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Power Quality Improvement on 11kV/440V Distribution System Using DSTATCOM

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ABSTRACT

In order to remove harmonics from the source and PCC sides of the current and voltage waveform, this article explains how to apply a distribution static compensator. Responsive power remuneration and voltage control are additionally remembered for the review. A technique for creating a reference current exchanging signal is recommended: simultaneous reference control. This study pertains to an imbalanced nonlinear load distribution system that operates at II kV/440V and uses three phase four wires. We examine the suggested distribution system's performance in relation to mitigation harmonics and DC link voltage using fuzzy logic and PI controllers. It is possible to reduce harmonic distortion and control reactive power using the suggested approach. The results of the simulations are generated by use of the MATLAB/SIMULINK program.

1. INTRODUCTION

In industrial applications, the use of power electronic devices has significantly increased over the last decade due to their efficiency in power transfer [1]. However, this widespread reliance on power electronic technology has led to several power quality issues, such as reactive power problems, imbalanced load currents, and harmonic pollution. These issues arise because distribution systems heavily depend on nonlinear loads, which distort the power waveform and degrade power quality.

One of the key concerns is poor power factor, which can cause sensitive equipment to malfunction, lead to overheated motors, and reduce transformer efficiency [2-3]. Additionally, unbalanced loads can result in unbalanced source voltages, further contributing to power quality deterioration. Unbalanced voltages can negatively affect electric machine drive systems, causing reduced torque and negative sequence currents. They can also lead to the generation of lower-order harmonic components in the power system, further worsening power quality [4-5].

Unbalanced and nonlinear loads also contribute to excessive neutral currents, which can disrupt power system operations. To mitigate these power quality issues, several power devices are employed, such as circulation static compensators, dynamic voltage restorers, and unified power quality conditioners. Among these, distribution static compensators (DSTATCOMs) are particularly useful for addressing reactive power issues, non-sinusoidal currents, load variations, voltage fluctuations, and current-related problems [7].

To improve waveform quality and eliminate neutral current, inverter-based solutions are another viable option. A three-leg voltage source inverter (VSI) with a split-type capacitor can be used in various transformer-based configurations, such as T-connected transformers and star-delta transformers [8-9]. These transformer-based solutions help remove the zero-sequence component of the current, while three-leg VSIs effectively control positive and negative current components. The DSTATCOM inverter-based design integrates different configurations, including three-phase VSIs with three single-type legs, four-leg VSIs with split-type capacitors, and three-phase VSIs with three legs [10-12]. Each of these techniques has its own advantages, requiring careful evaluation to determine the most suitable approach.

In this study, a three-legged VSI and a split-phase capacitor are employed. The synchronous reference frame (SRF) control method, combined with a proportional-integral (PI) regulator, is used to regulate the DC-link

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voltage. However, achieving precise mathematical model values for the PI controller can be challenging. Moreover, the PI controller may not yield accurate results when faced with parameter variations or load fluctuations [12-14].

Due to these limitations, fuzzy logic controllers have gained interest for DSTATCOM applications. Unlike PI controllers, fuzzy logic controllers do not require exact mathematical model values and can handle nonlinearities even with uncertain input values. The Mamdani-type fuzzy logic controller is commonly used in SRF-controlled DSTATCOMs due to its superior performance compared to traditional PI controllers [15-17].

This case study investigates the use of a split-phase capacitor VSI and an SRF-controlled DSTATCOM in an 11/0.4 kV distribution system. The performance of the proposed DSTATCOM is analyzed under unbalanced nonlinear load conditions, focusing on DC voltage regulation and harmonic reduction.

2. SYSTEM CONFIGURATION

The proposed Distribution static compensator (DSTATCOM) along with the system configuration in observed in Figure 1. It is introduced to 3-ϕ, four-wire distribution frameworks that have nonlinear and imbalanced (unbalanced) loads. An uneven nonlinear burden is connected to the 400V result of the 11/0.4Kv three stage transformers, which step down the 11 kv three stage source voltage. Power quality concerns are develop° at the PCC with the linked system due to an imbalanced nonlinear burden.

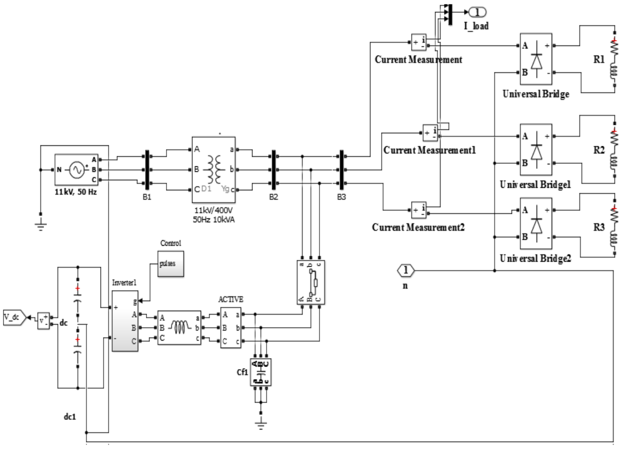


Fig. 1. System configuration.

Unbalanced loading at the PCC and load voltage may be removed and harmonics can constrained by associate DSTATCOM with a split-phase capacitor at the power conversion converter (PCC). Additional benefits include corrected power factor, regulated line voltage at the bus, and balanced loads.

An interface inductor (L_f) and six IGBT switches make up a three-leg voltage inverter based DSTATCOM. The L_f regulates the dc-interface voltage using a split-phase capacitor. To control the voltage transients and switching that happen during DSTATCOM switching, a three-phase filter made of capacitance (c_f) and resistance (r_f) may be used. The VSI DSTATCOM's exchanging signals are managed and controlled by utilizing a synchronous reference approach with hysteresis band current control.

3. PROPOSED CONTROL ALGORITHM

Figure 2 is a schematic depicting the proposed strategy for controlling SRF. On account of a nonlinear burden lopsidedness, the control approach is utilized to determine the key reference control signals. These signals are then utilized to activate VSI-based DSTATCOM, which regulates reactive and harmonic power.

Active, harmonics, and reactive parts developed with the nonlinear loads connected in a three-stage system. To account for it, we divide the reactive and harmonic currents according to Clark's equation, which is eq. (1). This change from three-stage load momentary currents to two-stage fixed α-β-0 edges is a piece of the detachment interaction.

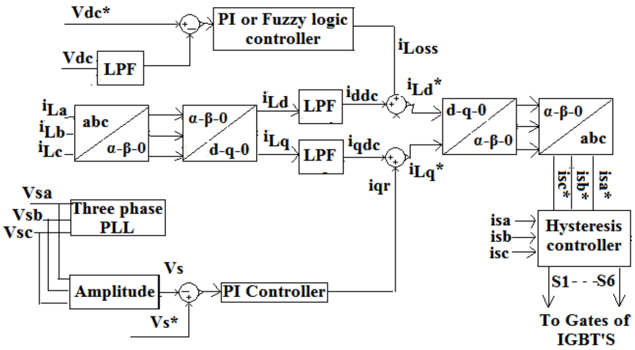


Fig. 2. The suggested control algorithm's block diagram.

$$\begin{bmatrix} i_{L0} \\ i_{L\alpha} \\ i_{L\beta} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1/\sqrt{2} & 1/\sqrt{2} & 1/\sqrt{2} \\ 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} i_{La} \\ i_{Lb} \\ i_{Lc} \end{bmatrix} \tag{1}$$

The three types of nonlinear load currents in a three-phase system are harmonic, active, and reactive. In order to make up for it, this separates the reactive and harmonic parts of the current. Using the help of Clark's change condition, given in condition (1), the two-stage fixed α-β-0 hub might be utilized to change over the momentary three-stage load flows into a separate process.

$$\begin{bmatrix} i_{L0} \\ i_{Ld} \\ i_{Lq} \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\theta & \sin\theta \\ 0 & -\sin\theta & \cos\theta \end{bmatrix} \begin{bmatrix} i_{L0} \\ i_{L\alpha} \\ i_{L\beta} \end{bmatrix} \tag{2}$$

In this instance, θ stands for the transformation angle. In order to make the current and voltage into synchronization, the sine θ and cos θ are gotten from the voltage supply of a 3-phase PLL block, which is otherwise called a phase locked circle. The active and reactive loads current are the ones they are derived from the currents of i_{Ld} and i_{Lq}, respectively. A typical current component, as shown in equations (3) and (4), comprises of a typical worth (the dc part) and a oscillating part (the ac part).

$$i_{Ld} = i_{ddc}+i_{dac} \tag{3}$$

$$i_{Lq} = i_{qdc}+i_{qac} \tag{4}$$

The normal or dc part of i_{Ld} is addressed by id dc and iqdc, whereas the wavering or ac part of iLq is represented by id ac and iqac. Here, oscillating part represent the harmonic component. By use of low pass filter is used to kill the oscillatory current part. Finally we get the active and reactive current parts by utilizing Conditions (5) and (6).

$$i_{Ld} = i_{ddc} \tag{5}$$

$$i_{Lq} = i_{qdc} \tag{6}$$

To maintain a steady DC connect voltage and give the misfortunes in DSTATCOM, the result current of the PI or fuzzy rationale regulator is added to the normal powerful reference current piece of the d-center point in the d-q outline as a misfortune current part (i_{Loss}). Afterwards, the actively used portion of the reference current is by eq. (7).

$$i_{Ld}{}^*=i_{ddc}+i_{loss} \tag{7}$$

The component of the direct axis reference current ($i_{Ld}{}^*$) serves as the rectifier for power factor and harmonics.

To modify the voltage at the PCC, a source is supposed to give the reactive current (iqr) and it is added to the typical reactive reference part of current (i_{qdc}) of the q-axis. This causes a portion of the final reactive reference current is given eq. (8)

$$i_{Lq}{}^*=i_{qdc}+i_{qr} \tag{8}$$

You can get the reactive current (i_{qr}) using the PI regulator's result, and you can get the PI regulator's contribution by taking comparison with the reference voltage (V^*_s) and the real voltage amplitude (V^*_s),

In this case, the PCC voltage amplitude is expressed as

$$\mathrm{Vs} = \sqrt{2/3\,(V_{sa}^2 + V_{sb}^2 + V_{sc}^2\ )} \tag{9}$$

This is the result of the PI regulator:

$$V_{qr(n)}=V_{qr(n-1)}+K_{pq}(V_{te(n)}-V_{te(n-1)})+K_{iq}V_{te(n)} \tag{10}$$

At the nth sampling instant, the difference between the reference (V^*_s) and real (V^*_s) terminal voltage abundancy is referred to as $V_{te(n)} = V^*_s - V_{s(n)}$. K_{pq} and K_{iq}, the proportional and integral values of the PI regulator, are utilized in this context, respectively.

To Applying the reactive reference current part ($i_{Lq}{}^*$) helps control the ac voltage and compensates for the load's reactive power.

The components of dynamic and reactive reference currents ($i_{Ld}{}^*$, $i_{Lq}{}^*$) are changed into the α-β-0 frame utilizing Converse Park's Condition (11).

$$\begin{bmatrix} \mathrm{i_{s0}}^* \\ \mathrm{i_{s\alpha}}^* \\ \mathrm{i_{s\beta}}^* \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\theta & -\sin\theta \\ 0 & \sin\theta & \cos\theta \end{bmatrix} \begin{bmatrix} \mathrm{i_{L0}}^* \\ \mathrm{i_{Ld}}^* \\ \mathrm{i_{Lq}}^* \end{bmatrix} \tag{11}$$

The reference flows from Opposite Park's might be changed into three-stage reference flows (a-b-c) by utilizing reverse Clark's Condition (12).

$$\begin{bmatrix} i_{sa}{}^* \\ i_{sb}{}^* \\ i_{sc}{}^* \end{bmatrix} = \sqrt{\tfrac{2}{3}} \begin{bmatrix} 0 & 1 & 0 \\ 0 & -1/2 & \sqrt{3}/2 \\ 0 & -1/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} \mathrm{i_{s0}}^* \\ \mathrm{i_{s\alpha}}^* \\ \mathrm{i_{s\beta}}^* \end{bmatrix} \tag{12}$$

To turn on the switches of the VSI of IGBTs, the getting three-phase reference current (isa*, isb*, isc,*) are match with the genuine filter current at the hysteresis band controller. When contrasted with different regulators, in terms of transporter based, dab beat, feed-forward, and fast movement, this hysteresis band regulator has various benefits, the most remarkable of which are its simplicity of establishment, further developed dependability, and speedier response time [18]. A significant drawback of the carrier based regulator, as check with the hysteresis band controller, is the pressure at switching components because of the constantly fluctuating the frequency of turn on & turn off devices.

4. DC BUS LINK REGULATION

The creation of the compensating reference current crucial to the performance and quality of DSTATCOM, and dc link voltage control is perhaps of the main calculate this interaction. V_{dc}, the dc-link voltage, goes up or down according on the compensatory current required. A certain reference value must be kept up with on the dc side of the inverter for VSI to function correctly [17]. By keeping the dc-interface voltage consistent, the channel and exchanging power misfortunes of the VSI are survived. Adding the typical dynamic current part ($i_{d\ dc}$) of the d-pivot requires a regulator in turning outline hypothesis to manage or keep the dc-connect voltage steady. In this case, we have included and compared the following two controllers.

- Controller with proportional and integral values.
- Controller with Fuzzy logic.

4.1. Controller with proportional and integral values

The block chart of the PI regulator is displayed in Figure 3. This is the control circuit's inner workings. The source must provide the dynamic reference current part 00 and the misfortune reference part of current (Loss) in order for the DSTATCOM and filter to supply losses. By looking at the reference dc transport voltage Vdc* with the genuine do transport voltage Vdc (Vdcl+Vdc2=Vdc) of VSI at the nth testing moment, the misfortune reference part of current

(i_{Loss}) may be derived.

$$V_{de(n)}=V_{dc*(n)}-V_{dc(n)} \tag{13}$$

One way to calculate the loss component (i_{Loss}) at the nth inspecting moment is by processing the compared error signal $V_{de(n)}$ via a PI controller.

$$i_{Loss(n)}=i_{loss(n-1)}+k_{pd}(V_{de(n)}-V_{de(n-1)})+k_{id}V_{de(n)} \tag{14}$$

The necessary increase of the PI regulator is denoted by kid, whereas the proportional gain is represented by kpd. The valves have a kpd of 0.6 and a kid of 0.09. When the PI regulator is finished, the DSTATCOM's misfortune reference part (i_{Loss}) is the outcome. To control the dynamic reference current (i_{Ld}^*), the misfortune reference current (i_{Loss}) is added to the typical dynamic reference current (i_{Ld}), In request to work on the exchanging of the VSI of IGBTs, the hysteresis band regulator contrasts the assessed reference current part and the genuine repaying channel flows.

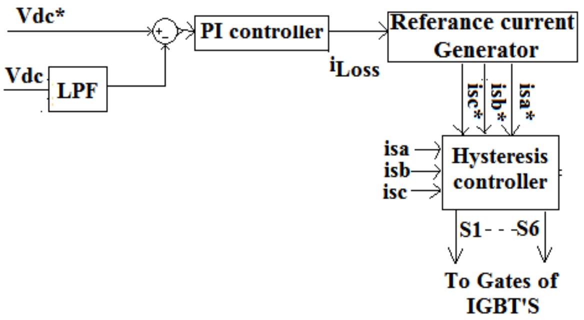


Fig. 3. Block diagram of PI controller.

4.2. Controller with Fuzzy logic

The suggested internal architecture of the fuzzy rationale regulator is displayed in Figure 4. We actually take a look at the voltage between the reference dc voltage and the genuine across the connection capacitor. The fuzzy rationale regulator processes the mistake signal. The mistake signal is gotten by looking at the genuine detected repaying channel current in the hysteresis band with the resultant compensating current, which is then added to the key dynamic current part. This cycle is rehashed until the dc-connect voltage stays steady and the dynamic power is sufficient to compensate the losses in the VSI. The error signal determines how the VSI operates. FIS includes tools for editing membership functions, rules, and surfaces, as well as tools for defuzzification and the Fuzzy Inference System (FIS) Editor. Tables [18-20].

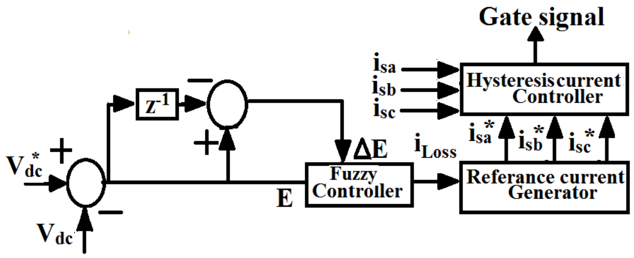


Fig. 4(a). Logic controller block diagram used in fuzzy logic.

This paper describes the fuzzy interface framework that we created as:

- The quantity of information sources and the quantity of results are 2.
- There are seven membership functions.
- The kind of implication (max-min operation described by Mamdani).
- Method for defuzzification (centroid of area approach).
- One hundred and forty-nine rules.
- This is a Gaussian input membership function.
- Triangular output function for membership

It was decided the decision variables may take on one of M potential values depending on the N2 possible permutations of the N phonetic factors utilized in the info and result. State is the name given to any conceivable combination. The resultant fuzzy matrix is 49, calculated as (42*M). The membership functions use all 49 states as control variables.

In terms of reaction time and overall improvement in DSTATCOM behavior, the fuzzy logic controller emerged victorious between the two.

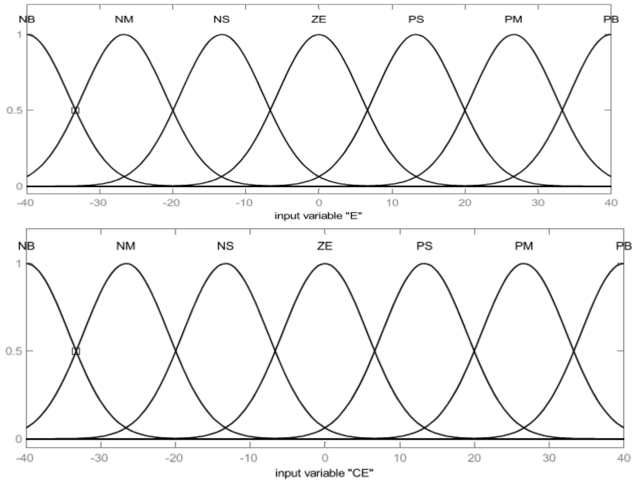


Fig. 4 (b). For the input variable (E), the Gaussian membership function is shown in Figure 4(c). For the change in the input variable (AE), the Gaussian membership function is used.

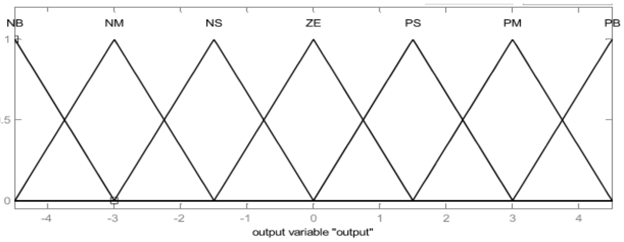


Fig. 4(d). Enrollment capability for a triangular output variable.

Table 1. Table of decision rules

E/ΔE	**NB**	**NM**	**NS**	**ZE**	**PS**	**PM**	**PB**
NB	NB	NB	NB	NB	NM	NS	ZE
NM	NB	NB	NB	NM	NS	ZE	PS
NS	NB	NB	NM	NS	ZE	PS	PM
ZE	NB	NM	NS	ZE	PS	PM	PB
PS	NM	NS	ZE	PS	PM	PB	PB
PM	NS	ZE	PS	PM	PB	PB	PB
PB	ZE	PS	PM	PB	PB	PB	PB

5. RESULTS AND DISCUSSION

The simultaneous reference outline control strategy with PI and FUZZY rationale regulator, the suggested DSTATCOM model is created in MATLAB/SIMULINK software. Under the circumstance of an imbalanced nonlinear burden, the model is affirmed. Consonant decrease, power factor fix, and voltage control at the PCC are all accomplished with the help of the suggested model. Also contrasted are the recreation results obtained using the FUZZY logic controller and the PI. For better observation, the simulation period is set between 02 and 0.3 seconds. In these scenarios, we can see how DSTATCOM works.

- Nonlinear imbalance load not using DSTATCOM
- With the PI Controller, DSTATCOM
- DSTATCOM integrated with a fuzzy logic controller
- THD evaluation

5.1. Nonlinear imbalance load not using DSTATCOM

As seen in Figure 5 (b), harmonics in the source current (Bus-1) might occur when an unbalanced nonlinear burden is connected to the proposed dispersion framework. The source voltage waveform under unbalanced nonlinear load condition as shown in Fig.5 (a). Harmonics in the waveform of the voltage and current at the PCC (bus 2) are also introduced by the unbalanced nonlinear load. And 5(d) display the loads connected to the PCC are affected by the harmonics. The voltage and current on the load are shown in Figures 5(e) and 5(f). A waveform representation of the current at the PCC (BUS-2) with respect to phase is shown in Figure 5 (g).

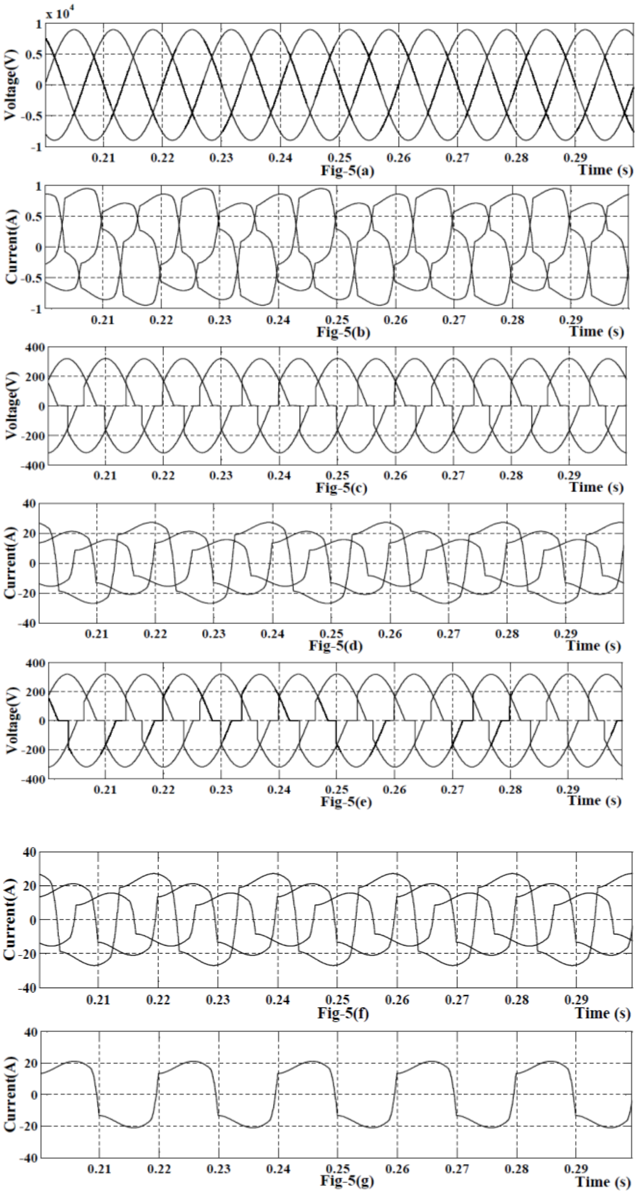


Fig. 5 (a) Waveform of the voltage, (b) Type of the wave from the supply of current, (c). Voltage at Bus-2, (d). Current at bus-2, (e). Waveform of load (f) addressing the current of load. As seen by the PCC current waveform in phase representing in fig (g). Under imbalanced nonlinear load without DSTATCOM.

5.2. DSTATCOM with PI Controller

At the point at the point when a SRF-controlled D-STATCOM is associated with the PCC, it infuses the receptive power expected to check the music in the current and voltage at the PCC, as well as those in the source current. You may manage the DC-interface voltage utilizing a PI regulator. Figure 6(b) and 6(d) are waveforms depicting the compensated source and PCC current, respectively. A compensation for the PCC voltage and R-C filter load is implemented. See the PCC's corrected and controlled voltage waveform in Fig. 6(c). Also, the heap voltage is changed, as found in figure 6 (e). See the waveform of the heap current in Figure 6(f). See Figure 6(g) for the DC-interface voltage waveform, Figure 6(h) for the per-phase load waveform, and Figure 6(i) for the PCC current waveform. Figure 6(J) illustrates the waveform of the voltage and current.

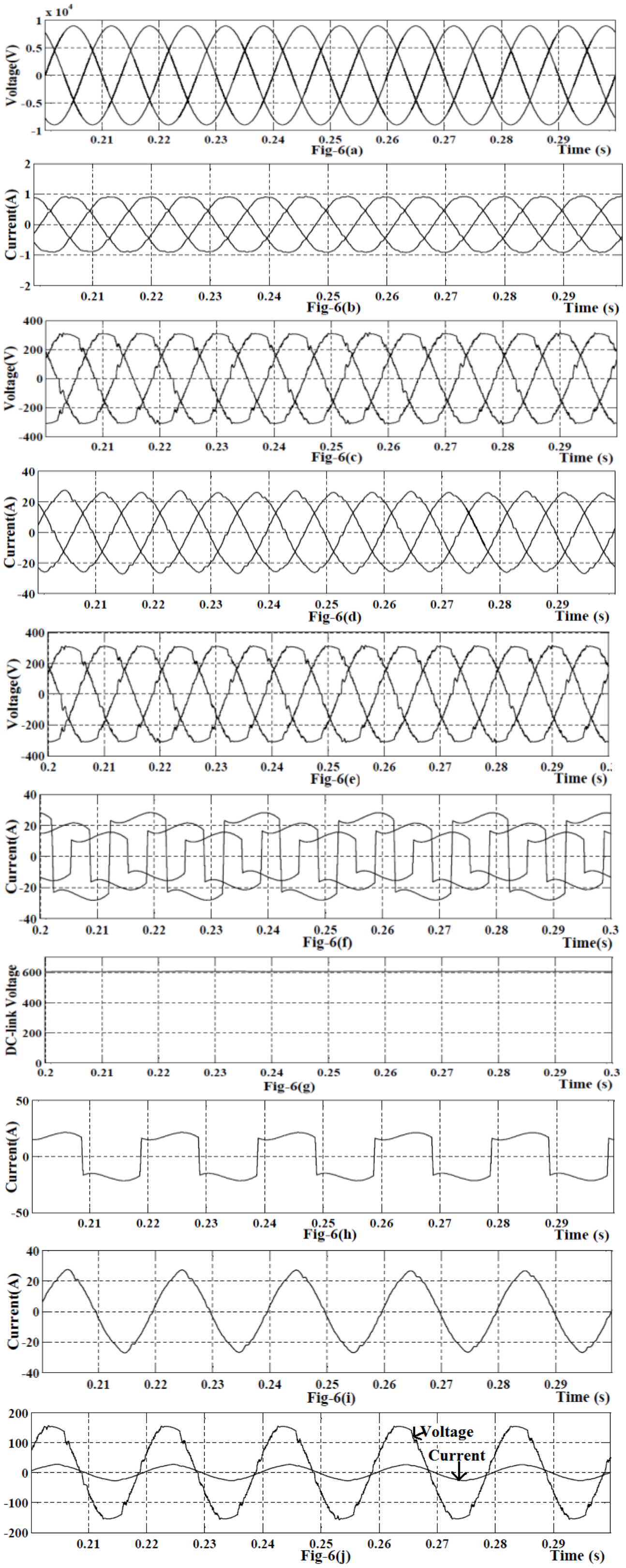
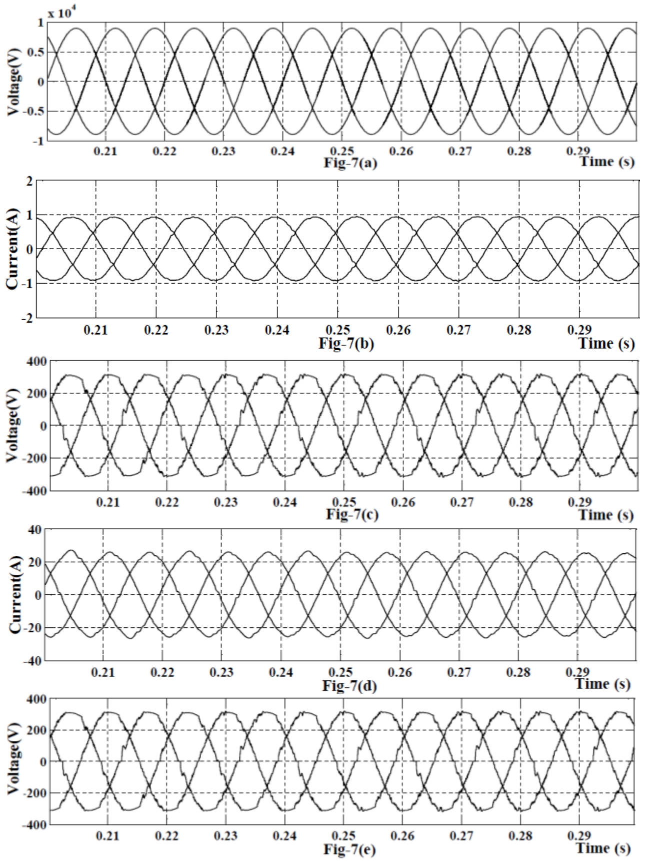


Fig. 6. (a). The voltage source's waveform, (b). Current of source, (c). Voltage of bus-2, (d). Current of Bus-2, (e). Voltage of load, (f). The waveform of current of load, (g). Voltage condition of the DC interface, (h). The load of current, addressed per stage, is (i). The ongoing waveform at the PCC, as shown per phase, (j). On the PCC (bus 2) the voltage and current waveform. Analysis of PI-controlled DSTATCOM,

5.3. DSTATCOM with Fuzzy logic controller

The SRF-controlled D-STATCOM is placed with the PCC, and it remunerates the harmonics of supply current and infuses the reactive power expected to neutralize the harmonics of the current and voltage at the PCC. The DC-interface voltage is controlled utilizing a fuzzy rationale framework. The fuzzy rationale regulator is viewed as predominant the PI regulator. Figure 7 shows the same waveforms for consonant and receptive power change while contrasting the fuzzy rationale regulator. The waveforms of the remedied source and PCC current might be found in figures 7 (b) and 7 **(d).** It makes up for PCC voltage and R-C filter load. The PCC voltage waveform that has been corrected and controlled is shown in Figure 7(c). In addition, the load voltage is changed, as tracked down in figure 7 (e). The waveform of current of load found in Figure 7 (f). Figures 7(h) and 7(i) show the waveforms of the DC-connect voltage and PCC current, respectively, while Figure 7(g) shows the per-phase depiction of the load. Figure 7(J) displays the waveform of the voltage and current.



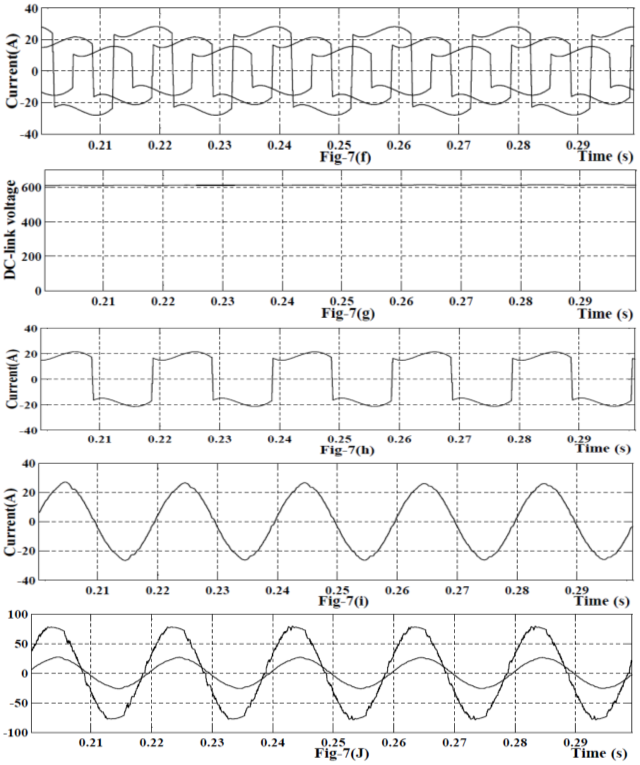


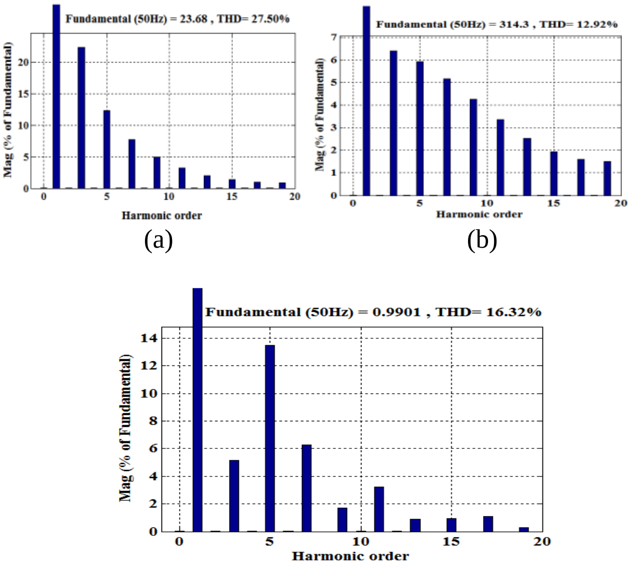
Figure 7 (a). Bus-1, voltage waveform. (b) Bus-1, Current waveform, (c). Bus-2 voltage waveform, (d). bus-2 current waveform (e). The burden voltage waveform, (f).The burden current waveform, (g).DC-transport voltage, (h) This is the waveform of the load current in phase, (i). Per phase, the current waveform at the bus-2, (j). The current and voltage waveform at bus-2, Analysis of fuzzy logic -controlled DSTATCOM.

5.4. Total Harmonic Distortion Analysis (THD)

Here we compare the suggested system with and without DSTATCOM in terms of complete symphonious bending at the source and PCC. Additionally, the analysis is carried out using PI and a fuzzy rationale regulator. source and PCC point, the THD of the proposed system with and without DSTATCOM studied here. Moreover, P1 and a fuzzy logic regulator are compared by utilization of the suggested controller.

5.4.1. Unbalanced nonlinear load without DSTATCOM

Figure 8. At the point When a nonlinear burden is associated with the framework without DSTATCOM, the all distortion (THD) is displayed in figure 8. The PCC shows an ongoing consonant contortion of 27.50% and a voltage harmonic distortion of 12.92%. Figure 8(a) and 8(b) illustrate this. The consonant contortion of the source current is 16.32%, as tracked down in figure 8 (c).in that order.



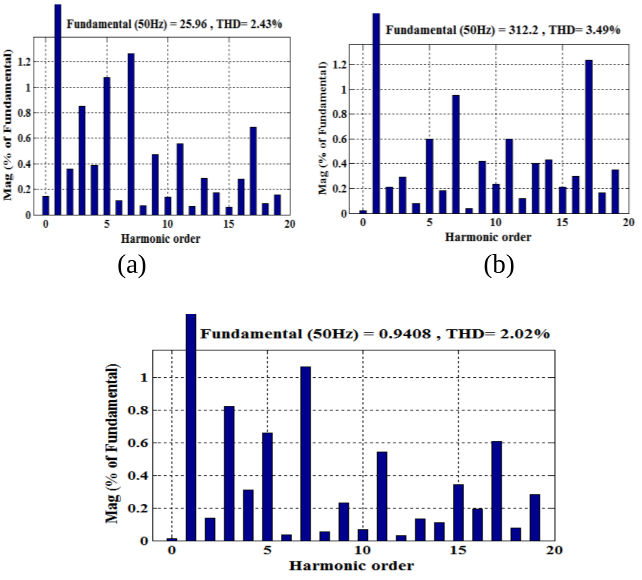
(a) (b)

(c).

Fig. 8. (a) Present total current harmonic distortion at bus-2, (b). Total harmonic distortion voltage at bus-2 (c). THD current at BUS-1.

5.4.2. DSTATCOM with PI Controller

Both Figure 9 (a) and 9 (b) demonstrate that the ongoing harmonics reduction at the PCC is diminished to 2.43% and voltage consonant twisting at the PCC is diminished to 349% subsequent to associating DSTATCOM to the proposed framework. The harmonics contortion of the source current is carried down to 2.02%, as found in figure 9(c).



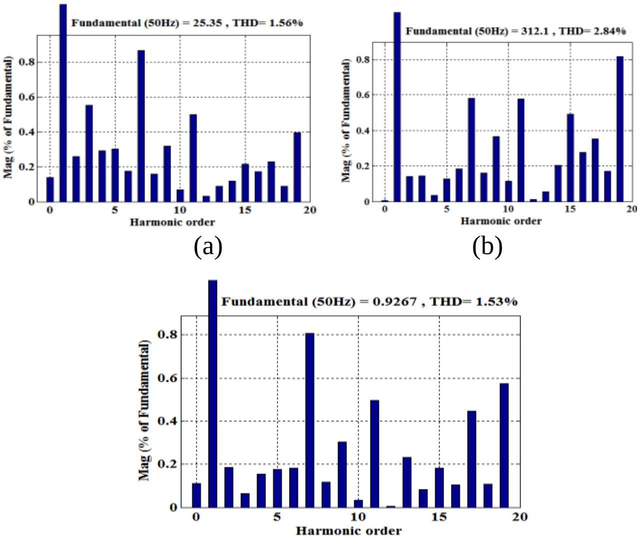
(a) (b)

(c)

Fig. 9(a). Total current harmonic distortion at bus-2, (b). Total harmonic distortion voltage at bus-2 (c). THD current at the supply (BUS-1).

5.4.3. DSTATCOM with Fuzzy Logic Controller

As seen in figures 10 (a) and 10 (b), the current & voltage harmonics at the PCC is reduced from 12.92% to 2.84%by means of fuzzy logic driven DSTATCOM. With a commensurate reduction of 1.53% in source current harmonic distortion, as seen in figure 10(c).



(a) (b)

(c)

Fig. 10(a). total current harmonic distortion of bus-2, (b). Total harmonic distortion voltage at bus-2 (c). THD current of supply BUS-1.

The section 5.4. Gives the detailed THD analysis, the study examination the, with fuzzy logic regulator DSTATCOM offers greater harmonic distortion reduction as compared to the PI regulator DSTATCOM.

6. CONCLUSIONS

This study looks at the utilization of VSI controlled DSTATCOM in managing voltage, controlling reactive power, and diminishing harmonics of three-stage, four-wire uneven nonlinear burden distribution system. The control strategy utilized is the synchronous reference control structure. This unbalanced nonlinear load distribution structure can be satisfactorily controlled with a straightforward, easily implementable control technique. We used FUZZY and PI logic controllers to analyze and compare individual performance. The DC bus voltage remains stable despite disturbances with the assistance of both controllers. Good compensation is provided by both controllers. But, in unbalanced nonlinear burden conditions, the fuzzy logic controller performs better. The MATLAB/SIMULINK software is used for getting the required results. By contrasting the PI-controlled DSTATCOM with the fuzzy logic-controlled is one, we find that the latter exhibit better transient behavior and improves power quality as a consequence of its more dynamic system response.

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