy Logic Controller																
1	309.5	309.5	309.5	**309.5**	307.7	307.9	307.7	**307.8**	8.420	8.426	8.416	**8.421**	8.527	8.532	8.531	**8.530**
2	309.5	309.5	309.5	**309.5**	307.9	308.0	307.9	**307.9**	8.402	8.403	8.401	**8.402**	8.535	8.539	8.536	**8.537**
3	309.6	309.5	309.5	**309.5**	313.4	312.9	315.9	**314.1**	8.516	8.565	8.496	**8.526**	8.741	8.677	8.736	**8.718**
4	154.4	154.4	154.4	**154.4**	307.3	307.3	307.2	**307.3**	8.563	8.560	8.561	**8.561**	8.514	8.517	8.512	**8.515**
5	464.6	464.6	464.6	**464.6**	308.6	308.8	308.6	**308.7**	8.396	8.389	8.389	**8.392**	8.552	8.556	8.554	**8.554**
6	0.4467	0.3918	0.3801	**0.4062**	314.0	293.4	304.9	**304.1**	4.024	3.778	3.608	**3.804**	8.874	8.195	8.193	**8.421**



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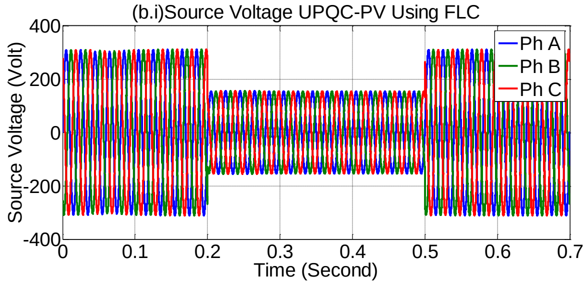
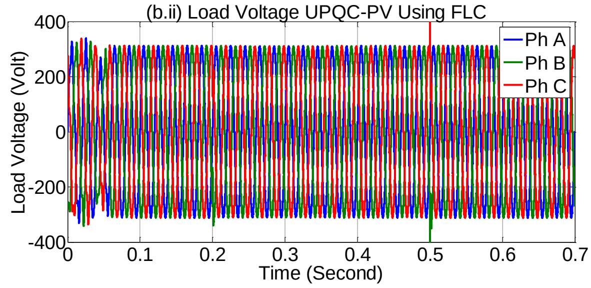
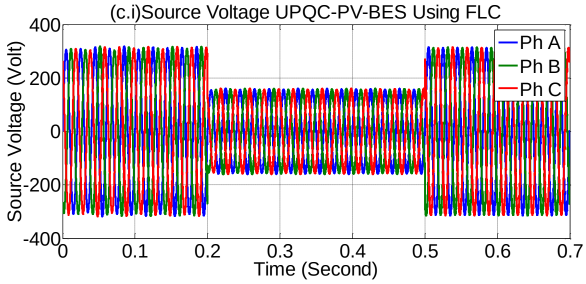
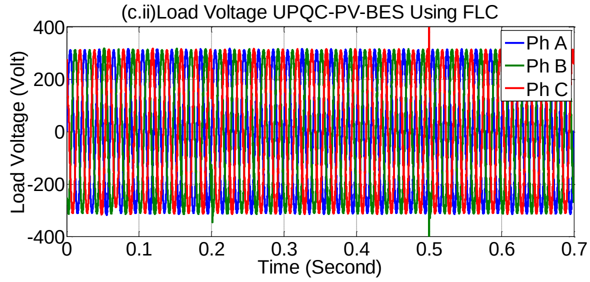
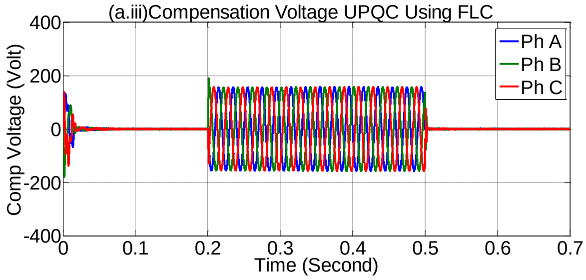
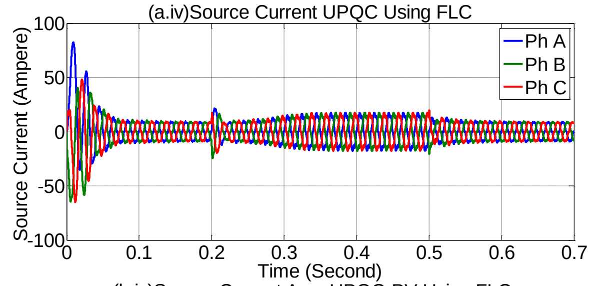


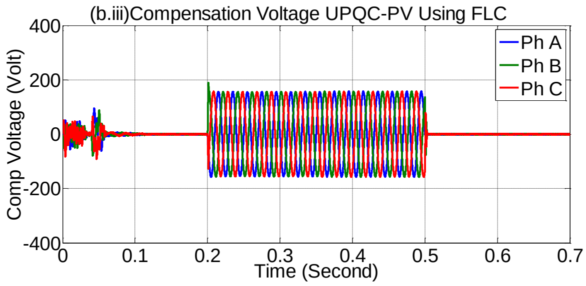


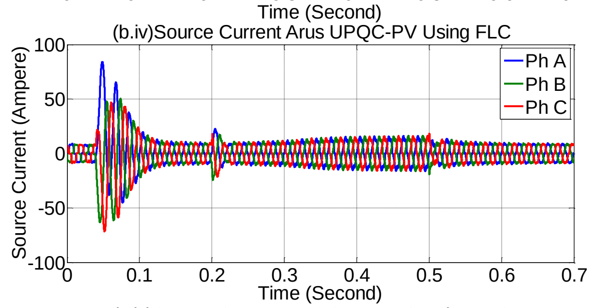


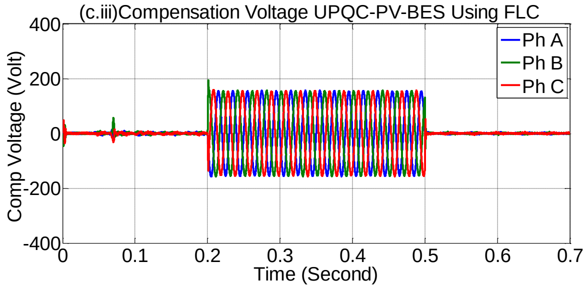


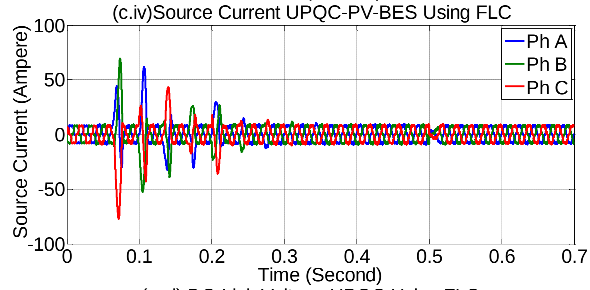


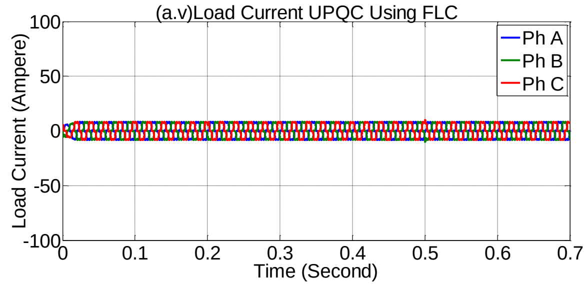


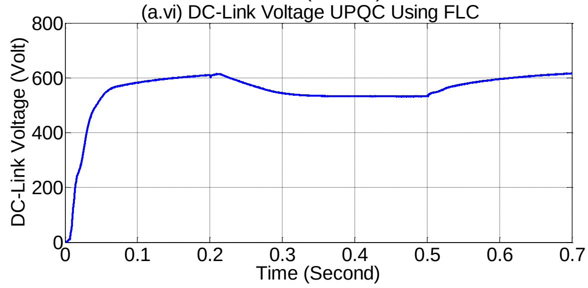












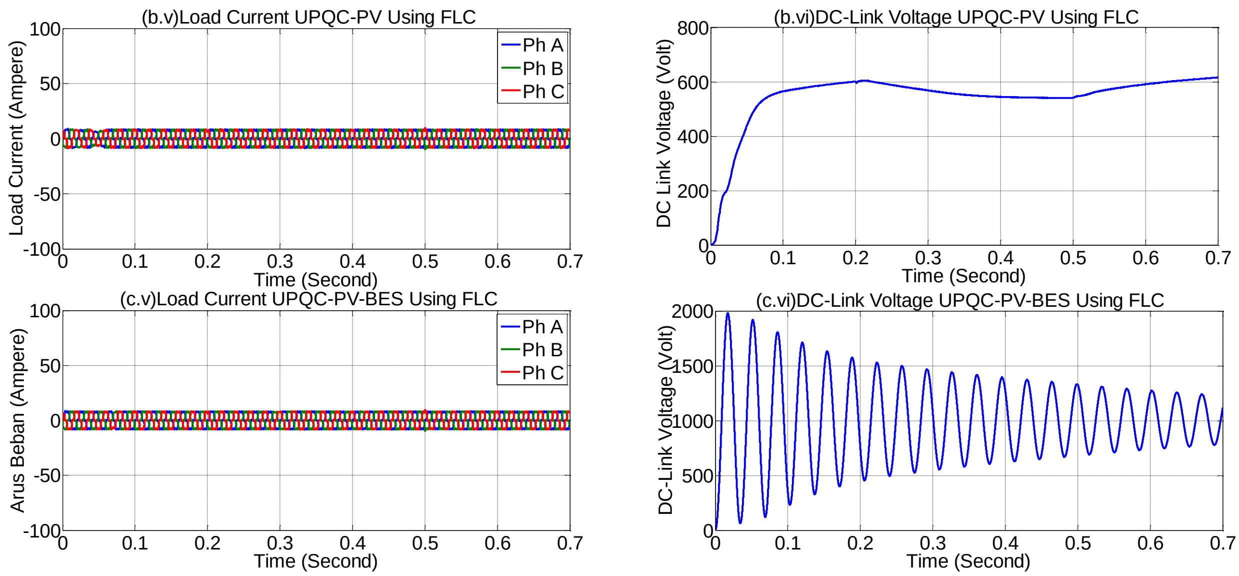
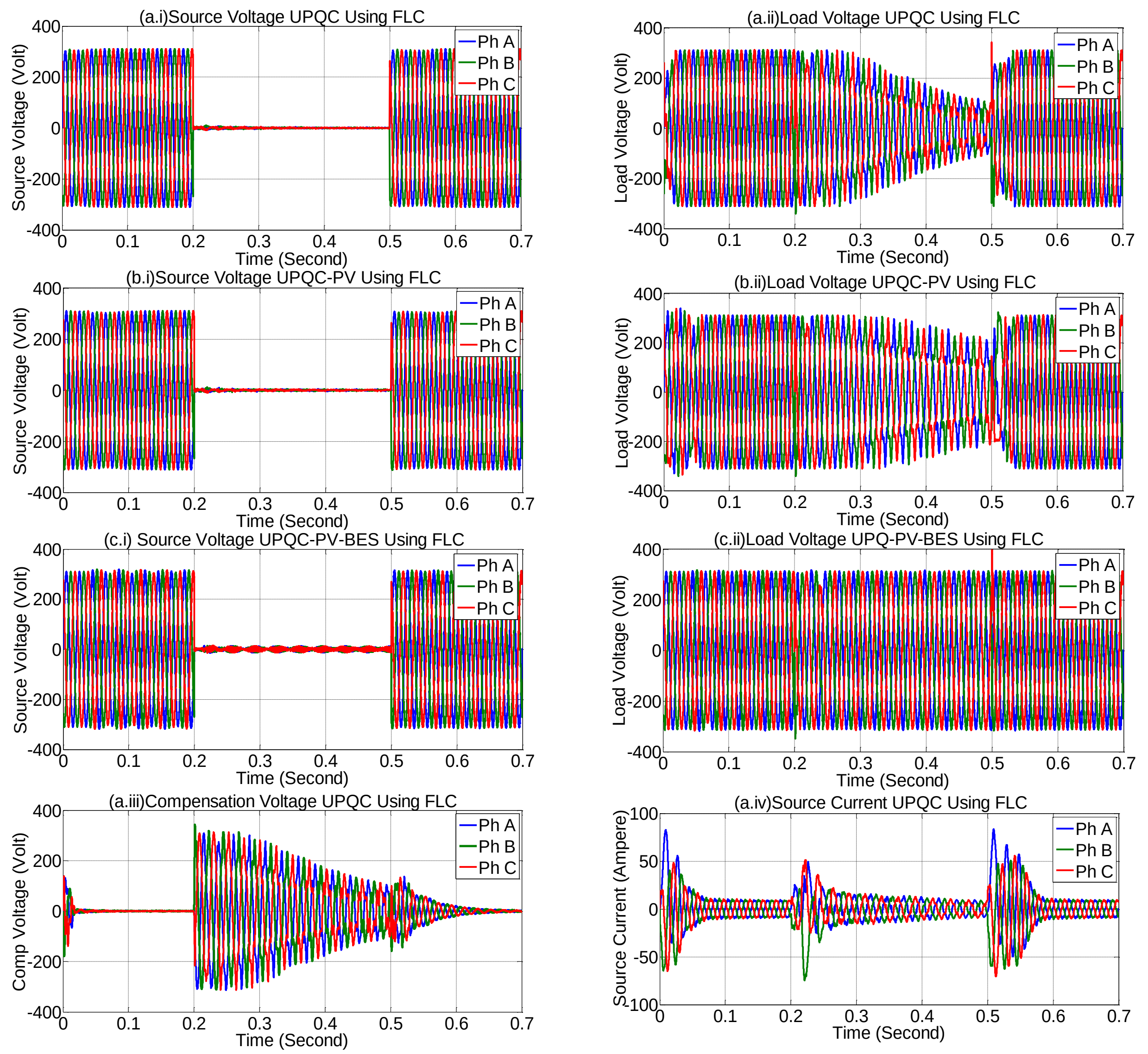


Figure 12. Performance of UPQC combinations using FLC in Scn 4: (a) UPQC; (b) UPQC-PV; (c) UPQC-PV-BES



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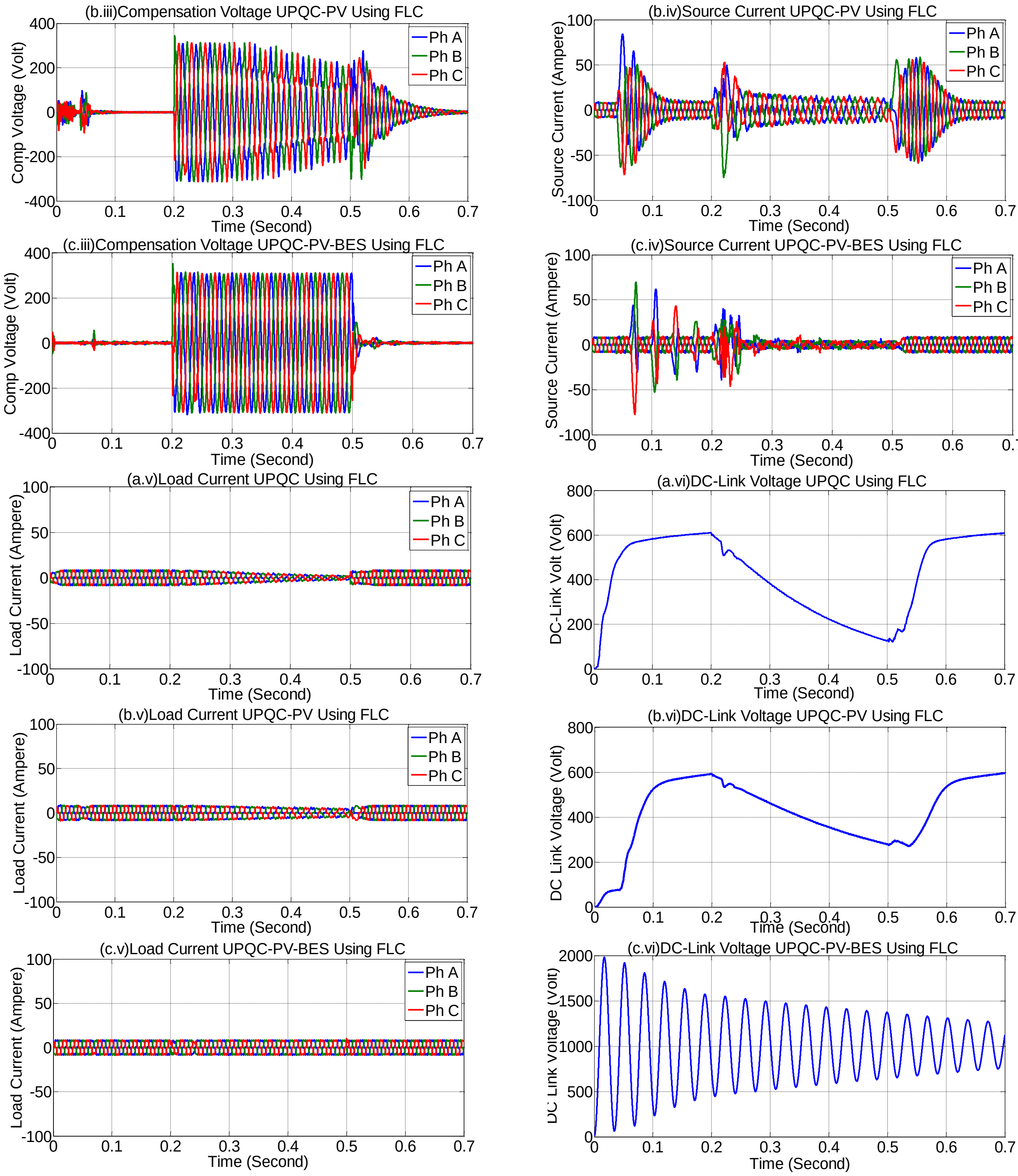
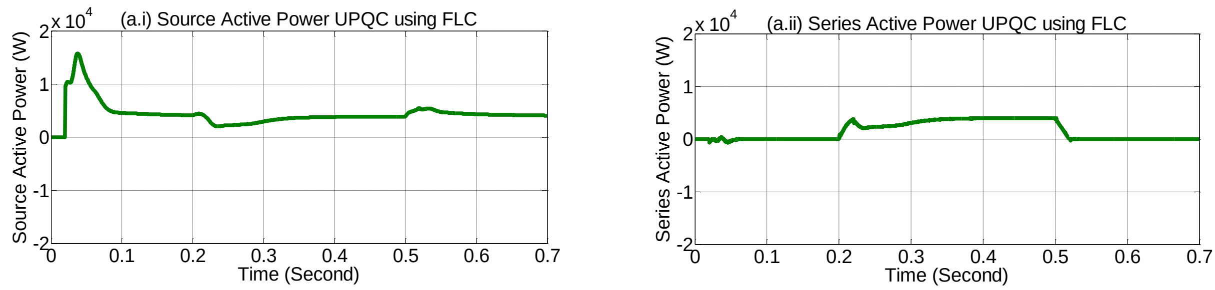


Figure 13. Performance of UPQC combinations using FLC in Scn 6: (a) UPQC; (b) UPQC-PV; (c) UPQC-PV-BES



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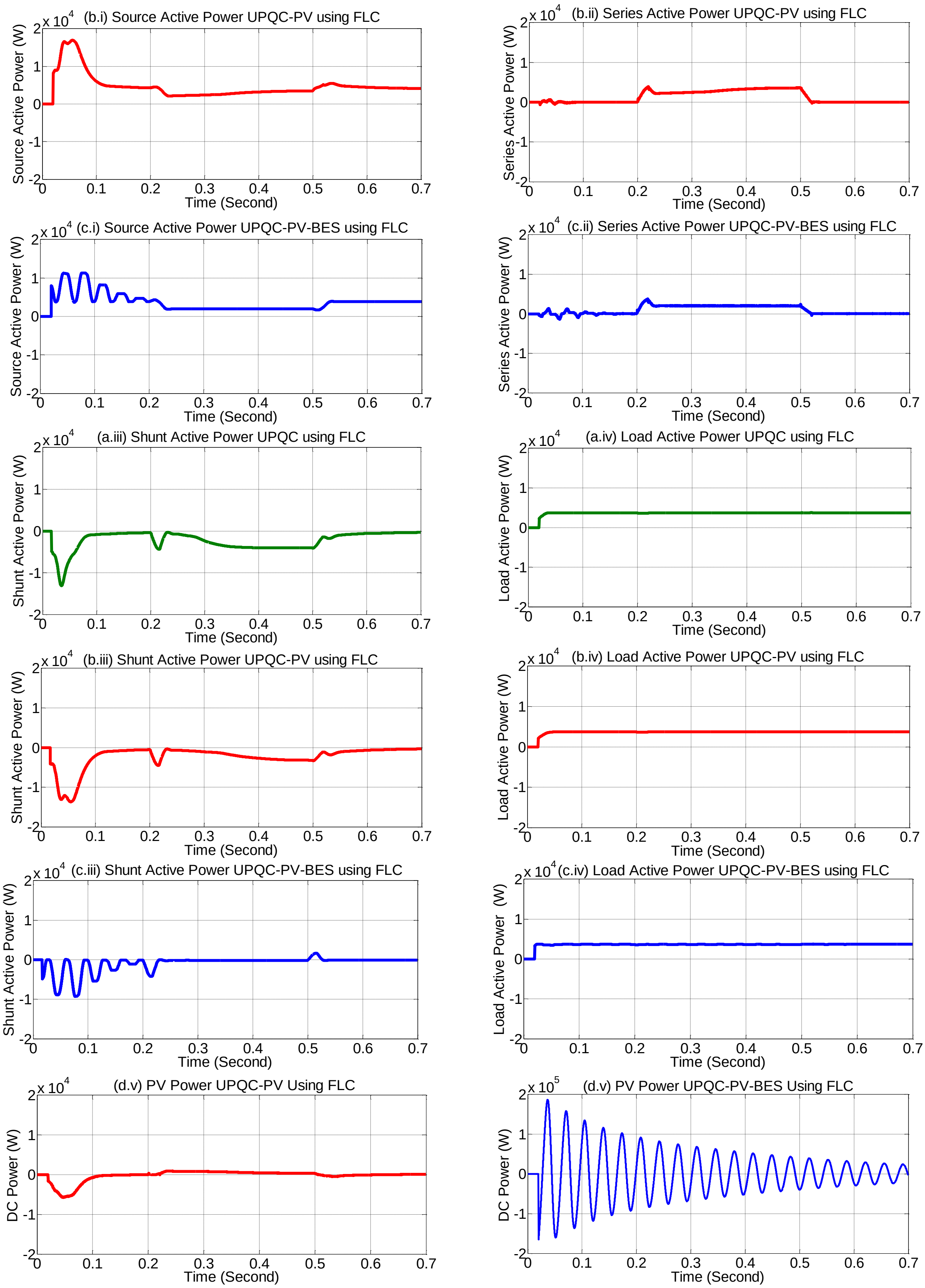

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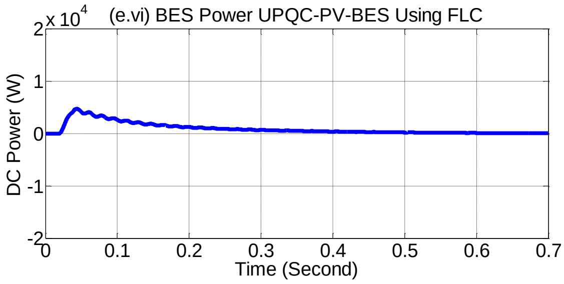
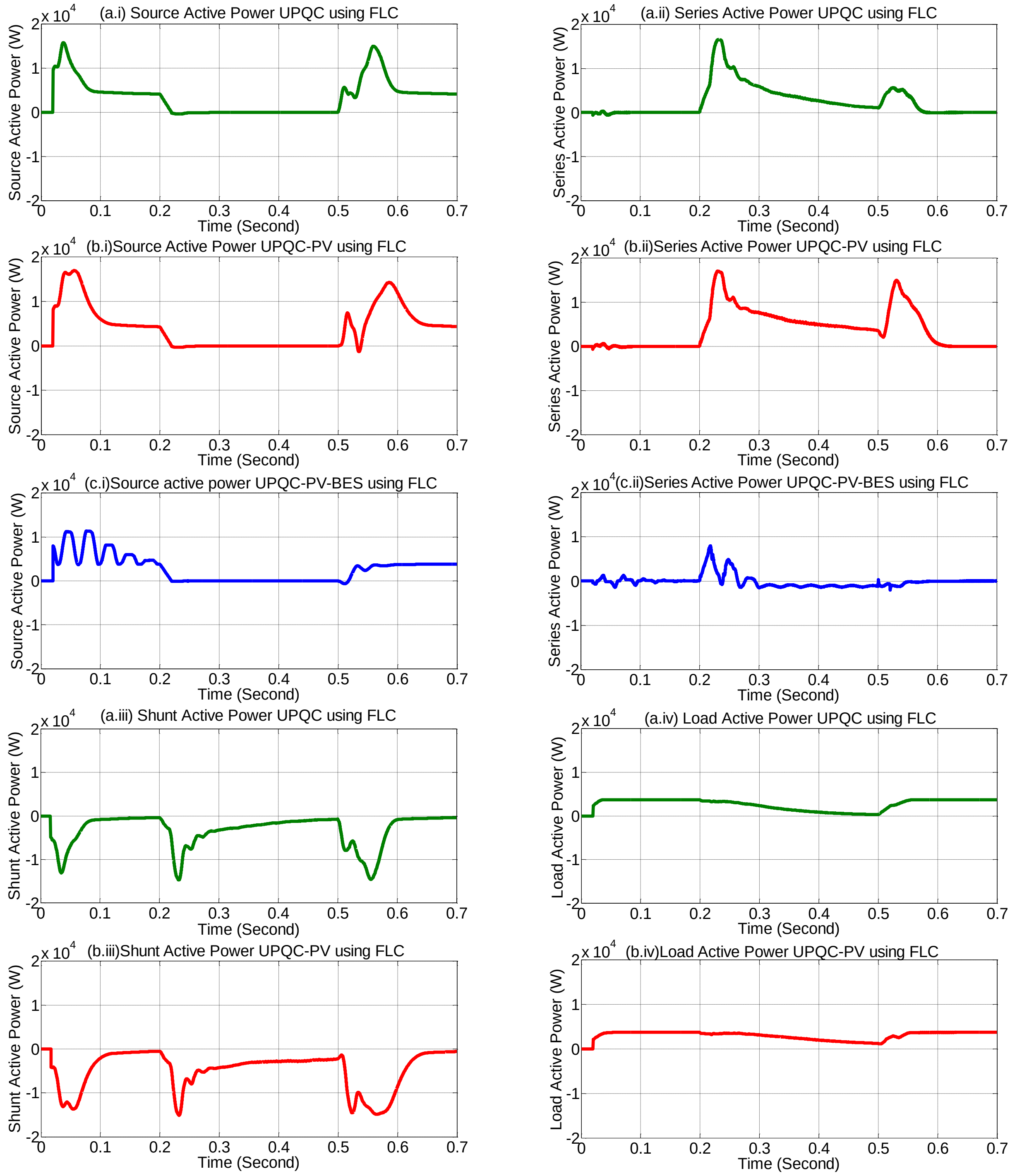


Figure 14. Active power transfer performance on three UPQC combinations use FLC in Scn 4



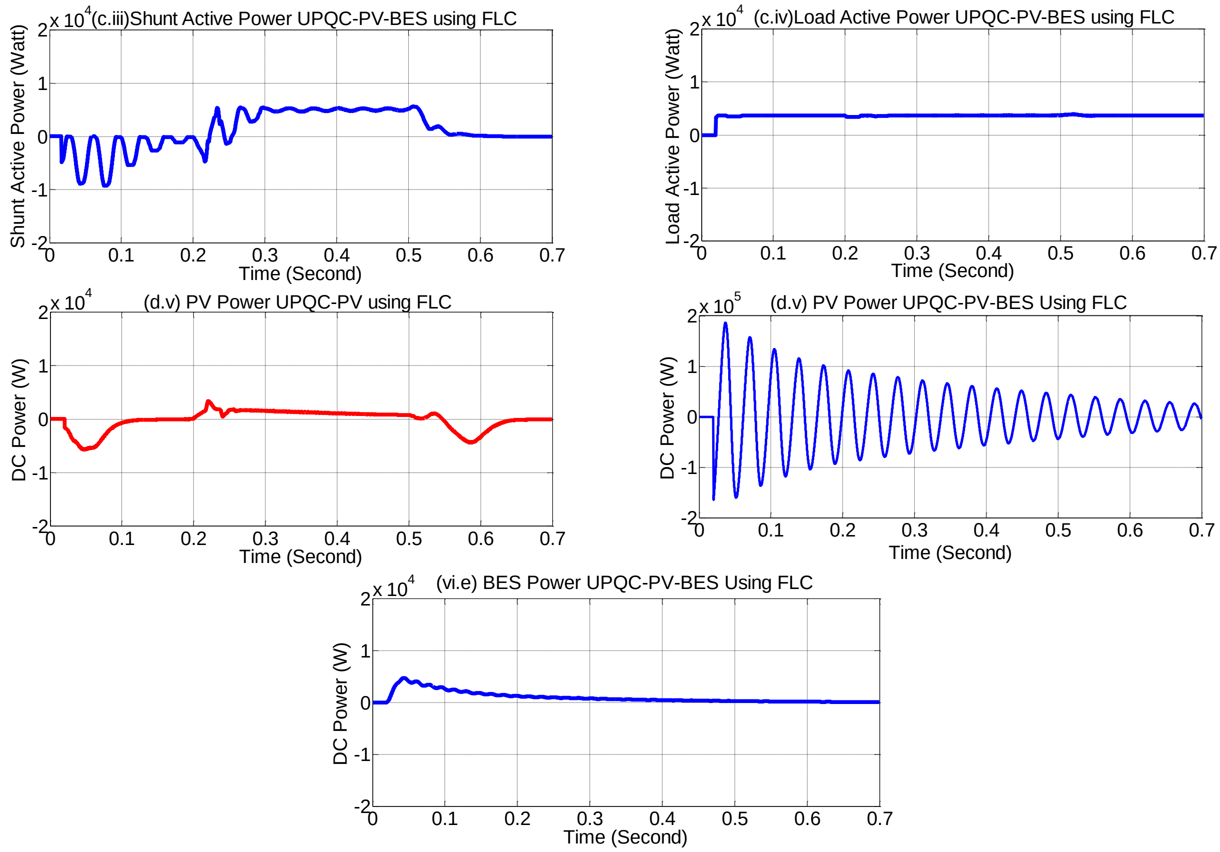


Figure 15. Active power transfer performance on three UPQC combinations use FLC in Scn 6

Fig.14 and Fig. 15 show active power transfer performance in three UPQC combinations use FLC in Scn 4 (Sag-NL) and Scn 6 (Inter-NL). Table 6, Table 7, and Table 8 show active power transfer in the combination of circuit: (a) UPQC, (b) UPQC-PV, and (c) UPQC-PV-BES using PI and FLC in six disturbances. Table 9 shows DC power UPQC-PV and UPQC-PV-BES.

Fig. 14.a.i shows that in Scn 4 of UPQC at t = 0.2 s to t = 0.5 s using FLC, the source active power (P_S) drops to 3700 W. The series active power (P_{Se}) (Fig. 14. a.ii) increases by 3850 W and the shunt active power (P_{Sh}) decreases by -3730 W (Fig. 14.a.iii), so that the load active power (P_L) (Fig. 15.a.iv) becomes 3714 W.

Fig. 14.b.i shows that in Scn 4 of UPQC-PV combination at t = 0.2 s to t = 0.5 s using FLC, the nominal of source active power (P_S) drops to 2800 W. The series active power (P_{Se}) (Fig. 14.b.ii) increases by 2860 W and shunt active power (P_{Sh}) decreases by -1840 W (Fig. 15.b.iii), PV power (P_{PV}) (Fig. 14.d.v) increases by 650 W, so that load active power (P_L) (Fig.14.b.iv) becomes of 3715 W.

Fig. 14.c.i shows that in Scn 4 of UPQC-PV-BES at t = 0.2 s to t = 0.5 s using FLC, the value of source active power (P_S) drops to 2000 W. The series active power (P_{Se}) (Fig. 14.c.ii) increases by 2000 W and shunt power (P_{Sh}) decreases by -150 W (Fig. 14.c.iii), PV power (P_{PV}) (Fig. 14.d.v) by 0 W, and BES power (P_{BES}) (Fig. 14.d.vi) of 530 W, so that load active power (P_L) (Fig. 14.c.iv) equal to 3680 W.

Fig. 15.a.i shows that in Scn 6 of UPQC at t = 0.2 s to t = 0.5 s using FLC, the source active power (P_S) drops to 0 W. The series active power (P_{Se}) (Fig. 15. a.ii) increases by 3800 W and shunt active power (P_{Se}) decreases by -2300 W (Fig. 15.a.iii), so that load active power (P_L) (Fig. 15.a.iv) decreases to 1420 W.

Fig. 15.b.i shows that in Scn 6 of UPQC-PV combination at t = 0.2 s to t = 0.5 s using FLC, the nominal of source active power (P_S) drops to 0 W. The series active power (P_{Se}) (Fig. 15.b.ii) increases by 6000 W and shunt active power (P_{Sh}) decreases by -3100 W (Fig. 15.a.iii), PV power (P_{PV}) (Fig. 15.d.v) rises by 1300 W, so that load active power (P_L) (Fig.15.b.iv) decreases to 2600 W.

Fig. 15.c.i shows that in Scn 6 of UPQC-PV-BES at t = 0.2 s to t = 0.5 s using FLC, the value of source active power (P_S) drops to 0 W. The series active power (P_{Se}) (Fig. 15.c.ii) decrease by -900 W and shunt active power (P_{Sh}) increases by 4700 W (Fig. 15.c.iii), PV power (P_{PV}) (Fig. 15.d.v) of 0 W, and BES power (P_{BES}) (Fig. 15.d.vi) of 600 W, so that load active power (P_L) (Fig. 15.c.iv) becomes 3700 W.

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Table 6. Active power transfer on UPQC

Scn	Active Power Transfer (Watt)			
	Source Power	Series Power	Shunt Power	Load Power
PI Controller				
1	4000	22	-260	3712
2	4000	20	-270	3712
3	4080	32	-280	3760
4	3675	3820	-3670	3714
5	5760	-1850	0	3712
6	0	2850	-1200	1400
Fuzzy Logic Controller				
1	4000	22	-240	3714
2	4010	25	-260	3714
3	4020	20	-228	3750
4	3700	3850	-3730	3714
5	5735	-1850	0	3713
6	0	3800	-2300	1420

Table 7. Active power transfer on UPQC-PV

Scn	Active Power Transfer (Watt)			
	Source Power	Series Power	Shunt Power	Load Power
PI Controller				
1	4000	20	-280	3715
2	4000	20	-290	3712
3	4000	25	-250	3750
4	2700	2800	-1800	3715
5	6000	-1700	0	3715
6	0	4900	-1900	2650
Fuzzy Logic Controller				
1	4000	20	-230	3714
2	4000	20	-240	3714
3	4000	25	-250	3760
4	2800	2860	-1840	3715
5	6000	-1700	0	3715
6	0	6000	-3100	2600

Table 8. Active power transfer on UPQC-PV-BES

Scn	Active Power Transfer (Watt)			
	Source Power	Series Power	Shunt Power	Load Power
PI Controller				
1	3600	15	150	3690
2	3600	15	135	3690
3	3700	80	120	3850
4	1700	1750	300	3680
5	5500	-1700	0	3600
6	0	-1100	5000	3720
Fuzzy Logic Controller				
1	3830	15	-80	3690
2	3830	10	-85	3690
3	3900	100	-100	3850
4	2000	2000	-150	3680
5	5725	-1850	0	3700
6	0	-900	4700	3700

Table 9. DC power on UPQC-PV and UPQC-PV-BES

Scn	DC Power(Watt)		
	PV	PV-BES	
	PV Power	PV Power	BES Power
PI Controller			
1	120	0	400
2	110	0	400
3	125	0	390
4	650	0	410
5	-560	0	380
6	1300	0	490
Fuzzy Logic Controller			
1	130	0	520
2	125	0	520
3	120	0	520
4	650	0	530
5	-550	0	500
6	1300	0	600

Table 10. Efficiency of UPQC combinations

Scn	Efficiency (%)		
	UPQC	UPQC-PV	UPQC-PV-BES
PI Controller			
1	98.67	96.25	88.59
2	98.98	96.67	88.92
3	98.12	96.16	89.74
4	97.09	85.40	88.46
5	94.94	99.34	86.12
6	84.85	61.63	84.74
Fuzzy Logic Controller			
1	98.20	94.75	86.12
2	98.38	95.10	86.32
3	98.37	96.54	87.11
4	97.23	83.11	84.02
5	95.57	99.07	84.57
6	94.67	61.91	84.10

Fig. 16 shows performance of load active power transfer in a combination of circuits: (a) UPQC, (b) UPQC-PV, and (c) UPQC-PV-BES using PI controller and FLC in six disturbance scns. The next step is to determine the efficiency of each combination i.e. (a) UPQC, (b) UPQC-PV, (c) UPQC-PV-BES using PI control and FLC. The efficiency of each circuit combination is determined using Eq. 14 and shown in Table 10 and Fig.17 Table 10 and Fig. 17 show that in Scn 1 to 6, the combination of UPQC-PV and UPQC-PV-BES respectively, results in lower efficiency compared to using only UPQC. In Scn 4 and 6, the UPQC-PV-BES combination produces higher efficiency compared than the UPQC-PV combination. In Scn 4 using FLC, UPQC-PV-BES combination produces efficiency of 84.02% compared to UPQC-PV combination of 83.11%. In Scn 6 using FLC, UPQC-PV-BES model produces efficiency of 84.10% compared to UPQC-PV of 61.91%.

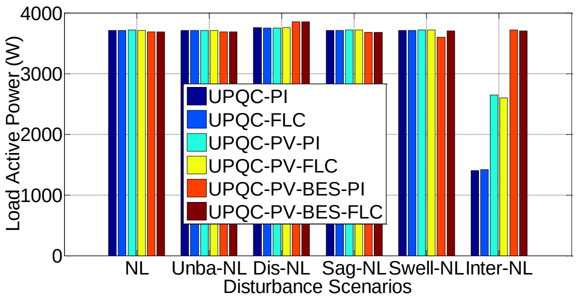

Figure 16. Active power transfer performance on three UPQC combinations in six scns

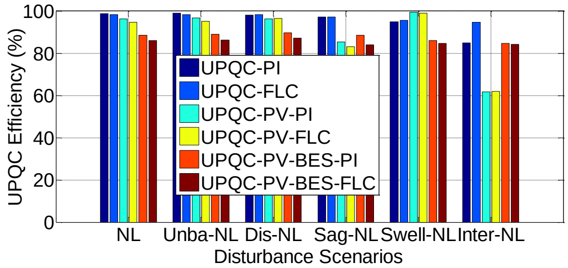

Figure 17. Efficiency of UPQC combinations

4. Conclussions

The implementation of UPQC-PV-BES in 3P3W system has been presented. In disturbance scns 1 to 5, the 3P3W system using three combinations of UPQC with PI control and FLC is still able to maintains load voltage and load current to be above 300 V and 8 A. Whereas in Scn 6, only the UPQC-PV-BES combination with FLC is able to maintain the load voltage and load current to be higher compared than the two UPQC combinations of 304.1 V and 8.421 A respectively. In disturbance scns 1 to 5, the 3P3W system using three combinations of UPQC with PI controller and FLC is capable of producing load active power above 3600 W. Whereas in Scn 6, only the combination of UPQC-PV-BES with PI controller and FLC is able to produce a load voltage of 3720 W and 3700 W, respectively. In Scn 1 to 6, the combination of UPQC-PV-BES results in lower efficiency compared to using UPQC and UPQC-PV. In Scn 6, however, the combination of UPQC-PV-BES with FLC is able to produce higher load voltage, load current, and load active power compared to UPQC-PV and UPQC. Thus, the UPQC-PV-BES model using FLC is able to compensate to the load voltage and load current, and to enhance the load active power in case an interruption voltage occurs on source bus.

This research uses BES with 100% state of charge (SoC) or fully charged. The use of BES with varying SoC (0% to 99%) is proposed as future work to find out load active power transfer performance of UPQC-PV-BES system in unfully charged BES condition.

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Appendix

Three phase sources: RMS voltage 380 volt (line-line), 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; non-linear 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; BES: type = nickel metal hybrid, DC voltage = 650 volt, rated capacity = 200 Ah, initial state of charge = 100%, inductance L_1 = 6 mH, capacitance C_1 = 200 µF; solar photovoltaic: active power = 0.6 kW temperature = 25^0 C, radiation = 1000 W/m^2; PI controller: K_P= 0.2, K_I = 1.5; fuzzy logic controller model: method = mamdani, composition = max-min; input MF: Vdc error $(V_{dc-error})$ = trapmf, trimf, delta Vdc error $(\Delta V_{dc-error})$ = trapmf, trimf; output MF: instantaneous power loss $\bar{p}_{loss}$ = trapmf, trimf.

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