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Abstract

In present era, world is running one of the major and utmost striving renewable energy capacity expansion and integrated to distribution system with power electronic components. Extensive use of power electronic devices in distribution system to produce harmonics and power quality issues. Hence there is a requirement to mitigate the power quality issues. Over the various compensation devices, the mostly renowned Multipurpose DSTATCOM (MP-DSTATCOM) integrated to grid and enhances the power quality problems. In co-generation scheme, solar Photovoltaic (PV) is connected to grid under variable loading conditions and the voltage is not constant. To overcome the above said problems, in this paper developed the various novel current controllers such as fuzzy and hybrid fuzzy controllers to maintain the output of cogeneration system as constant. The performance of proposed MP-DSTATCOM has been analyzed by proportional- integral (PI), proposed fuzzy logic and hybrid fuzzy based novel current controller using

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Thanks a lot for your information.

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POWER QUALITY ENHANCEMENT IN PHOTOVOLTAIC SYSTEM INTEGRATED DISTRIBUTION SYSTEM WITH SOFT COMPUTING TECHNIQUES

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Abstract:

In present era, world is running one of the major and utmost striving renewable energy capacity expansion and integrated to distribution system with power electronic components. Extensive use of power electronic devices in distribution system to produce harmonics and power quality issues. Hence there is a requirement to mitigate the power quality issues. Over the various compensation devices, the mostly renowned Multipurpose DSTATCOM (MP-DSTATCOM) integrated to grid and enhances the power quality problems. In co-generation scheme, solar Photovoltaic (PV) is connected to grid under variable loading conditions and the voltage is not constant. To overcome the above said problems, in this paper developed the various novel current controllers such as fuzzy and hybrid fuzzy controllers to maintain the output of cogeneration system as constant. The performance of proposed MP-DSTATCOM has been analyzed by proportional- integral (PI), proposed fuzzy logic and hybrid fuzzy based novel current controller using MATLAB/Simulink and discuss with different waveform total harmonic distortion (THD) comparisons.

1. Introduction:

The main purpose of the electric utility is to supply clean and stable power and it is while maintaining a constant voltage. It was observed, there was a sudden rise of nonlinear loads in power systems such as power electronic devices deployed in communication systems, household applications like mixers, washing machines and adjustable speed drives, etc [1]. With the development of power electronic devices leads to obtaining high power rating and robust in nature. However, these power electronic devices generate a huge amount of harmonics, reactive power from the grid, efficiency and decrease the power factor in the distribution system. Furthermore, protection equipment of nearby consumers sometimes failure or trip due to power quality issues [2].To enhance the power quality in the distribution system with power electronic devices, passive filters such as tuned filters and pulse converter circuits are integrated at the point of common coupling (PCC). But they are undesirable to eliminate the harmonics. Also, shunt active filters and series active filters are introduced for compensating the harmonic distortion, but those filters usage of switching devices number and cost is very high[3] –[5]. To overcome the drawbacks of passive and active filters, introduced the hybrid filters (a combination of PFs and AFs). The hybrid filters only compensate for the harmonics and but not eliminate the resonance problem [6]. Now a day's most of the researchers mainly focus on current issues such as reactive power, balancing load and current harmonics etc. Few of the researchers introduced the PQ theory for an active filter in a distribution system to compensate for the current harmonics [7].

Tejas Zaveri et al. [8] developed Distributed Static Compensator (DSTATCOM) for eliminating current harmonics to create a unity power factor on source end in a distribution system with variable load

conditions. It also implemented a new approach i.e. instantaneous active and reactive current component theory for the generation of gating pulses and connected to DSTATCOM with a hysteresis controller scheme. The instantaneous active and reactive current component theory-based approach under non-linear variable conditions for harmonic compensation is not fully satisfactory. It has some problems like poor performance in voltage distortion and unbalances the distribution system. Consequently, the synchronous reference frame (SRF) theory has been developed for the generation of gating pulses. A one-most important feature of the SRF theory is that the reference currents are directly generated from the load current without considering the source voltage, it means that reference current is not affecting the source voltage distortion. C. Kumar et al. [9] developed SRF theory based hybrid DSTATCOM for compensating the harmonics and reactive power at the source end and load end over the conventional schemes, it has good desirable features such as efficiency, cost and weight. M. Manoj Kumar et al. [10] has been proposed the dual voltage-source inverter (DVSI) scheme, in which the power produced by the distributed generation (DG) is injected as real power by the primary voltage source inverter (VSI), harmonics and unbalanced compensation was done by secondary voltage source inverter. In the DVSI scheme, usage of many switching elements leads to an increase the switching stresses, cost, size and decreases the performance of the distribution system. In the present paper it has been proposed MP-DSTATCOM minimizes the additional DG- VSC topology and compensation costs which raises the capability of power demand. The main aim of the scheme is to compensate harmonics, reactive power, power factor improvement and unbalanced load. The secondary aim is to integrate of SPV system as a local load of voltage source converter (VSC) to stable the sudden load demand. Due to uneven vary of SPV system, the output at VSC is not constant and may create unbalanced grid voltages. For controlling the grid output, novel current based controllers such as fuzzy and hybrid fuzzy controllers are introduced in this paper. It mainly focuses on achieving the following objectives. (i) To reduce the current harmonics in the distribution system due to sudden load variations with SPV system (ii) To maintain the active power connected to load is constant (iii) To analyze the % THD comparative analysis of classical and soft computing controllers with MP- DSTATCOM in distribution system.

2. Methodology

Figure 1 represents Single line diagram of PV fed MP – DSTATCOM based soft computing techniques in a power distribution system.

2.1 Proposed PV fed MP – DSTATCOM control scheme

It comprises the voltage source converter (VSC) module, DC- DC Converter, dc link capacitor, sensing elements and solar PV system etc. VSC module system device not only eliminating harmonics from various load disturbances but also act as inverter in DG operation. In harmonic elimination, VSC only the control current in distribution system. During DG operation, VSC act as inverter to control the voltage and supply active power to load. In DG system, Addition of battery to increases more energy storage. Furthermore, charge management schemes are required to improve the performance of battery [11]. Over the Battery energy storage system (BESS), Renewable energy source (RES) is the major role in DG operation. Out of many all RES systems, Solar PV system is enhances the power generation abruptly and bestowed method. The SPV system is connected to DC-DC converter to increase the level of voltage which is connected to VSC via DC link capacitor [12].The gating pulses generated using modified SRF theory and connected to MP – DSTATCOM. These control theory scheme is most advantageous in comparison with other transformations [13]. In Modified SRF scheme, first to convert a-b-c three phase currents to α - β curents and then tranformed into d – q currents. The MP- DSTATCOM supervises currents at PCC in distribution system for mitigation of harmonics, active power injection and reactive power exchanging etc.

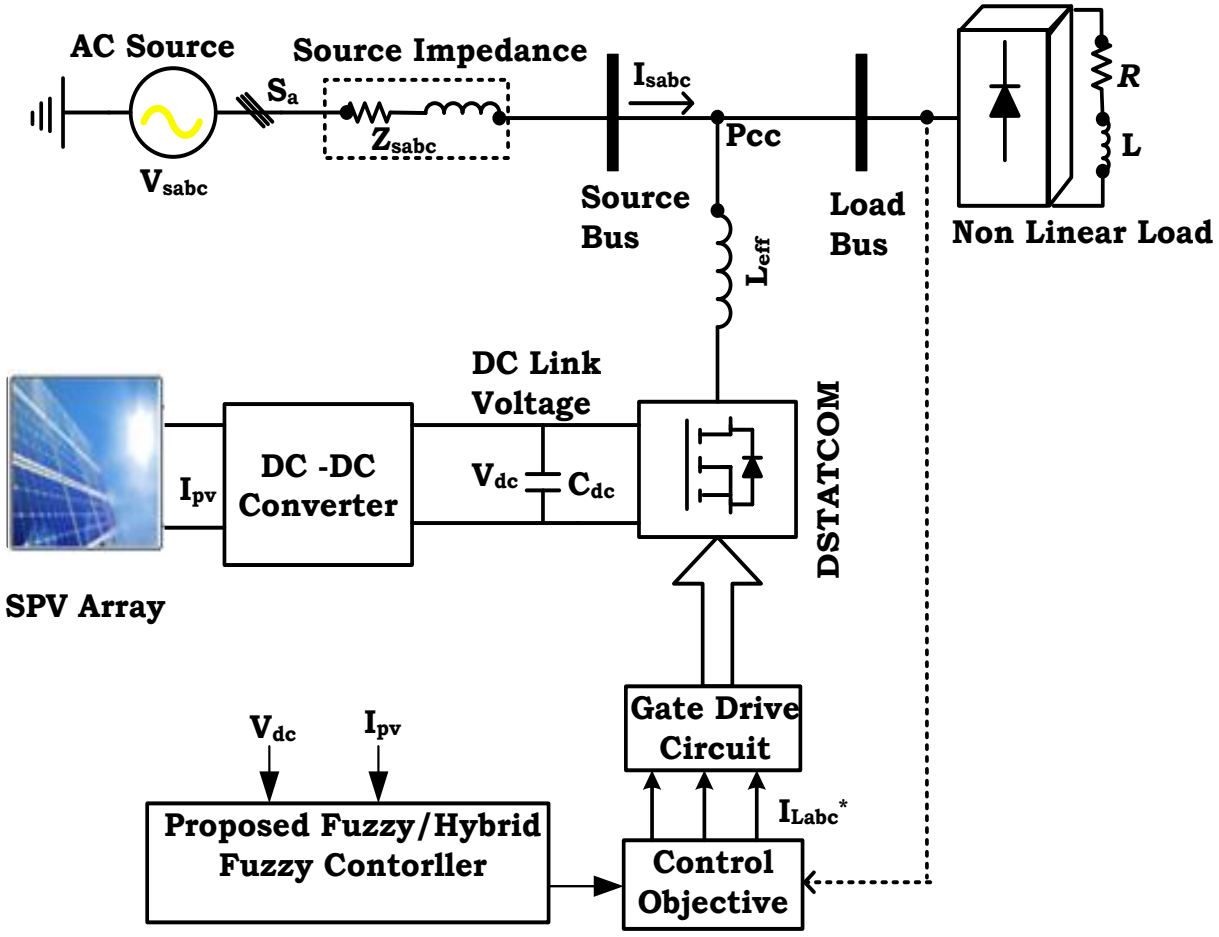

Figure 1 Single line diagram of PV fed MP – DSTATCOM based soft computing techniques in power distribution system

2.2 Proposed current based ontrollers

Over the years, control process in industry done by skilled technical experts through conventional controllers because of low cost and robust performance. These conventional controllers lagging from steady sate and transient issues such as rise time, setting time and overshoot. Later, the new technologies have been invented and developed to overcome the limitations of the conventional controller's, which includes auto tuning PI controllers, adaptive and compensation techniques. Soft computing techniques have shown to be well suited to deal with major uncertainties that may encounter in solving real world problems.

2.2.1 Fuzzy logic current controller

Fuzzy control is a flexible and effective approach, which deals with uncertainities of variable loads. Figure 2 shows proposed block diagram of fuzzy logic current controller which is performed various operations such as fuzzification, fuzzy inference and defuzzification. The determination of output signal was done in fuzzy inference with a rule base having IF-then rules. With the rule base , the value of the output was changed according to the value of the error signal 'e' and rate of error Δe. In general one introduces for each variable three, five or seven sets represented by membership functions in triangular form. In Fuzzy rule base , sizes are identical in seven classes such as Negative Big (NB), Negative Medium (NM), Negative Small (NS), Zero (ZR), Positive Small (PS), Positive Medium (PM) and Positive Big (PB). The number of the sets depend on the resolution and interference of the desired adjustmant [14]. The fuzzy rule base table illustrated in Table.1.

Table 1. Fuzzy Rule base control

△e \ e	NB	NM	NS	ZR	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	ZR
NM	NB	NB	NB	NM	NS	ZR	PS
NS	NB	NB	NM	NS	ZR	PS	PM
ZR	NB	NM	NS	ZR	PS	PM	PB
PS	NM	NS	ZR	PS	PM	PB	PB
PM	NS	ZR	PS	PM	PB	PB	PB
PB	ZR	PS	PM	PB	PB	PB	PB

The adopted law is a function of the error and its variation (U = f(e,Δe). The general form of law of command is given by

$$U_{K+1} = U_K + (G_{K+1} \times \Delta U_{K+1}) \quad (1)$$

Where G_{K+1} is the profit associated with the order U_{K+1} and ΔU_{K+1} is the exit of the fuzzy controller which represents variation of the command U. During defuzzification process,centroid method is used for balace the heights.it is defined as follows.

$$X_R^* = \Delta U = \sum_{i=1}^{n} \frac{\mu(x_i)x_i}{\mu(x_i)} \quad (2)$$

The difference between reference DC-link voltage (v_{dcr}) and measured DC-link voltage(v_{dca}) gives the error voltage (v_{dcer}) is shown Eqn. (3).

$$v_{dcer} = v_{dcr} - v_{dca} \quad (3)$$

The error voltage is processed through Fuzzy logic controller and provide the active current as Δi_d.The resultant reference current is the sum of $I_{pv,}$ Δ_{id}components and fundamental active i_{Ldq} components for active compensation of PQ enhancement and operation of DG in the 3 - phase distribution power system is illustrated in Eqn. (4).

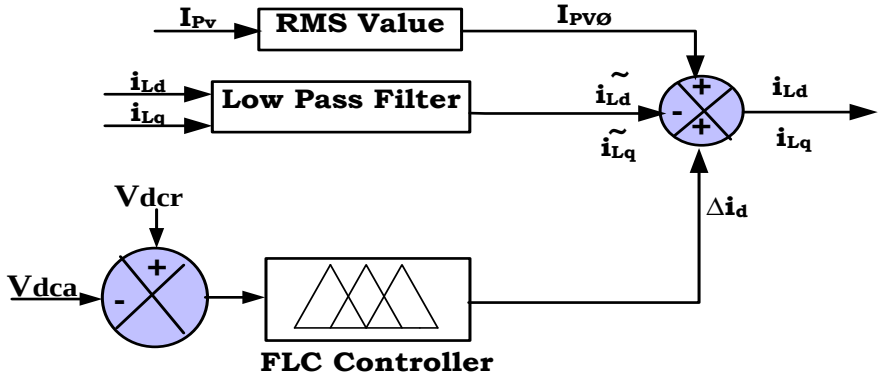

Figure 2 proposed block diagram of fuzzy logic current controller

$$\begin{bmatrix} i_{Ld} \\ i_{Lq} \end{bmatrix} = \begin{bmatrix} \overline{i_{Ld}} \\ \overline{i_{Lq}} \end{bmatrix} + \begin{bmatrix} \tilde{i}_{Ld} \\ \tilde{i}_{Lq} \end{bmatrix} + \Delta i_d + I_{pv} \tag{4}$$

The fuzzy logic controller generates reference currents to trigger the switches of MP-DSTATCOM and control the harmonics and voltage in distribution system.

2.2.2 Hybrid Fuzzy based current controller

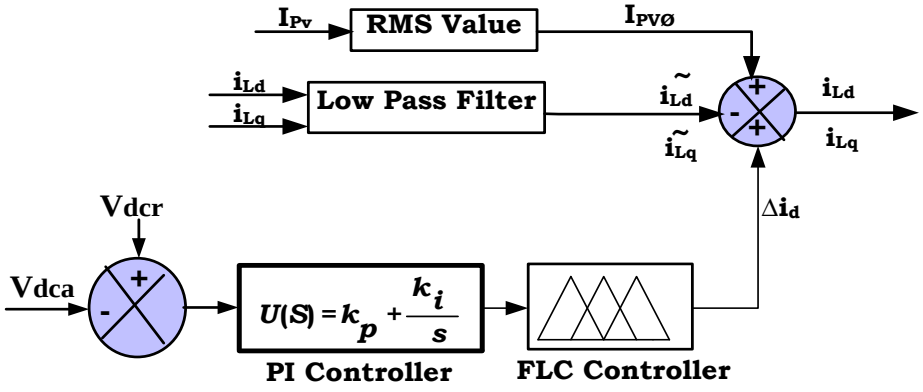

Figure 3 Block diagram of hybrid fuzzy based current controller

The PI controller possesses specifically good performance under steady state conditions, where fuzzy controller performance was good at transient conditions, the advantages of both of the theses controllers was included in the single controller i.e. hybrid fuzzy based controller[15].

3. Results and Discussion

The proposed PV fed MP-DSTATCOM based fuzzy and hybrid fuzzy current based controller in distribution system parameters are described in table 2.

Table 2. System Parameters

Parameter(s)	Value(s)
Source Voltage	415V
Impedance of source	0.1+j0.28Ω
Impedance of load	30+j9.42Ω
DC-Link Capacitor	4000μF
Proportional gain (K_p)	18.3
Integral gain (K_i)	6.3
Resistance(R)	0.1Ω
Inductance (L)	5mH

3.1 Evaluation of MPDSTATCOM with MSRF control scheme with DG operation under 50% loading condition in distribution power system

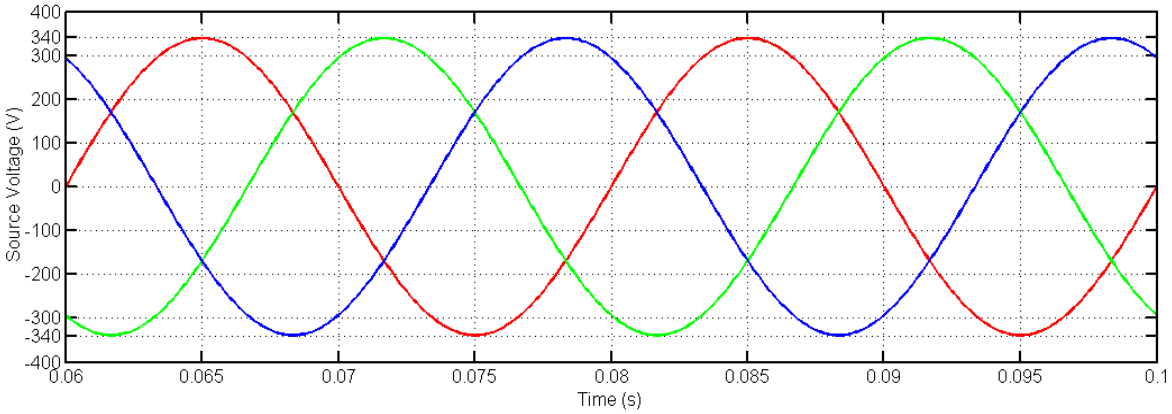

Figure 4(a) Source Voltage

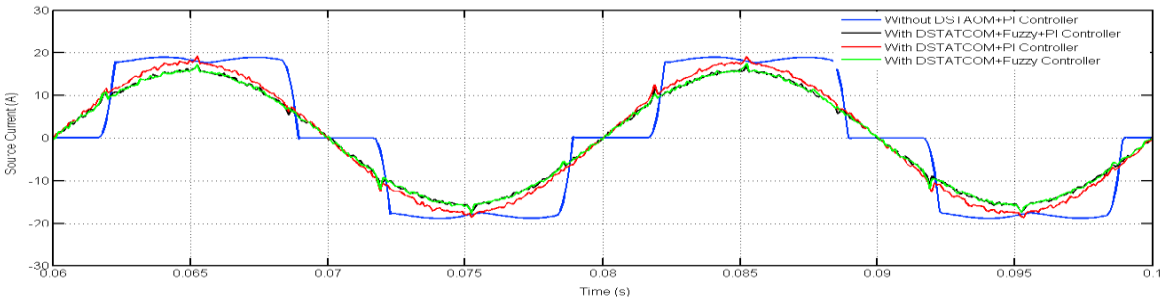

Figure 4(b) Source current

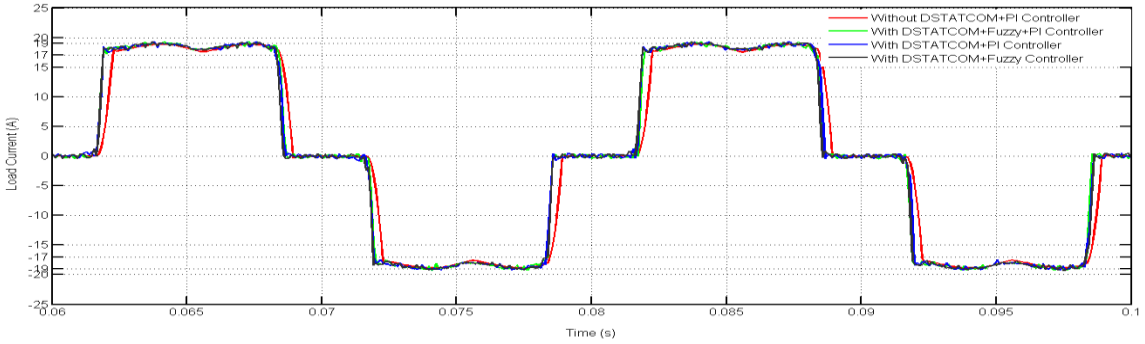

Figure 4(c) Load Current

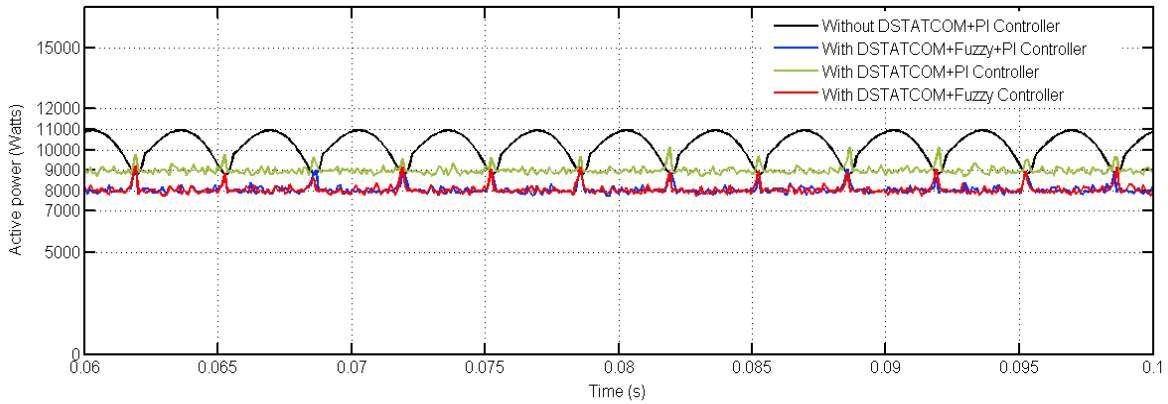

Figure 4(d) Active power

Figure 4 Simulation results of PV fed MP – DSTATCOM based soft computing techniques in power distribution system under 50% loading condition

Figure 4 shows the simulation results of PV fed MP – DSTATCOM based soft computing techniques in power distribution system under 50% loading condition. The distribution system is connected to supply, which is driven by 415 V, 50Hz and load side connected to nonlinear balanced load of (30+j30) Ω respectively. Due to nonlinear load, the source voltage doesn't disturbed and it gives pure sinusoidal waveform with the voltage of 340V is illustrated in figure 4(a). Figure 4(b) represents source current of without MP - DSTATCOM, with MP - DSTATCOM +PI controller, With MP-DSTATCOM +Fuzzy controller, and With MP-DSTATCOM + PI + Fuzzy controller respectively. Without MP- DSTATCOM, the source current shows non sinusoidal waveform due to nonlinear load and it has large number of har*monics with a peak current is* 18A. After connecting MP –DSTATCOM with PI Controller, the source current is modified into sinusoidal wave form of current 18A peak magnitude and with fewer harmonic. In MP – DSTATCOM with fuzzy logic controller, the source current was reduced to harmonics with a magnitude of 16A and sinusoidal. In MP-DSTATCOM with fuzzy and PI controller, the source current shows pure sinusoidal with less harmonics. Figure 4(c) shows load current of without MP - DSTATCOM, with MP - DSTATCOM +PI controller, With MP-DSTATCOM +Fuzzy controller, and With MP-DSTATCOM + PI + Fuzzy controller respectively. The distribution system on load side connected to nonlinear load. Due to this load, the current drawn on load side with peak magnitude of 18A and wave form is non-sinusoidal in all cases. But MP - DSTATCOM only concentrate on source side end but not in load side end. Without MP- DSTATCOM, the active power transfer to load is not constant is represented in figure 4(d). The MP – DSTATCOM with PI, Fuzzy and PI+ Fuzzy controllers, the active power transferred to load is maintained constant. The total harmonic distortion source current comparative analysis of several controllers under 50% DG energy loading condition is depicted in table 3.

Table 3 THD source current comparative analyses several controllers under 50% DG energy loading condition

THD (%)	Without MP-DSTATCOM	With MP-DSTATCOM+PI controller	With MP-DSTATCOM+fuzzy controller	With MP-DSTATCOM+ PI +fuzzy controller
Source Current	27.07	3.40	2.49	2.05

3.2 Evaluation of MPDSTATCOM with MSRF control scheme with DG operation under 100% loading condition in distribution power system

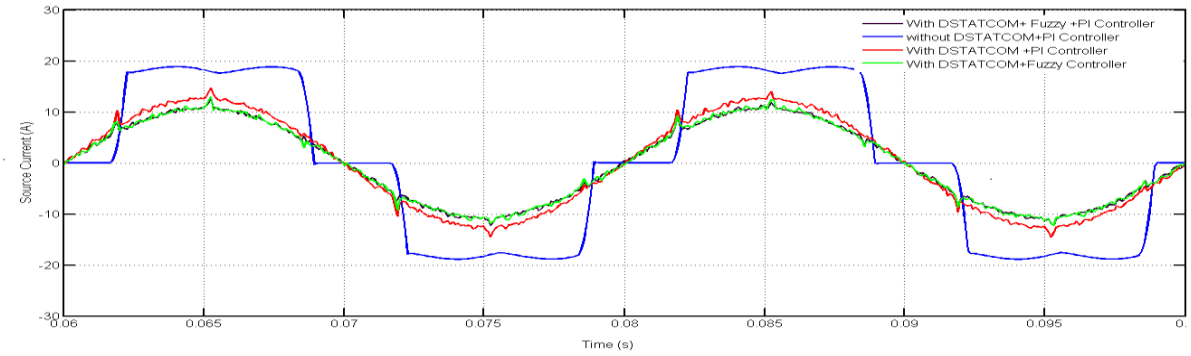

Figure 5(a) Source current

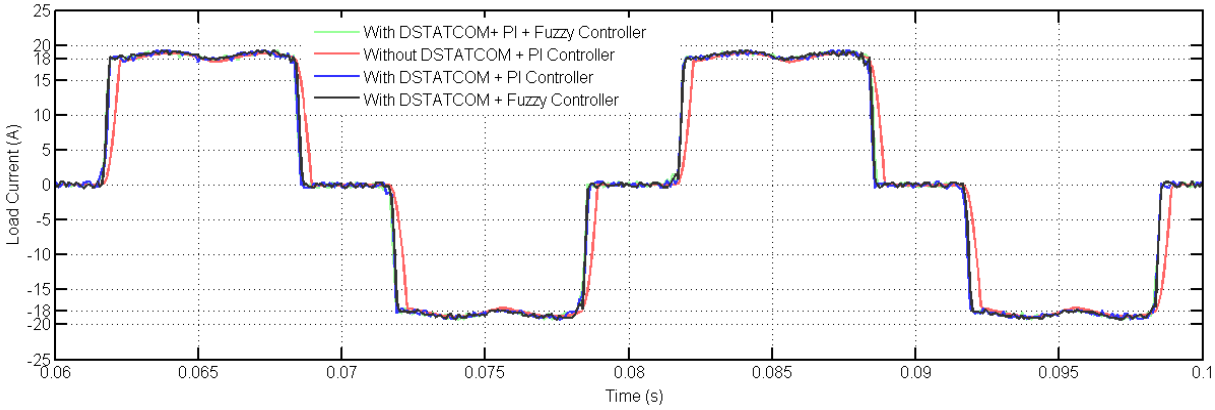

Figure 5(b) Load current

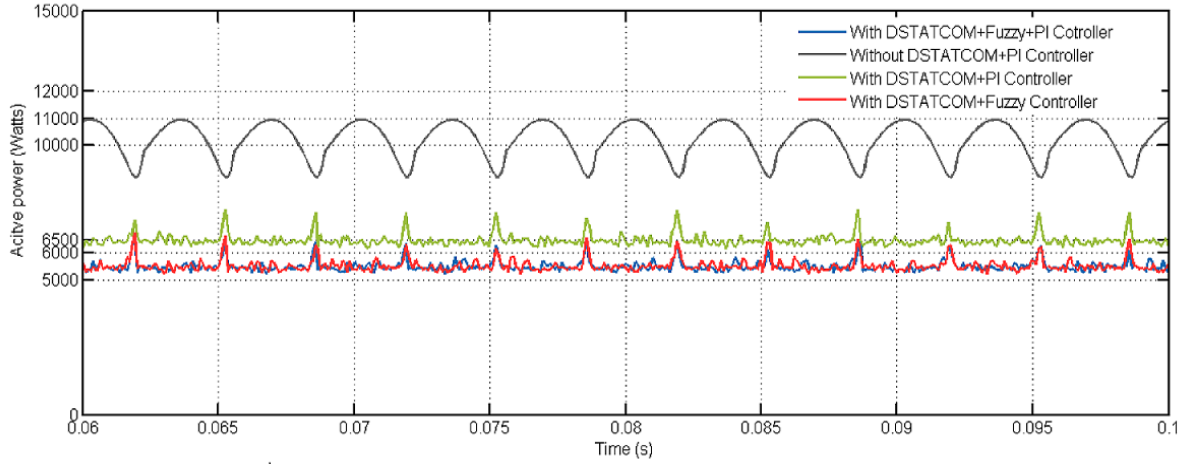

Figure 5(c) Active power

Figure 5 Simulation results of PV fed MP – DSTATCOM based soft computing techniques in power distribution system under 100% DG Loading condition

Figure 5 shows the simulation results of PV fed MP – DSTATCOM based soft computing techniques in power distribution system under 100% loading condition. The distribution system is connected to supply, which is driven by 415 V, 50Hz and load side connected to nonlinear balanced load of (30+j30) Ω respectively.

Due to nonlinear load, the source voltage doesn't disturbed and it gives pure sinusoidal waveform with the voltage of 340V. Figure 5(a) represents source current of without MP - DSTATCOM, with MP - DSTATCOM +PI controller, With MP-DSTATCOM +Fuzzy controller and With MP-DSTATCOM + PI + Fuzzy controller respectively. Without MP- DSTATCOM, the source current shows non sinusoidal waveform due to nonlinear load and it has large number of harmonics with a peak magnitude is 18A. After connecting MP –DSTATCOM with PI Controller, the source current is modified into sinusoidal wave form of current 14A peak magnitude and with fewer harmonic. In MP – DSTATCOM with fuzzy logic controller, the source current was reduced to harmonics with a magnitude of 13A and sinusoidal. In MP- DSTATCOM with fuzzy and PI controller, the source current shows pure sinusoidal with less harmonics with a magnitude of 12A. Figure 5(b) shows load current of without MP - DSTATCOM, with MP - DSTATCOM +PI controller, With MP-DSTATCOM +Fuzzy controller, With MP-DSTATCOM + PI + Fuzzy controller respectively. The distribution system on load side connected to nonlinear load. Due to this load, the current drawn on load side with peak magnitude of 18A and wave form is non-sinusoidal in all cases. But MP - DSTATCOM only concentrate on source side end but not in load side end. Without MP- DSTATCOM, the active power transfer to load is not constant is represented in figure 5(c). The MP – DSTATCOM with PI, Fuzzy, PI+ Fuzzy controllers, the active power transferred to load is maintained constant. The total harmonic distortion source current comparative analysis of several controllers under 100% DG energy loading condition is depicted in table 4.

Table 4 THD source current comparative analysis several controllers under 100% DG energy loading condition

THD (%)	Without MP-DSTATCOM	With MP-DSTATCOM+PI controller	With MP-DSTATCOM+fuzzy controller	With MP-DSTATCOM+ PI +fuzzy controller
Source Current	27.07	4.03	3.35	2.21

4. Conclusions

In this paper, MP-DSTATCOM based fuzzy and hybrid (PI+ Fuzzy) current controllers are proposed and which provides the optimal switching states under both power quality and DG operation. The following conclusions are discussed in this paper is:

- MSRF control strategy-based PV fed MP – DSTATCOM under different loading are modeled and eliminated source side current harmonics due to non - linear load.
- The advanced control theory (MSRF) furnishes constant active power to the load under variations in SPV system by using active control function which reduces the cost, size and additional controller.
- Validation results of source current at PCC of THD clearly indicated that, MSRF theory-based PV fed MP-DSTATCOM under various controllers such as PI, fuzzy and PI+ fuzzy in Distribution system are well within IEEE 512-1992 standard limits.

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POWER QUALITY ENHANCEMENT IN PHOTOVOLTAIC SYSTEM INTEGRATED DISTRIBUTION SYSTEM WITH SOFT COMPUTING TECHNIQUES

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Abstract:

In present era, world is running one of the major and utmost striving renewable energy capacity expansion and integrated to distribution system with power electronic components. Extensive use of power electronic devices in distribution system to produce harmonics and power quality issues. Hence there is a requirement to mitigate the power quality issues. Over the various compensation devices, the mostly renowned Multipurpose DSTATCOM (MP-DSTATCOM) integrated to grid and enhances the power quality problems. In co-generation scheme, solar Photovoltaic (PV) is connected to grid under variable loading conditions and the voltage is not constant. To overcome the above said problems, in this paper developed the various novel current controllers such as fuzzy and hybrid fuzzy controllers to maintain the output of cogeneration system as constant. The performance of proposed MP-DSTATCOM has been analyzed by proportional- integral (PI), proposed fuzzy logic and hybrid fuzzy based novel current controller using MATLAB/Simulink and discuss with different waveform total harmonic distortion (THD) comparisons.

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1. Introduction:

The main purpose of the electric utility is to supply clean and stable power and it is while maintaining a constant voltage. It was observed, there was a sudden rise of nonlinear loads in power systems such as power electronic devices deployed in communication systems, household applications like mixers, washing machines and adjustable speed drives, etc [1]. With the development of power electronic devices leads to obtaining high power rating and robust in nature. However, these power electronic devices generate a huge amount of harmonics, reactive power from the grid, efficiency and decrease the power factor in the distribution system. Furthermore, protection equipment of nearby consumers sometimes failure or trip due to power quality issues [2].To enhance the power quality in the distribution system with power electronic devices, passive filters such as tuned filters and pulse converter circuits are integrated at the point of common coupling (PCC). But they are undesirable to eliminate the harmonics. Also, shunt active filters and series active filters are introduced for compensating the harmonic distortion, but those filters usage of switching devices number and cost is very high[3] –[5]. To overcome the drawbacks of passive and active filters, introduced the hybrid filters (a combination of PFs and AFs). The hybrid filters only compensate for the harmonics and but not eliminate the resonance problem [6]. Now a day's most of the researchers mainly focus on current issues such as reactive power, balancing load and current harmonics etc. Few of the researchers introduced the PQ theory for an active filter in a distribution system to compensate for the current harmonics [7].

Tejas Zaveri et al. [8] developed Distributed Static Compensator (DSTATCOM) for eliminating current harmonics to create a unity power factor on source end in a distribution system with variable load

conditions. It also implemented a new approach i.e. instantaneous active and reactive current component theory for the generation of gating pulses and connected to DSTATCOM with a hysteresis controller scheme. The instantaneous active and reactive current component theory-based approach under non-linear variable conditions for harmonic compensation is not fully satisfactory. It has some problems like poor performance in voltage distortion and unbalances the distribution system. Consequently, the synchronous reference frame (SRF) theory has been developed for the generation of gating pulses. A one-most important feature of the SRF theory is that the reference currents are directly generated from the load current without considering the source voltage, it means that reference current is not affecting the source voltage distortion. C. Kumar et al. [9] developed SRF theory based hybrid DSTATCOM for compensating the harmonics and reactive power at the source end and load end over the conventional schemes, it has good desirable features such as efficiency, cost and weight. M. Manoj Kumar et al. [10] has been proposed the dual voltage-source inverter (DVSI) scheme, in which the power produced by the distributed generation (DG) is injected as real power by the primary voltage source inverter (VSI), harmonics and unbalanced compensation was done by secondary voltage source inverter. In the DVSI scheme, usage of many switching elements leads to an increase the switching stresses, cost, size and decreases the performance of the distribution system. In the present paper it has been proposed MP-DSTATCOM minimizes the additional DG- VSC topology and compensation costs which raises the capability of power demand. The main aim of the scheme is to compensate harmonics, reactive power, power factor improvement and unbalanced load. The secondary aim is to integrate of SPV system as a local load of voltage source converter (VSC) to stable the sudden load demand. Due to uneven vary of SPV system, the output at VSC is not constant and may create unbalanced grid voltages. For controlling the grid output, novel current based controllers such as fuzzy and hybrid fuzzy controllers are introduced in this paper. It mainly focuses on achieving the following objectives. (i) To reduce the current harmonics in the distribution system due to sudden load variations with SPV system (ii) To maintain the active power connected to load is constant (iii) To analyze the % THD comparative analysis of classical and soft computing controllers with MP- DSTATCOM in distribution system.

2. Methodology

Figure 1 represents Single line diagram of PV fed MP – DSTATCOM based soft computing techniques in a power distribution system.

2.1 Proposed PV fed MP – DSTATCOM control scheme

It comprises the voltage source converter (VSC) module, DC- DC Converter, dc link capacitor, sensing elements and solar PV system etc. VSC module system device not only eliminating harmonics from various load disturbances but also act as inverter in DG operation. In harmonic elimination, VSC only the control current in distribution system. During DG operation, VSC act as inverter to control the voltage and supply active power to load. In DG system, Addition of battery to increases more energy storage. Furthermore, charge management schemes are required to improve the performance of battery [11]. Over the Battery energy storage system (BESS), Renewable energy source (RES) is the major role in DG operation. Out of many all RES systems, Solar PV system is enhances the power generation abruptly and bestowed method. The SPV system is connected to DC-DC converter to increase the level of voltage which is connected to VSC via DC link capacitor [12].The gating pulses generated using modified SRF theory and connected to MP – DSTATCOM. These control theory scheme is most advantageous in comparison with other transformations [13]. In Modified SRF scheme, first to convert a-b-c three phase currents to α - β curents and then tranformed into d – q currents. The MP- DSTATCOM supervises currents at PCC in distribution system for mitigation of harmonics, active power injection and reactive power exchanging etc.

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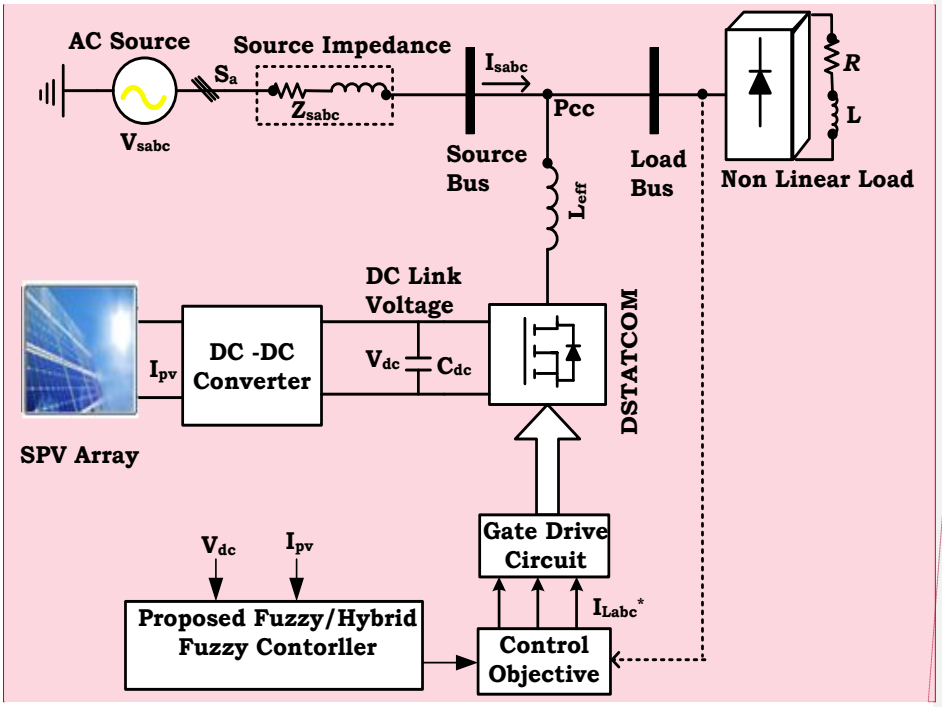

Figure 1 Single line diagram of PV fed MP – DSTATCOM based soft computing techniques in power distribution system

2.2 Proposed current based ontrollers

Over the years, control process in industry done by skilled technical experts through conventional controllers because of low cost and robust performance. These conventional controllers lagging from steady sate and transient issues such as rise time, setting time and overshoot. Later, the new technologies have been invented and developed to overcome the limitations of the conventional controller's, which includes auto tuning PI controllers, adaptive and compensation techniques. Soft computing techniques have shown to be well suited to deal with major uncertainties that may encounter in solving real world problems.

2.2.1 Fuzzy logic current controller

Fuzzy control is a flexible and effective approach, which deals with uncertainities of variable loads. Figure 2 shows proposed block diagram of fuzzy logic current controller which is performed various operations such as fuzzification, fuzzy inference and defuzzification. The determination of output signal was done in fuzzy inference with a rule base having IF-then rules. With the rule base , the value of the output was changed according to the value of the error signal 'e' and rate of error Δe. In general one introduces for each variable three, five or seven sets represented by membership functions in triangular form. In Fuzzy rule base , sizes are identical in seven classes such as Negative Big (NB), Negative Medium (NM), Negative Small (NS), Zero (ZR), Positive Small (PS), Positive Medium (PM) and Positive Big (PB). The number of the sets depend on the resolution and interference of the desired adjustmant [14]. The fuzzy rule base table illustrated in Table.1.

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Table 1. Fuzzy Rule base control

△e \ e	NB	NM	NS	ZR	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	ZR
NM	NB	NB	NB	NM	NS	ZR	PS
NS	NB	NB	NM	NS	ZR	PS	PM
ZR	NB	NM	NS	ZR	PS	PM	PB
PS	NM	NS	ZR	PS	PM	PB	PB
PM	NS	ZR	PS	PM	PB	PB	PB
PB	ZR	PS	PM	PB	PB	PB	PB

The adopted law is a function of the error and its variation (U = f(e,Δe). The general form of law of command is given by

$$U_{K+1} = U_K + (G_{K+1} \times \Delta U_{K+1}) \quad (1)$$

Where G_{K+1} is the profit associated with the order U_{K+1} and ΔU_{K+1} is the exit of the fuzzy controller which represents variation of the command U. During defuzzification process,centroid method is used for balace the heights.it is defined as follows.

$$X_R^* = \Delta U = \sum_{i=1}^{n} \frac{\mu(x_i)x_i}{\mu(x_i)} \quad (2)$$

The difference between reference DC-link voltage (v_{dcr}) and measured DC-link voltage(v_{dca}) gives the error voltage (v_{dcer}) is shown Eqn. (3).

$$v_{dcer} = v_{dcr} - v_{dca} \quad (3)$$

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The error voltage is processed through Fuzzy logic controller and provide the active current as Δi_d.The resultant reference current is the sum of $I_{pv,}$ Δ_{id}components and fundamental active i_{Ldq} components for active compensation of PQ enhancement and operation of DG in the 3 - phase distribution power system is illustrated in Eqn. (4).

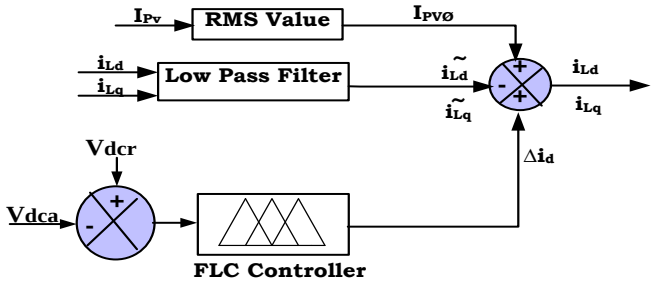

Figure 2 proposed block diagram of fuzzy logic current controller

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$$\begin{bmatrix} i_{Ld} \\ i_{Lq} \end{bmatrix} = \begin{bmatrix} \overline{i_{Ld}} \\ \overline{i_{Lq}} \end{bmatrix} + \begin{bmatrix} \tilde{i}_{Ld} \\ \tilde{i}_{Lq} \end{bmatrix} + \Delta i_d + I_{pv} \quad (4)$$

The fuzzy logic controller generates reference currents to trigger the switches of MP-DSTATCOM and control the harmonics and voltage in distribution system.

2.2.2 Hybrid Fuzzy based current controller

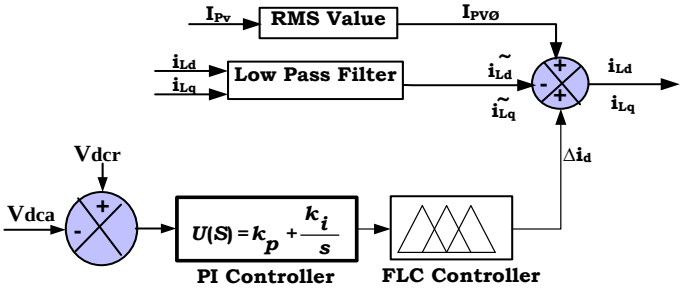


Figure 3 Block diagram of hybrid fuzzy based current controller

Commented [WU7]: Draw the membership function variables (input and output variables) for your fuzzy set model. If it is the same as the previous fuzzy MFs, just draw it once.

The PI controller possesses specifically good performance under steady state conditions, where fuzzy controller performance was good at transient conditions, the advantages of both of the theses controllers was included in the single controller i.e. hybrid fuzzy based controller[15].

3. Results and Discussion

The proposed PV fed MP-DSTATCOM based fuzzy and hybrid fuzzy current based controller in distribution system parameters are described in table 2.

Table 2. System Parameters

Parameter(s)	Value(s)
Source Voltage	415V
Impedance of source	0.1+j0.28Ω
Impedance of load	30+j9.42Ω
DC-Link Capacitor	4000μF
Proportional gain (K_p)	18.3
Integral gain (K_i)	6.3
Resistance(R)	0.1Ω
Inductance (L)	5mH

3.1 Evaluation of MPDSTATCOM with MSRF control scheme with DG operation under 50% loading condition in distribution power system

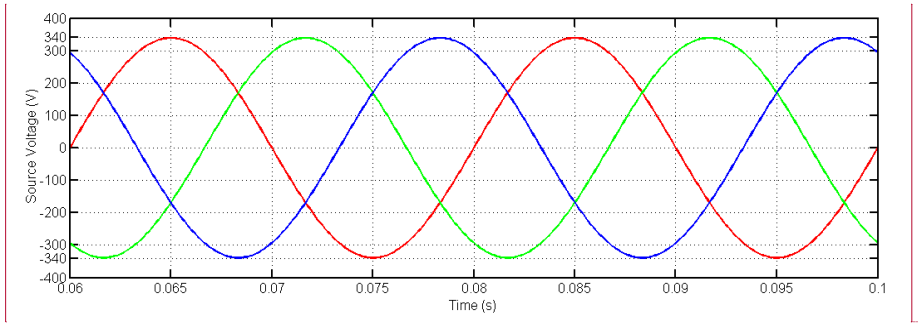


Figure 4(a) Source Voltage

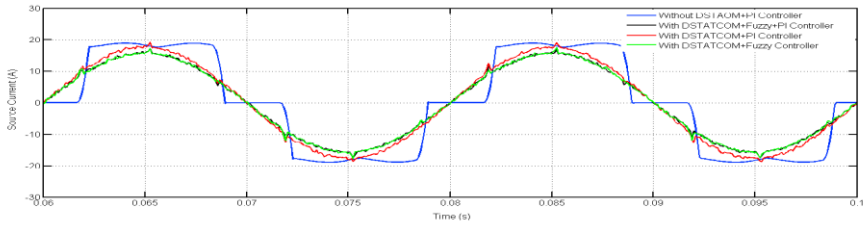
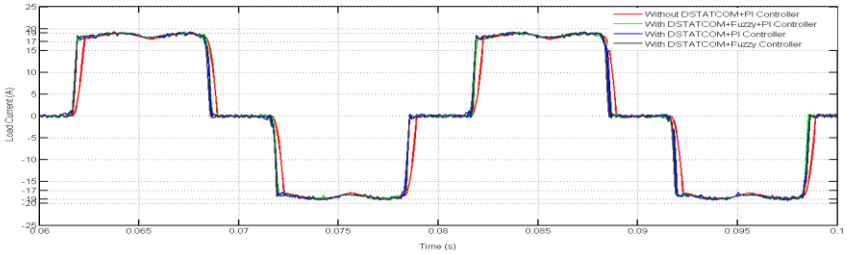


Figure 4(b) Source current



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2. You don't need to use the grid in the image if you want to highlight the numbers in the image that overlap each other to analyze the results. Use the zoom menu in the figure section do you want to enlarge and place it also in this figure.

Figure 4(c) Load Current

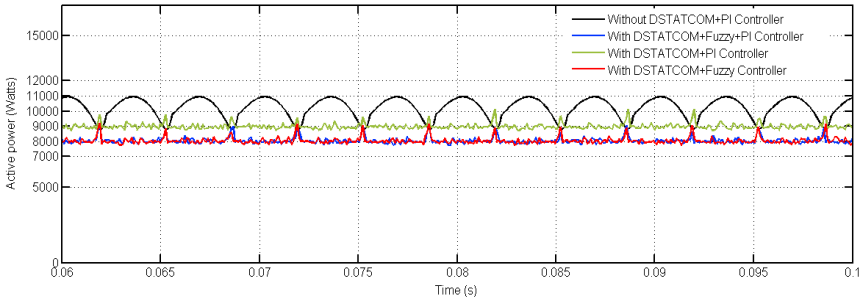

Figure 4(d) Active power

Figure 4 Simulation results of PV fed MP – DSTATCOM based soft computing techniques in power distribution system under 50% loading condition

Figure 4 shows the simulation results of PV fed MP – DSTATCOM based soft computing techniques in power distribution system under 50% loading condition. The distribution system is connected to supply, which is driven by 415 V, 50Hz and load side connected to nonlinear balanced load of (30+j30) Ω respectively. Due to nonlinear load, the source voltage doesn't disturbed and it gives pure sinusoidal waveform with the voltage of 340V is illustrated in figure 4(a). Figure 4(b) represents source current of without MP - DSTATCOM, with MP - DSTATCOM +PI controller, With MP-DSTATCOM +Fuzzy controller, and With MP-DSTATCOM + PI + Fuzzy controller respectively. Without MP- DSTATCOM, the source current shows non sinusoidal waveform due to nonlinear load and it has large number of har*monics with a peak current is* 18A. After connecting MP –DSTATCOM with PI Controller, the source current is modified into sinusoidal wave form of current 18A peak magnitude and with fewer harmonic. In MP – DSTATCOM with fuzzy logic controller, the source current was reduced to harmonics with a magnitude of 16A and sinusoidal. In MP-DSTATCOM with fuzzy and PI controller, the source current shows pure sinusoidal with less harmonics. Figure 4(c) shows load current of without MP - DSTATCOM, with MP - DSTATCOM +PI controller, With MP-DSTATCOM +Fuzzy controller, and With MP-DSTATCOM + PI + Fuzzy controller respectively. The distribution system on load side connected to nonlinear load. Due to this load, the current drawn on load side with peak magnitude of 18A and wave form is non-sinusoidal in all cases. But MP - DSTATCOM only concentrate on source side end but not in load side end. Without MP- DSTATCOM, the active power transfer to load is not constant is represented in figure 4(d). The MP – DSTATCOM with PI, Fuzzy and PI+ Fuzzy controllers, the active power transferred to load is maintained constant. The total harmonic distortion source current comparative analysis of several controllers under 50% DG energy loading condition is depicted in table 3.

Table 3 THD source current comparative analyses several controllers under 50% DG energy loading condition

THD (%)	Without MP-DSTATCOM	With MP-DSTATCOM+PI controller	With MP-DSTATCOM+fuzzy controller	With MP-DSTATCOM+ PI +fuzzy controller
Source Current	27.07	3.40	2.49	2.05

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2. For the system with MP-DSTATCOM+ PI +fuzzy controller, the THD value is 2.05. Is the average THD for phases A, B, and C or only THD for one phase.
3.Simulate and plot harmonic spectra of 2.05.

3.2 Evaluation of MPDSTATCOM with MSRF control scheme with DG operation under 100% loading condition in distribution power system

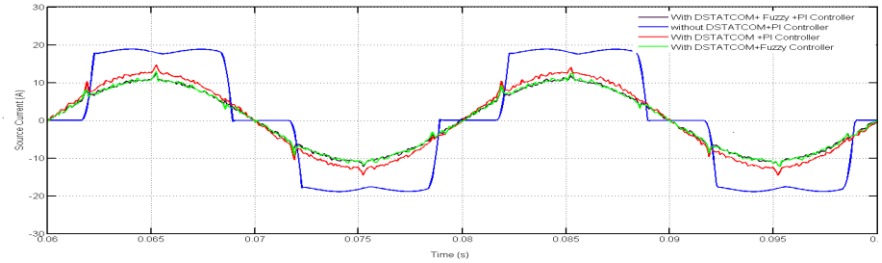

Figure 5(a) Source current

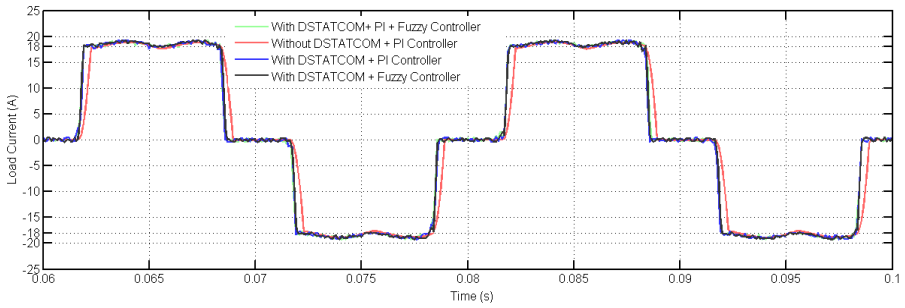

Figure 5(b) Load current

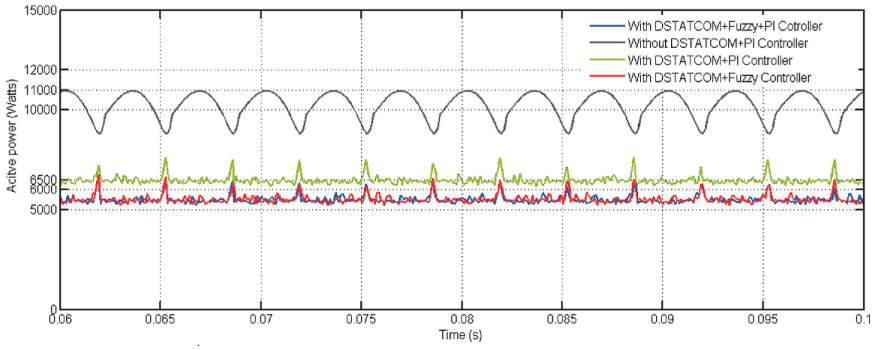

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Table 4 THD source current comparative analysis several controllers under 100% DG energy loading condition

THD (%)	Without MP-DSTATCOM	With MP-DSTATCOM+PI controller	With MP-DSTATCOM+fuzzy controller	With MP-DSTATCOM+ PI +fuzzy controller
Source Current	27.07	4.03	3.35	2.21

Commented [WU14]: Same question with Table 4. for MP-DSTATCOM+ PI +fuzzy controller for THD source current of 2.21.

4. Conclusions

In this paper, MP-DSTATCOM based fuzzy and hybrid (PI+ Fuzzy) current controllers are proposed and which provides the optimal switching states under both power quality and DG operation. The following conclusions are discussed in this paper is:

- MSRF control strategy-based PV fed MP – DSTATCOM under different loading are modeled and eliminated source side current harmonics due to non - linear load.
- The advanced control theory (MSRF) furnishes constant active power to the load under variations in SPV system by using active control function which reduces the cost, size and additional controller.
- Validation results of source current at PCC of THD clearly indicated that, MSRF theory-based PV fed MP-DSTATCOM under various controllers such as PI, fuzzy and PI+ fuzzy in Distribution system are well within IEEE 512-1992 standard limits.

Commented [WU15]: 1. Make all concluding statements in one paragraph (not per point).
2. Describe the weaknesses of your proposed method and the future work required to solve the problem. Explain at the end of the conclusion paragraph.

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Reviewer's questionnaire

Author – s: Chinna Kullay Reddy D [1*], Satya Narayana S [2] and Sri Kumar K [3]

Title of the manuscript: POWER QUALITY ENHANCEMENT IN PHOTOVOLTAIC SYSTEM INTEGRATED DISTRIBUTION SYSTEM WITH SOFT COMPUTING TECHNIQUES

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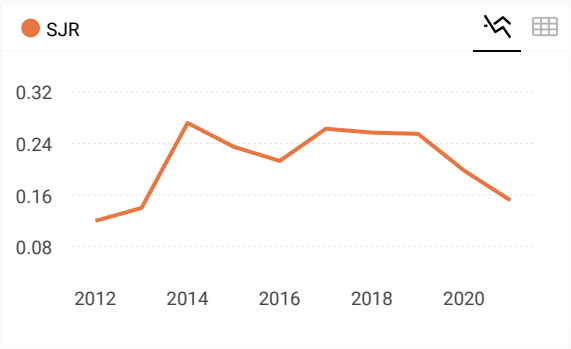

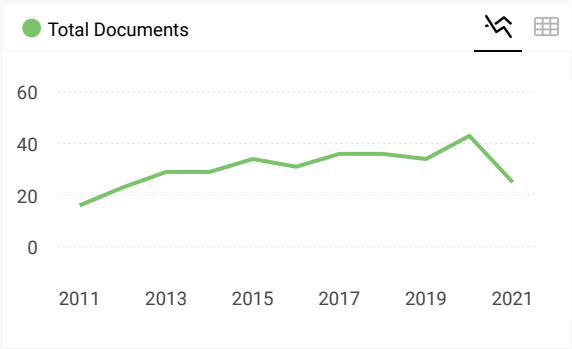

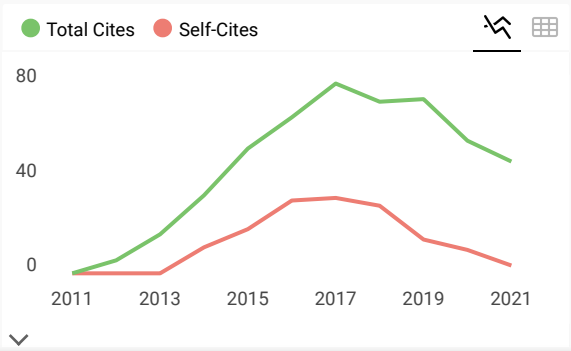

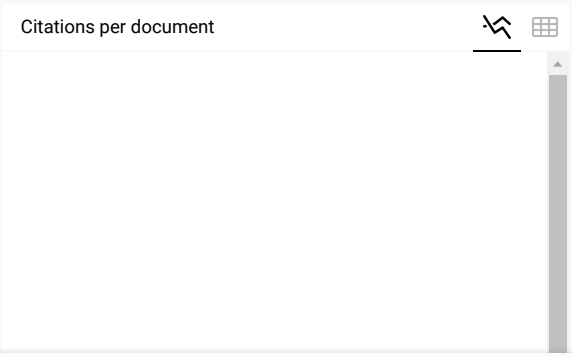

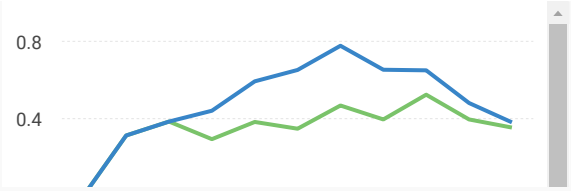

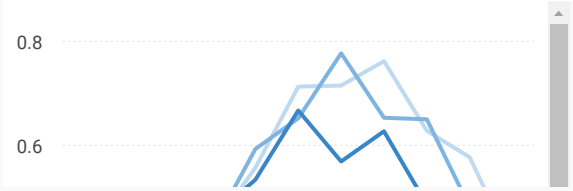

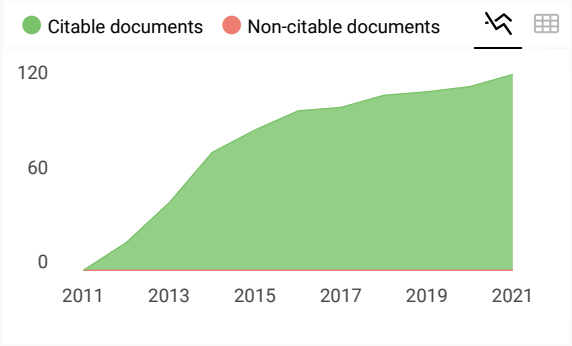

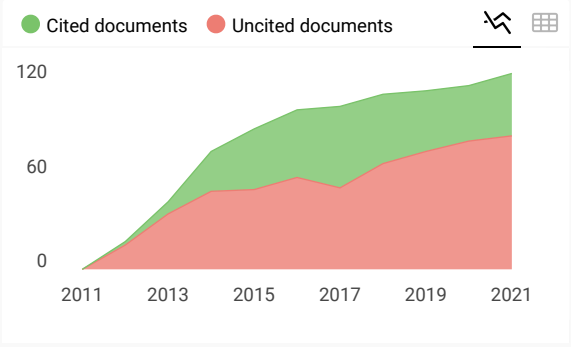

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