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An Innovative Fast Energy Based Fuzzy Logic DC-Link Voltage Controller for Three Phase DSTATCOM to Correct AC Loads

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***Abstract*— The distribution static compensator's (DSTATCOM) transient response is crucial when balancing unbalanced and nonlinear loads that vary fast. Any change in load will have an immediate impact on the dc-link voltage. A quick decrease in load will cause the dc-link voltage to fall below its reference value, whereas a sudden increase in load will cause the voltage to rise above the reference value. The dc-link voltage should be adjusted for dstatcom operation within the established parameters. The departure of the capacitor voltage from its reference value will be used as the input by a standard PI controller, although this controller has a delayed transient response. In this essay, a quick proposed acting fuzzy logic-based dc-link voltage controller will enable quick transient reaction. Matlab/Simulink was used to produce the simulation results.**

***Keywords*— DC-link voltage controller, distribution static compensator(DSTATCOM), harmonics, power quality (PQ), fuzzy logic, power factor**

INTRODUCTION

Due to nonlinear and unbalanced loads, power-quality (PQ) issues in the power distribution network have been growing quickly. They result in high levels of neutral-to-ground voltage, voltage distortion, excessive neutral currents, overheating of electrical equipment, and interference with communication systems [1],[2]. The transmission system is being served by the flexible ac transmission system, while the distribution system is being served by Custom Power. Among other advantages, the flexible ac transmission system enables better control over power flow and secure loading of transmission lines to levels closer to their thermal limitations.

Therefore, the functions of the traditional DSTATCOM should be expanded to both supply the dc loads from its dc link and reduce the aforementioned PQ issues. The design and rating of the VSI determine how the load is shared between the ac and dc bus. This DSTATCOM is unique from typical ones in that its dc link may supply dc loads in addition to supporting instantaneous compensation.

However, since the DSTATCOM's dc link also supplies the dc load, the corresponding dc power is comparable to the average load power and thus significantly affects the compensator's transient response. Consequently, there are two significant difficulties. The first is the control of the dc-link voltage within set parameters when transient loads are present. The dc-link voltage controller's settling time is the second. PI controllers are typically employed to keep the dc-link voltage constant.

This research proposes an energy-based fuzzy logic voltage controller based on the energy of the dc-link capacitor. To demonstrate the effectiveness of this energy-based fuzzy logic controller, thorough modelling, simulation, and experimental verifications are provided..

COMPENSATION OF AC AND DC LOADS BY USING DSTATCOM

A 3-phase H-bridge VSI architecture is depicted in Fig. 1 due to its simplicity, lack of dc-link voltage unbalance, and independent current monitoring with regard to other phases.

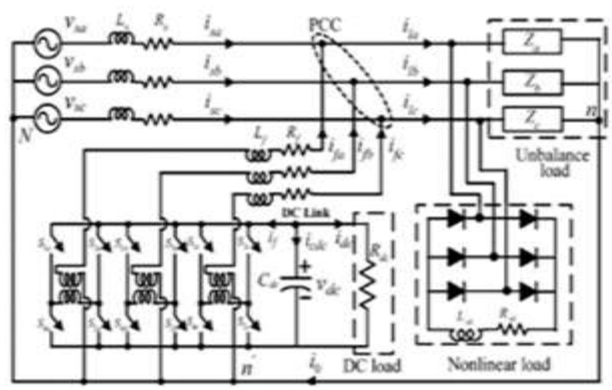

Fig.1 H-bridge VSI topology-based DSTATCOM for Three-phase copmensated system

The system in the above figure uses an H-bridge VSI topology-based DSTATCOM to adjust for an imbalanced and nonlinear ac load. A DC load is also connected across the DC link in addition to this. Twelve insulated-gate bipolar transistor (IGBT) switches, each with an antiparallel diode, a dc storage capacitor, three isolation transformers, and three interface inductors, make up the DSTATCOM. The neutral of the source and load is linked to the star point of the isolation transformers. Figure 1 shows a three-phase, four-wire compensated system with DSTATCOM based on the H-bridge VSI architecture. Interface inductors link the H-bridge VSIs to the PCC. For a variety of combinations of the switching states of the VSI, the isolation transformers guard against a short circuit of the dc capacitor. The source voltages are considered to be balanced and sinusoidal, and the inductance and resistance of the isolation transformers are also taken into account. The DSTATCOM serves the dc load through its dc bus while compensating by maintaining balanced sinusoidal source currents with unity power factor.

The source will produce balanced and sinusoidal voltage under normal conditions. This type of system experiences unbalance and harmonics in the load current if the unbalanced and nonlinear load suddenly decreases or increases [4], [5]. DSTATCOM will be utilised to inject these currents into the PCC. The dc capacitor, which gives the necessary dc load, aids in the operation of the compensator [6] [7].

MODELING OF THE DSTATCOM

As shown in Fig. 2, a DSTATCOM comprises of a three-phase voltage source inverter that is shunt-connected to the distribution network using a coupling transformer. Due to its structure, the device can produce three voltages that are almost sinusoidal and have controlled amplitude and phase angles at the fundamental frequency. In general, the DSTATCOM can be used to provide load levelling, harmonics compensation, power factor correction, and voltage regulation [3]. A more adaptable integrated controller is produced by the inclusion of energy storage via an appropriate interface to the power custom device. The DSTATCOM/capacity ESS's to deliver extra active power efficiently enables it to increase its compensatory actions, lower transmission losses, and improve the performance of the electrical grid.

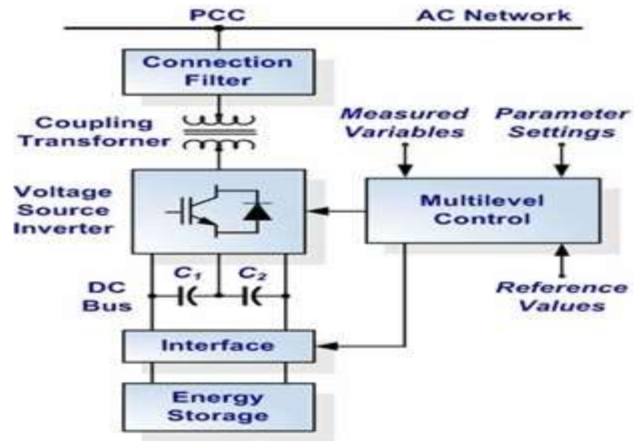

Fig.2 Basic circuit of a DSTATCOM

The state-space equations are written using the following system notations in order to calculate the system actual currents:

$$\dot{x} = Ax + Bu \quad \text{........ (1)}$$

x=state vector

u=input vector

$$x = [i_{fa} \quad i_{fb} \quad i_{fc} \quad V_{dc}]\Gamma$$

$$u = [v_{sa} \quad v_{sb} \quad v_{sc}]\Gamma$$

$$A = \begin{pmatrix} -\frac{R_f}{L_f} & 0 & 0 & \frac{(s_a-\overline{s_a})}{L_f} \\ 0 & -\frac{R_f}{L_f} & 0 & \frac{(s_b-\overline{s_b})}{L_f} \\ 0 & 0 & -\frac{R_f}{L_f} & \frac{(s_c-\overline{s_c})}{L_f} \\ -\frac{(s_a-\overline{s_a})}{C_{dc}} & -\frac{(s_b-\overline{s_b})}{C_{dc}} & -\frac{(s_c-\overline{s_c})}{C_{dc}} & -\frac{1}{R_{dc}C_{dc}} \end{pmatrix} \quad \text{............... (2)}$$

$$B = \begin{pmatrix} \frac{1}{L_f} & 0 & 0 \\ 0 & \frac{1}{L_f} & 0 \\ 0 & 0 & \frac{1}{L_f} \\ 0 & 0 & 0 \end{pmatrix} \quad \text{.................... (3)}$$

The system state variables are computed at each instant using the state-space model discussed above [1].

The DSTATCOM must absorb active power from the power source to supply the power losses and charge the DSTATCOM's dc-link capacitor in order to maintain the dc-link voltage of the inverter during operation at a specified level. Therefore, the DSTATCOM controller manages the active current | Ir| of the DSTATCOM by using a proportional-integral type feedback controller [13]. and three phase currents are necessary for base current comparison. The controllers will get the outcome in the form of voltages. With the use of the following diagram, as illustrated in fig.3, these currents are obtained.

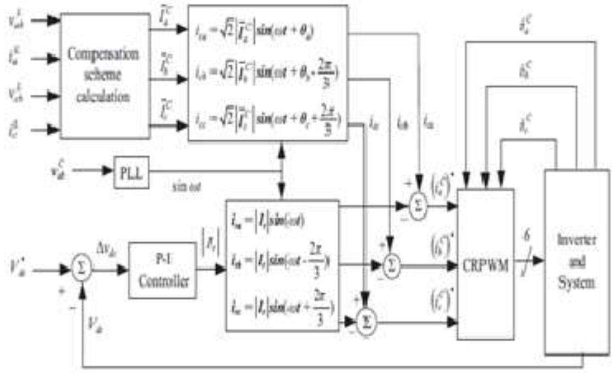

Fig. 3 Block diagram of the proposed DSTATCOM controller currents

Design Of Fuzzy Logic Controller

Using the MATLAB fuzzy logic toolbox, a Mamdani type fuzzy PD controller is designed [8]. The toolbox defines the membership functions of the input (error and rate of change of error), output (control action), and rule base variables. The proposed Fuzzy Inference System took the place of the PI controller block in the DSTATCOM's control architecture (FIS). The DSTATCOM was then simulated for the same load while keeping all other settings.

Fuzzy Control Scheme For D-Statcom.

The core of fuzzy set theory is fuzzy logic (FL) controller, which uses linguistic variables rather than numerical ones as its main characteristic. This quality control method is founded on the assumption that people can comprehend how a system behaves. Fuzzy logic offers a straightforward method for drawing a firm conclusion from hazy, imprecise, noisy, ambiguous, or missing input data.

Figure 4 shows the structure of an FLC, which consists of four main parts.

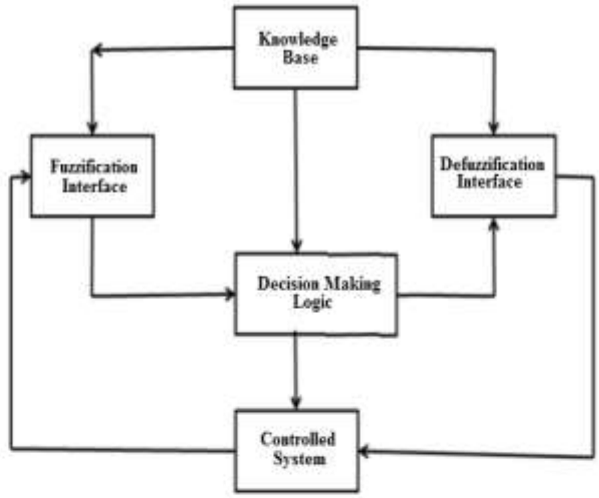

Fig.4 Basic structure of fuzzy logic controller

- The input data will be converted into appropriate linguistic values by the fuzzification interface.
- The Knowledge Base is a data base containing a set of control rules and the necessary language definitions.
- A Decision Making Logic will interface the fuzzy control action from the knowledge of the control rules and the language variable definitions, emulating a human decision process.
- A non-fuzzy control action is produced by the defuzzification interface from an inferred fuzzy control action.

Membership Functions

The input and output membership functions and the rule base are shown below.

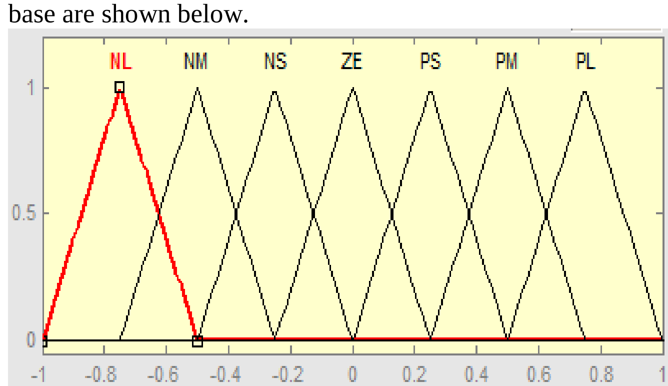

Fig. 5: Error as input

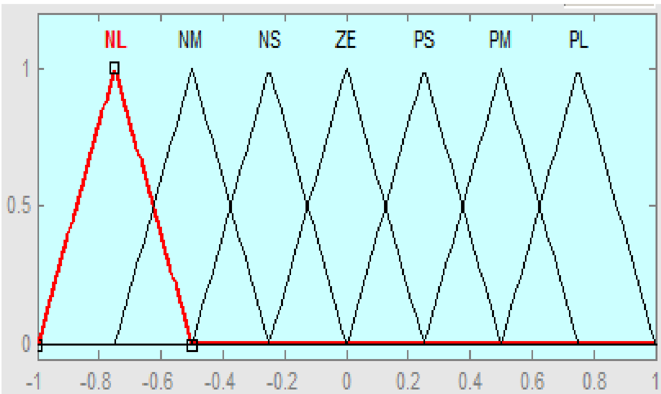

Fig. 6: Change in error as output

The membership functions are used to create the fuzzy logic controller's rules. The rules are organised in Table.1 as indicated in the table below, and they are represented using the notations that follow.

The two inputs were expressed as negative large (NL), negative medium (NM), negative small (NS), zero (ZE), positive small (PS), positive medium (PM), and positive large (PL) in linguistic values. The two inputs were represented by sets of seven membership functions (PB). Both the "error" input range and the "change of error" range were predetermined. When interpreting the IF-THEN rules, the AND technique was "min" and the OR approach was "max." Additionally, the "max" method was utilised for aggregation while the "min" method was employed for implications [9, 10]. The 49 illegible IF-THEN

TABLE I FUZZY RULE BASE

C.E / E	NL	NM	NS	ZE	PS	PM	PL
NL	NL	NL	NL	NM	NM	NS	ZE
NM	NL	NL	NM	NS	NS	ZE	PS
NS	NL	NM	NS	NS	ZE	PS	PM
ZE	NM	NS	NS	ZE	PS	PM	PL
PS	NM	NS	ZE	PS	PS	PM	PL
PM	NS	ZE	PS	PS	PM	PL	PL
PL	ZE	PS	PM	PM	PL	PL	PL

SIMULATION RESULTS

As indicated in the figure, we created a Matlab/Simulink model to examine the system performance. Here, an unbalanced load and a non-linear load are linked to a three-phase source, and the dstatcom is connected in shunt at the point of common coupling. Here, regulating the dc-link voltage is the key goal. Any time there is a change in the load, the dc-link voltage deviates from the reference value. Here, we are studying three situations to restore the dc-link voltage to its reference value. I Controlling the DC-link voltage using a traditional PI controller (ii) Controlling the DC-link voltage using an energy-based PI controller (iii), and (iv) Controlling the DC-link voltage using an energy-based fuzzy logic controller. Regarding these three circumstances, we are getting the variation of dc-link voltage at t=0.4 sec and at t=0.8 sec. The explanation of control circuit and the simulation results are as follows.

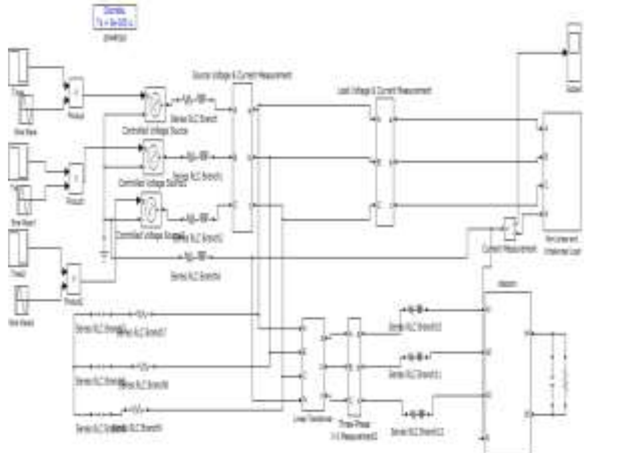

Fig. 7 Simulink diagram of the system with D-STATCOM

DC-Link voltage control with conventional PI controller

The controlling circuit with conventional PI controller is shown in the fig below.

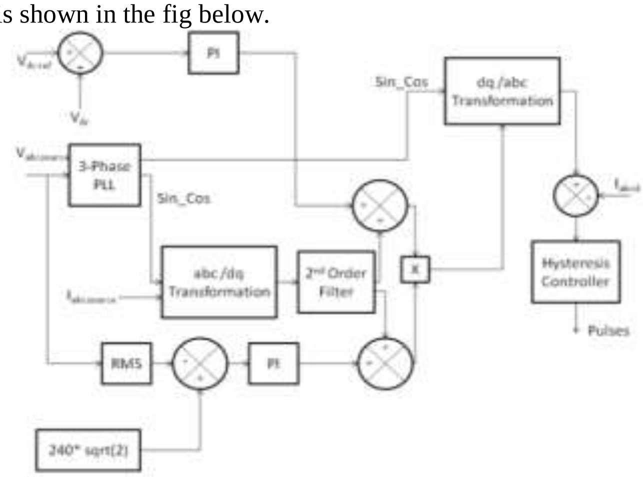

Fig.8 Simulink diagram of the system with Conventional PI Controller

Here, we'll look at two scenarios: I a sudden load reduction; and (ii) a quick load increase that results in a full load condition. If the load suddenly drops in the first scenario, the dc-link capacitor will take in the increased power from the source. Fig. illustrates the rise in DC-Link capacitor voltage over the reference level. The dc-link capacitor voltage is then brought in 0.04 seconds to reference level by the PI controller. In the second scenario, if the load returns to being at full load, the capacitor must provide the necessary voltage. As a result, the voltage will be lower than the reference value. Once more, this will again bring back to its reference value with the help of conventional PI controller.

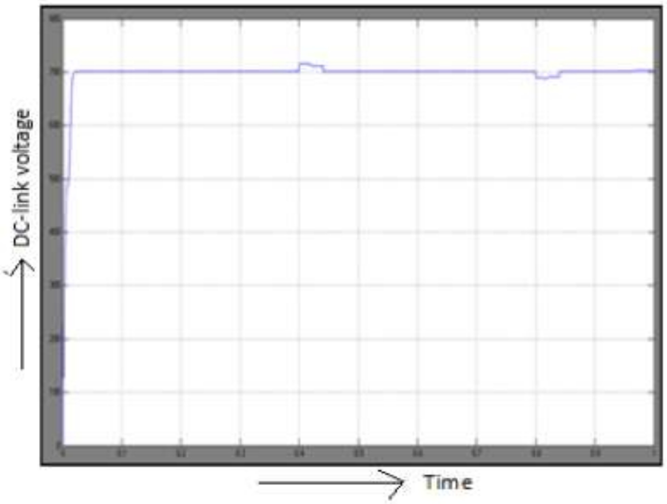

Fig. 9 DC-link voltage with conventional PI controller takes 0.04 sec to settle down to reference value

DC-Link voltage control with Fuzzy controller

The controlling circuit with Fuzzy controller is shown below.

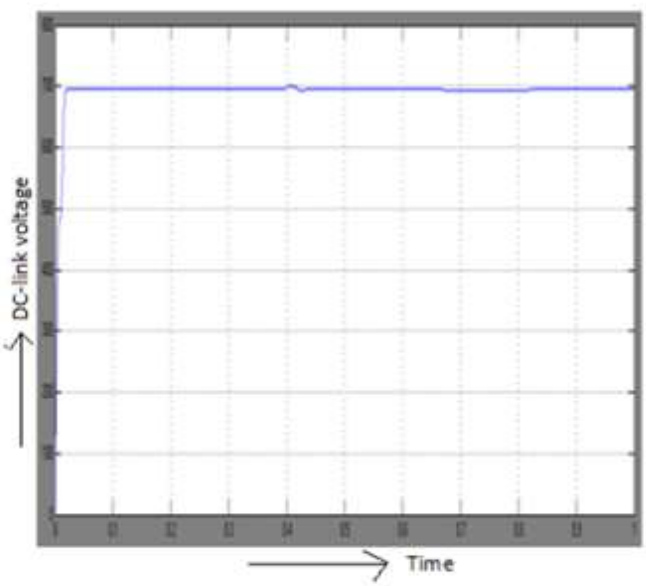

Fig. 11 DC-link voltage with fuzzy controller, transient response improved by t=0.02 sec

Here, a fuzzy controller is used in place of the traditional PI controller to produce the desired results. The small spike that appeared in the results above at t=0.4 and t=0.8 sec after changes in load is only controlled in 0.02 sec.

DC-Link voltage control with Energy based Fuzzy controller

Here, we take the square of the DC voltage and its reference, compare the results, and then apply a fuzzy controller to the resulting value. The DC load power is then determined. The two situations mentioned above will also be taken into consideration here. Here, we are bringing the voltage to its reference value in 0.002 seconds following changes in load by utilising the energy-based fuzzy controller.

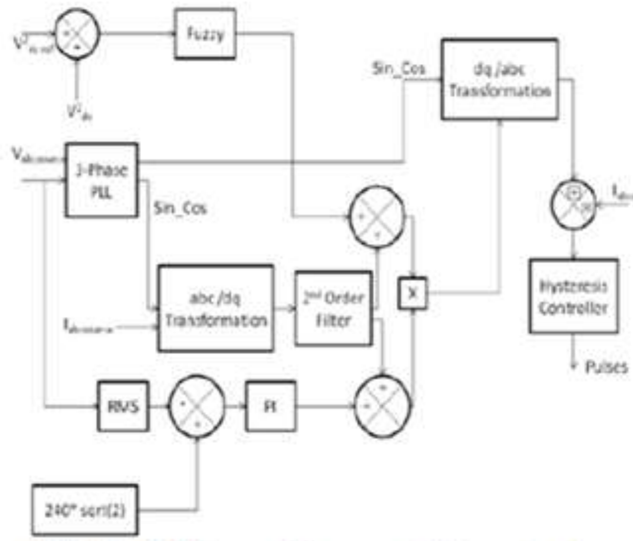

Fig.12 Simulink diagram of the system with Energy based Fuzzy Controller

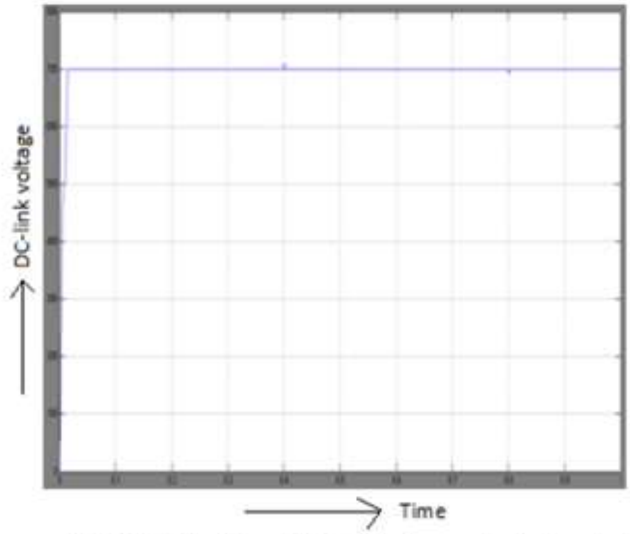

Fig. 13 DC-link voltage with fast acting fuzzy controller, transient response improved by t=0.002 sec

COMPARISIONS

The comparison of dc link voltages for adjusting load variation is shown in the following fig. 14. Referring to Figure 9, Graph 1 above shows that the settling time is 0.42 seconds. Referring to Figure 11, Graph 2 shows that the settling time is 0.402 seconds. Referring to Figure 13, Graph 3 shows that the settling time is 0.4002 seconds. The graph above shows that the energy-based fuzzy control is superior, and the power factor has improved to 0.98, as indicated in the graph below.

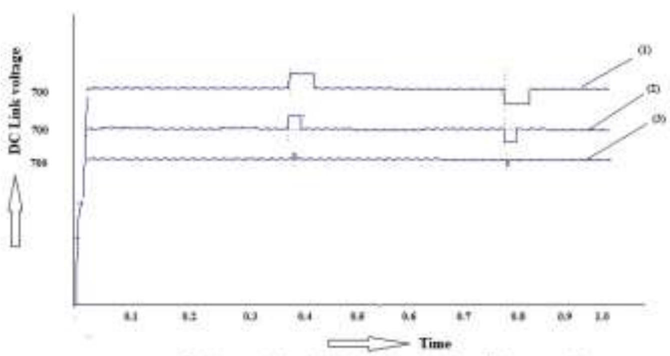

Fig.14 comparision of dc link voltages for three diffrent controllers.

The following diagram illustrates the power factor improvement for PI controllers and fuzzy logic controllers.

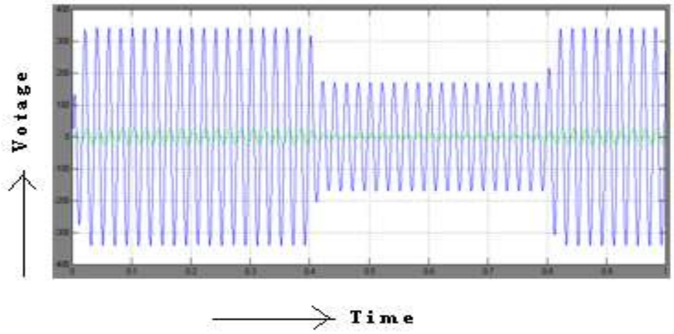

Fig.15 Power factor for PI controller

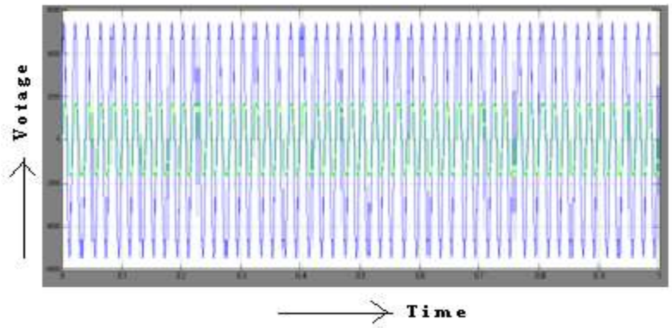

Fig.16 Power factor for Energy based FUZZY controller

The FFT analysis of the load voltage for traditional PI, energy-based PI, and with fuzzy logic controllers is shown in Figs. 16, 17, and 18. Below is a comparison table between various controllers..

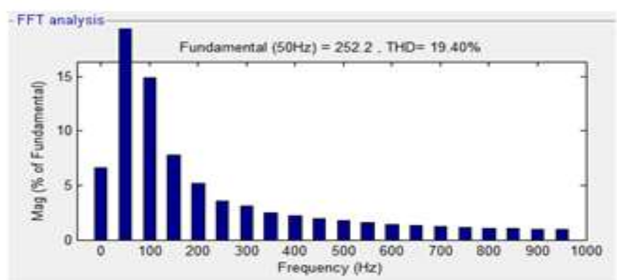

Fig. 17 Total Harmonic Distortion of 19.40%

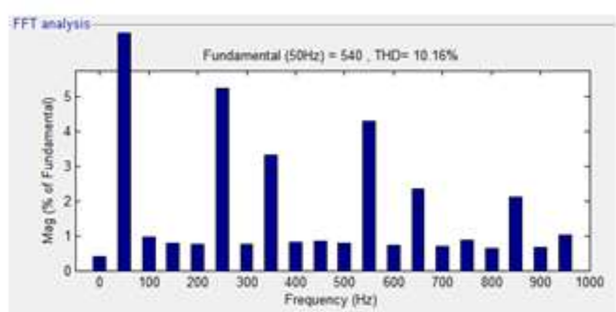

Fig. 18 Total Harmonic Distortion reduced to 10.16%

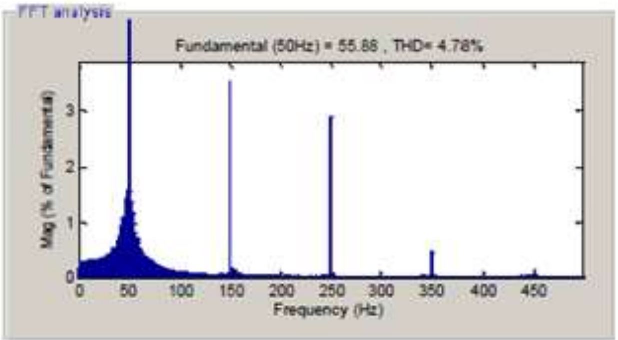

Fig. 19 Total Harmonic Distortion reduction to 4.78%

CONCLUSION

Consumers are suffering indirect consequences such as more frequent plant outages as a result of utilities' struggles to maintain electricity quality at the consumer end. Unbalanced and nonlinear load currents can be compensated for by the Shunt linked Custom Power device DSTATCOM. A d.c. link voltage controller that is energy-based is particularly effective in enhancing power quality. Further enhancing Power Quality is a fuzzy controller with quick reference voltage generation to control Unbalance voltage in a three-phase system. We come to the conclusion that a Mamdani type fuzzy PD controller is capable of serving the same purpose as a traditional PD controller. One of the main benefits of fuzzy control over conventional controller is the ability to reduce the impact of sensor errors on system performance by adding additional rules. By doing so, the need for expensive sensors is diminished, and the cost of the control system is decreased without sacrificing performance. If we have in-depth understanding of the system, we can simply obtain the rule base and membership function of the input and output variables. The simulation findings demonstrate very strong performance of the approach and the control strategy under arbitrary utility supply failure scenarios. System limits have been shown by simulation findings.

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