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Design and control of STATCOM fed Distributed Generation using Fuzzy Controller based Reverse voltage Technique

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Abstract

Power quality enhancement is one of the major concerns from the last few years due to fluctuations occurring in the power transmission and distribution. This paper presents the design of distributed generation system for reducing power quality problems in the distribution system and grid side supply. It involves the design of distributed generation using renewable energy source and also reverse voltage technique based multilevel inverter for integration into the grid. This paper also presents the design of fuzzy controller based modified synchronous rotating frame theory for regulating the DC link voltage and multilevel inverter currents. The system was simulated using MATLAB Simulink and the results are verified with single phase and three phase non linear loads.

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1. Introduction

Now a day's power fluctuations have been increasing due to several problems occurring on the grid side. Also, due to the switching of non-linear loads also leads to the injection of harmonics on the supply side voltages and currents. So to avoid these power fluctuation problems, voltage sags, swells, interruptions and also to reduce the supply side harmonics, a solution has to be designed.

Distributed generation is a solution which can reduce all the above mentioned problems and provides quality of power to the grid. Renewable energy sources have also seen an increase in use in recent years, owing to its numerous benefits, such as being limitless, readily available, and environmentally beneficial. Among the numerous renewable energy sources like biomass, hydro power, solar, wind, etc. solar energy has been spreading all around the world as it is readily available. So solar energy based distributed generation has been designed and stored across the DC link capacitor. As the grid requires AC power and the generated power is DC power, so an inverter is required to convert DC generated power into AC power. Conventional two level inverter suffers from the harmonics problems and also requires additional filters resulting in a rise in the system's cost.

So a multilevel inverter is an option which produces output with multi levels and leads to reduction in harmonics and also requirement of filters. Diode clamped multilevel inverters, capacitor clamped multilevel inverters, and bridge multilevel inverters are all types of multilevel inverters. But these multi-level inverters involve the use of several capacitors, diodes and switches which leads to complexity of the inverter, increase in the cost of inverter and also switching losses. So to avoid these disadvantages reverse voltage technique based multilevel inverter has been used which involves less number of Switches and production of multiple levels with reverse voltage technique. Because the output across the DC link capacitor cannot be

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maintained at a consistent level, modified synchronous rotating frame theory has been used which provides controlling of grid currents, and inverter currents. To provide fast dynamic response and lower harmonic output fuzzy logic controller has been used in the modified synchronous rotating frame to provide injection of active, reactive power during switching on of single phase loads and three phase loads.

The paper is organized as follows; the first section deals with the block diagram explanation of proposed multilevel inverter based distributed generation, the second section deals with proposed fuzzy logic controller based synchronously rotating frame theory, the third section deals with the software realization of the proposed system and the fourth part deals with the conclusion.

2. Block Diagram Explanation of Proposed Distribution Generation

The Block Diagram for the proposed Distributed Generation is shown in below figure. It consists of grid which generates and transmits the power and non-linear load. When the non-linear load is switched on, harmonic currents get injected into the grid. There by grid currents and voltages gets disturbed and so power quality problems occurs. To overcome these problems, solar power generation based distributed generation is designed. When the solar rays falls on the solar panel, DC electrical energy gets produced across the output terminals of the solar panel. This energy gets stored in the DC link capacitor. As grid supply is pure AC, this DC link capacitor's energy gets converted into AC energy with the help of reverse voltage technique based multilevel inverter. The reverse voltage technique based multilevel inverter consisting of 12 switches and four DC link capacitors separates output voltage into level and polarity generation units where level generation unit generates positive polarity of voltage and polarity unit generates polarity of voltage and the levels can be extended with the addition of middle part. So it requires very few switches when compared to the conventional multilevel inverters. To control the DC link voltage and grid currents, fuzzy logic controller based modified synchronous rotating frame theory has been designed which controls the voltage of the DC link with the reference value and also generates gate pulses for the three phase reverse voltage technique based multilevel inverter. The proposed distributed generation system has been designed for the single phase nonlinear loads and three phase non-linear loads.

The shunt inverter control converts the var reference into a shunt current request, then changes the inverter's gating to get the desired current. A feedback signal indicating the dc bus voltage is also required for this method of control. The shunt converter reactive current

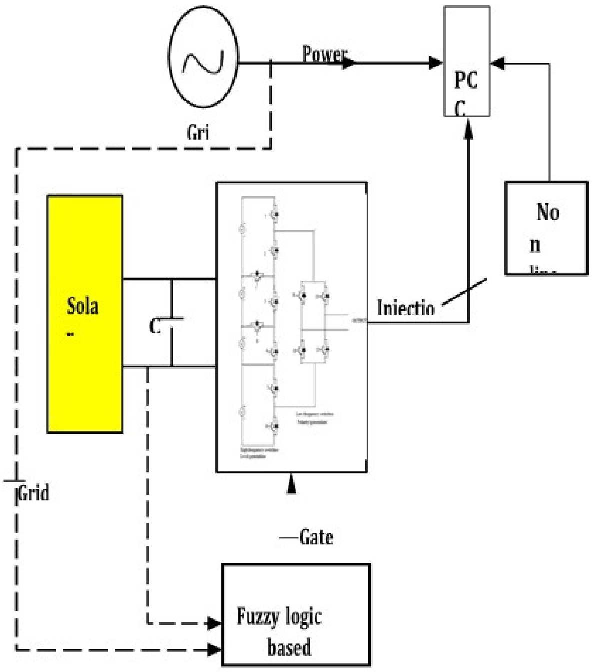

Figure 1. Block Diagram of Proposed Distributed Generation.

is automatically controlled in automatic voltage control mode to keep the transmission line voltage at the point of connection to a reference value. Voltage feedback signals are acquired from the transmitting end bus feeding the shunt coupling transformer for this kind of control.

Assume V1 is the voltage across the shunt transformer's secondary coil and V2 is the produced voltage of the VSC. Only reactive power flows when the voltage V2 is in phase with V1 in steady state operation. When V2 is less than V1, Q flows from V1 to V2; for example, STATCOM absorbs reactive power. If V2 is greater than V1, Q flows from V2 to V1, indicating that STATCOM is generating reactive power.

$P = (V_1 V_2) sin\delta / X \ldots..1$

$Q = (V_1((V_1 - V_2 cos\delta))/X \ldots..2$

3. Fuzzy Controller based STATCOM

The block diagram for the fuzzy logic controller based STATCOM is shown in below figure. A voltage-source converter is a power electronic interface that can be wired to the grid in shunt or parallel. It may produce a sinusoidal voltage of any magnitude, frequency, or phase angle. The VSC was used to either fully substitute or inject the voltage that was absent. The disparity between the nominal and real voltage is known as the "missing voltage." It also transforms the DC voltage through the storage devices into three step AC output

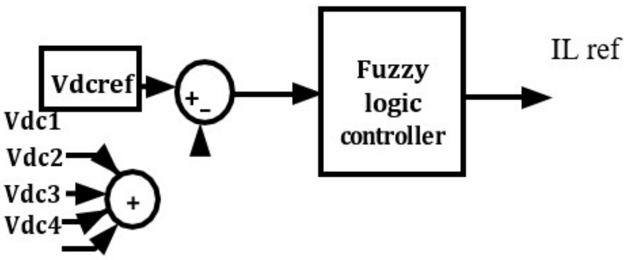

Figure 2. Block Diagram of Proposed DC Link Voltage Controller.

voltages. D-STATCOM also has the ability to produce or consume reactive power. D- STATCOM is said to be in capacitive mode if the VSC output voltage is higher than the AC bus terminal voltages. As a result, the reactive power will be compensated by the AC system, and the lost voltages will be controlled. Via the reactance of coupling transformers, these voltages are in phase and coupled with the AC system. The step and magnitude of the DSTATCOM output voltages can be adjusted to effectively regulate active and reactive power exchanges between the D-STATCOM and the AC grid. Furthermore, the converter is usually built on some kind of energy storage that provides a DC voltage to the converter.The block diagram for the DC link voltage controller is shown in above fig 2 where the DC reference voltage will be compared with the sum of all the four DC voltages actual voltages across all the capacitors and then error will be calculated. Then the error will be sent into a fuzzy logic controller, which calculates the error and error change. These values when given to the controller are converted into fuzzy membership functions.

Then rules are framed out for the input member ship functions using triangular membership functions. Then using the rule based system, fuzzy output membership function will be produced. This will be converted into crisp output using defuzzification technique producing reference load current.

A synchronous frame is one in which the time coordinate specifies appropriate time for all observers travelling in the same direction. It is produced by starting with a constant time hyper surface that has a normal along the time line in every point and a light cone with an apex in that point; all interval elements on this hyper surface are space-like. Although not unique, such a design, and therefore the option of synchronous frame, is always feasible. It allows for any non-time transformation of space coordinates, as well as a transformation caused by the arbitrary choice of hyper surface utilized for this geometric design. The control technique includes the abc frame to d-q frame

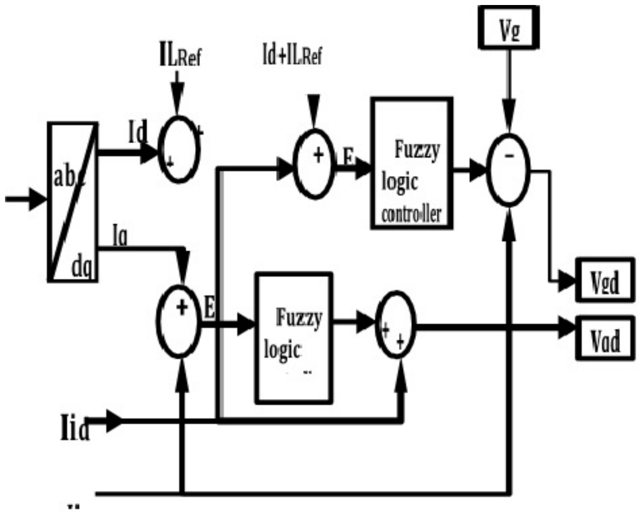

Figure 3. Block Diagram of Proposed Synchronous Rotating Frame Theory.

conversion block, PLL block, HPF, PI controller, DQ to ABC conversion block, and hysteresis controller. The abc frame to d-q frame translation block uses parks transition to convert three step load current parameters (Iabc) to dq0 (Id,Iq) parameters frame. To begin, the current components from block are created in co-ordinates. The phases of Iabc can then be converted to – coordinates. For the transition block, the phase locked loop is used to produce Sinwt and coswt signals. HPF stands for high pass filter, and it is used to filter out low frequency components from the conversion block. The reference load current (ILRef) and inverter current will be compared with the actual load current and inverter actual current and again fed to the fuzzy controller producing grid voltage. This will be fed to the phase opposition carrier based pulse width modulation technique generating pulses to the inverter.

(i.)Fuzzy controller

A fuzzy controller is an intelligent controller that provides a fast, vibrant response with no steady-state error. It's a remote regulator that has more retort than traditional analogue controllers. It is based on a framework of specialist expertise and experience. It attempts to keep the difference between the true and reference values as small as possible. The fuzzifier, fuzzy inference, rule-based system, and defuzzifier blocks make up the fuzzy logic based regulator. The error and change in error inputs are used in the fuzzy rule-based regulator that was designed. Fuzzifier converts crisp variables to fuzzy variables using membership functions, which are then passed to the inference engine as input variables. Fuzzy rules are directed to membership functions in the fuzzy rule based inference engine, and processing is done to generate a rule- based system. After completing the rule-based system and calculating the output, the data will be directed to a defuzzifier, which will convert the fuzzy variables into crisp variables. The mamdani inference system is used in the fuzzy controller because it has advantages such as being easier to formulate rules, producing accurate output, being robust in the face of noisy input, behaving more like a human, and being simple to develop rules. In general, the error and change in error inputs of the controller are specified in terms of memberships, and the controller's yield is also specified in terms of membership operation. The error between the integrated system's power point voltage and actual voltage is fed as one of the blurry controller's inputs, and the change in error is fed as another. Fuzzifier uses these as input to transform crisp variables to fuzzy variables. Then, using seven variables called PB, PM, PS, ZE, NS, NM, and NB, the two transformed fuzzy membership functions were evaluated. The output membership feature was created by designing and applying 49 IF-THEN rules from the rule-based scheme. The expression for the if- then rule for the fuzzy set can be given as

IF R THEN μ(x) .... (3)

The expression for the AND operation for the fuzzy rules can be given as

$\mu A \cap B(x) = min[\mu A(x, \mu B(x)]$.....4

The equation for the error of the system can be given as $e(t) = V_ref - V_out$.....5

The equation for the change in error of the system can be given as

$de(t)/dt = d[V_ref - V_out]/dt$....6

(ii.)Reverse voltage technique

In traditional cascaded multilevel inverters, a large number of switches are required, and the power switches are coupled to provide output in both positive and negative polarities. There is no need to employ all of the high frequency switches in the suggested multilayer inverter. The output voltage is split into level and polarity generation components in this scheme. The positive polarity levels are generated by the level creation section. The polarity creation section creates the output voltage's polarity. The polarity generating component necessitates low-frequency switches working at line frequency, whereas the level generation component necessitates high-frequency switches. The middle component of this multilayer inverter may be enlarged to achieve larger voltage levels. This architecture uses fewer switches and may be used in three phases. SPWM based on Phase Disposition (PD) requires half the amount of typical carriers. Eight carriers are required for PD-SPWM in nine- level conventional converters, whereas only four carriers are required in the proposed system. Positive voltage is delivered to the polarity generator portion to produce polarity. The fundamental benefit of multilevel inverter control is that it uses fewer carriers. This architecture necessitates the use of a separate DC source. The suggested multilayer inverter outperforms traditional multilayer inverters in terms of efficiency. When the voltage polarity has to be altered to negative polarity, the polarity generation component of the circuit reverses the output of the level generating component[1].

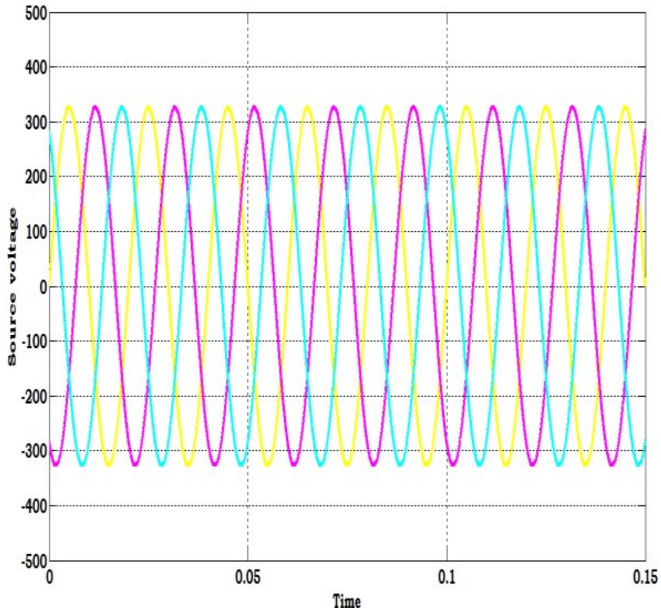

Figure 4. Waveform of Voltage at PCC

4. Software Realization of the proposed system

The proposed system has been simulated using MATLAB Simulink with a single phase load and three phase load and the following are the results obtained.

(i.)Proposed fuzzy logic controller based DG system with three phase load

The above figure shows three phase grid voltage which was sinusoidal with switching of 3-phase nonlinear load at t=0.1s and with switching of DG system at t=0.15s whose value was 315V which was maintained constant.

The above figure shows three phase grid current which was not sinusoidal with switching of 3-phase nonlinear load at t=0.1s whose value is 25A and with switching of DG system at t=0.15s, it was maintained near to sine wave and also its value has been increased to 100A showing injection.

The above figure shows active power and reactive power of grid whose value is near to zero from t=0 to t=0.1s and with switching of 3-phase nonlinear load at t=0.1s whose values are 1000W, 1000VAR and and with switching of DG system at t=0.15s, it was maintained

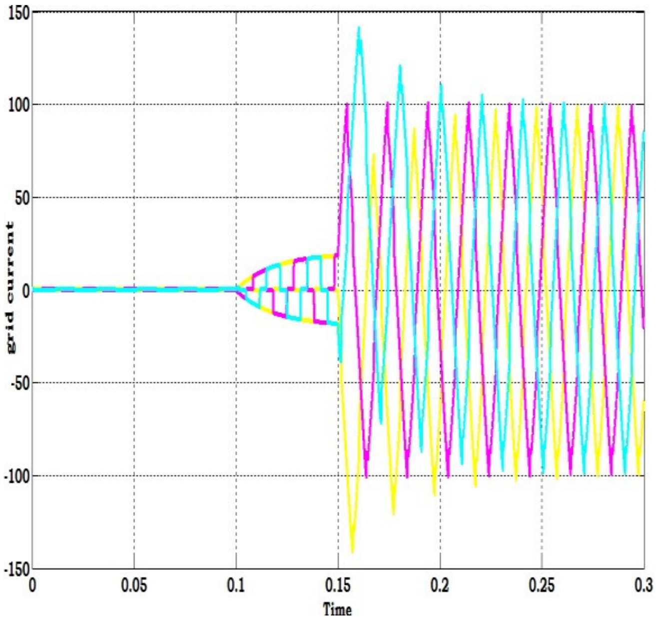

Figure 5. Waveform of Current at PCC

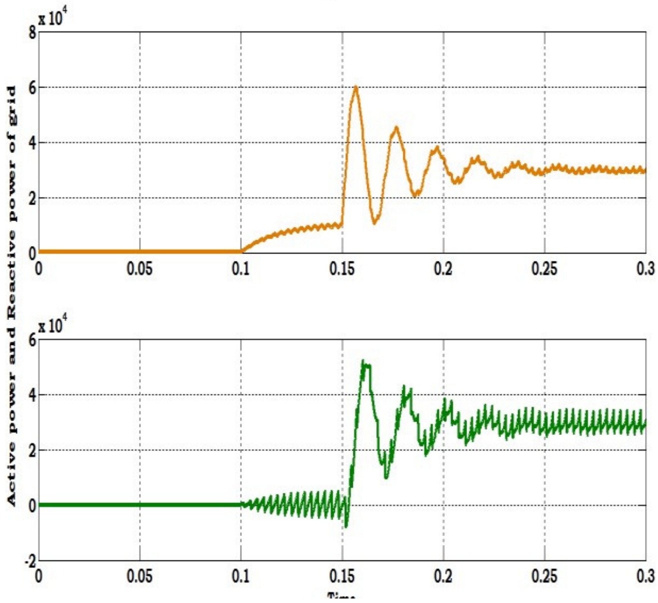

Figure 6. Active Power and Reactive Power of Grid

at 3000W, 3000VAR injecting the active power, reactive power.

The above figure shows three phase load voltage which was not sinusoidal with switching of 3-phase nonlinear load at t=0.1s whose value is 310V and with switching of DG system at t=0.15s, it was maintained near to sine wave and also its value has been increased to 300V maintaining sinusoidal value.

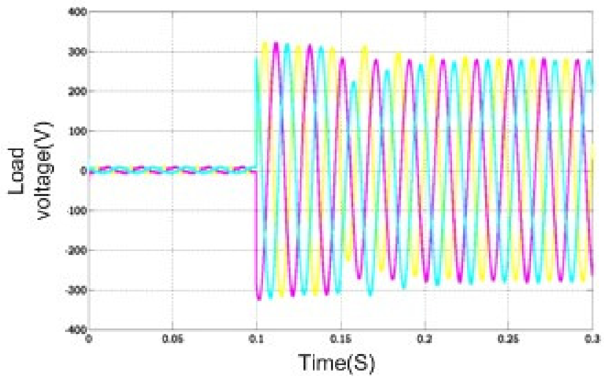

Figure 7. Waveform of Load Voltage

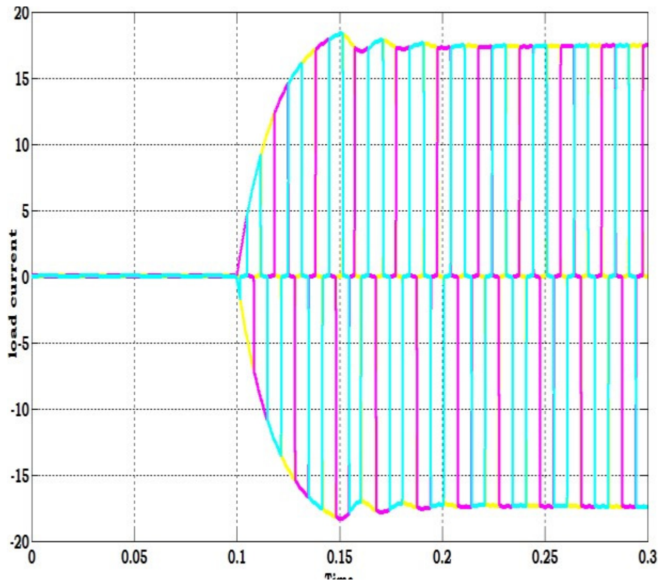

Figure 8. Waveform of Current at Load

The above figure shows three phase load current which was not sinusoidal with switching of 3-phase nonlinear load at t=0.1s and with switching of DG system at t=0.15s, it was maintained near to sine wave and also its value has been increased to 17A due to sudden switching of load.

The above figure shows active power and reactive power of load whose value is near to zero from t=0 to t=0.1s and with switching of 3-phase nonlinear load at t=0.1s whose values are 0W, 0VAR and with switching of DG system at t=0.15s, it was maintained at 8000W, 4500VAR showing injection of power.

The above figure shows three phase inverter voltage which was not sinusoidal with switching of 3-phase nonlinear load at t=0.1s whose value is 800V and with switching of DG system at t=0.15s, it was maintained

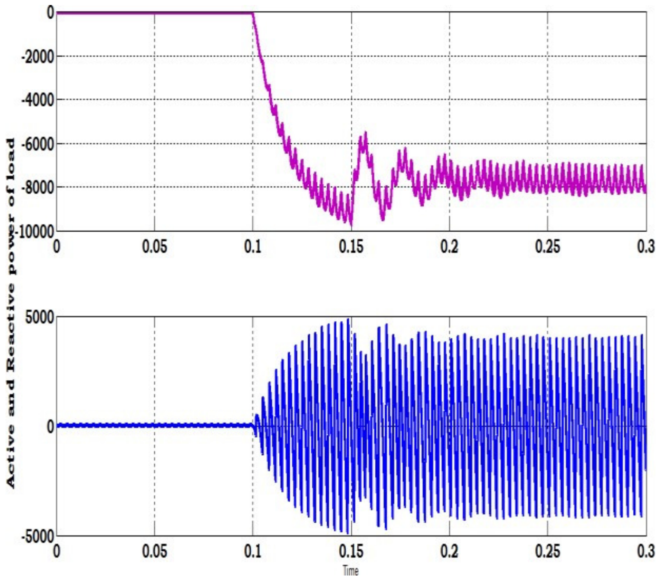

Figure 9. Waveform of Active and Reactive Power of Load

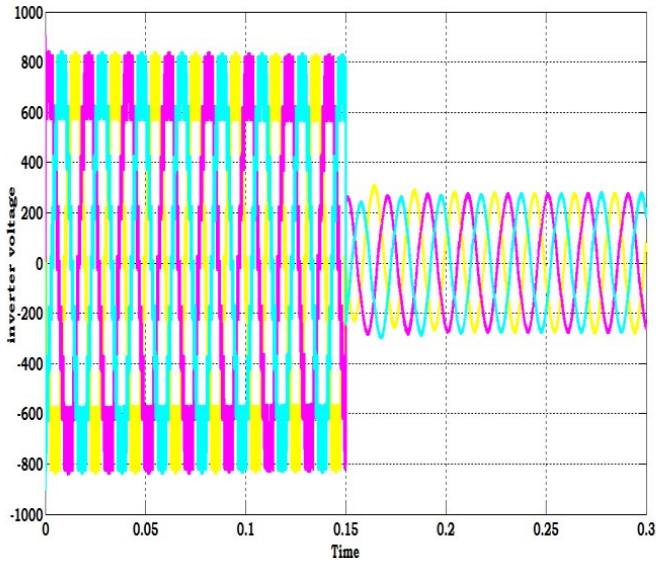

Figure 10. Waveform of Inverter Voltage

near to sine wave and also its value has been increased to 300V.

The above figure shows three phase inverter current which was not sinusoidal with switching of 3-phase nonlinear load at t=0.1s and with switching of DG system at t=0.15s, it was maintained near to sine wave and also its value has been increased to 90A.

The figure 12 shows active power and reactive power of inverter whose value is near to zero from t=0 to t=0.1s and with switching of 3-phase nonlinear load at t=0.1s whose values are 0W, 0VAR and with switching

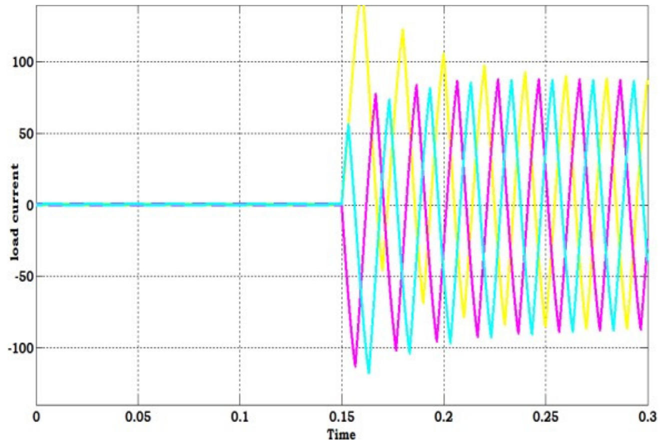

Figure 11. Waveform of Load Current

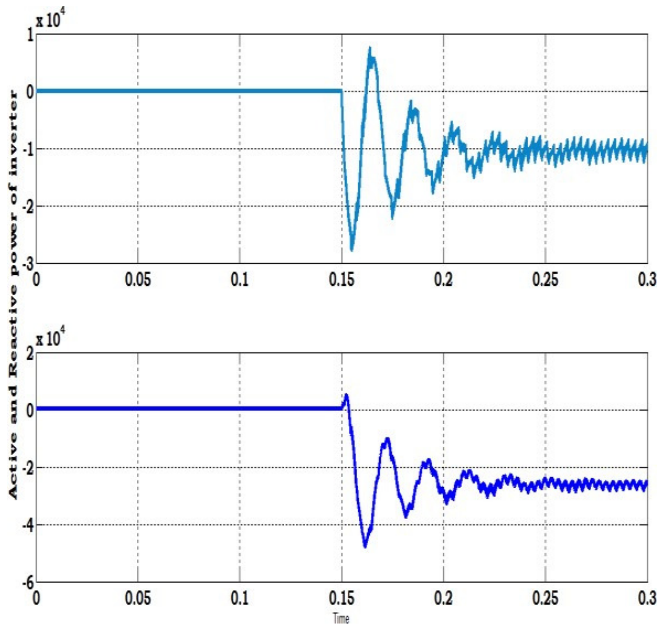

Figure 12. Waveform of Active and Reactive Power of Inverter

of DG system at t=0.15s, it was maintained at 1000W, 2500VAR showing injection of power.

The above figure shows the total harmonic distortion grid voltage with the switching of DG system.

(ii.)Proposed fuzzy logic controller based DG system with single phase load

The above figure shows three phase grid current which was not sinusoidal with switching of 1-phase nonlinear load at t=0.1s whose value is 20A and with switching of DG system at t=0.15s, it was maintained near to sine wave and also its value has been increased to 100A.

The above figure shows active power and reactive power of grid whose value is near to zero from t=0 to t=0.1s and with switching of 1-phase nonlinear load at

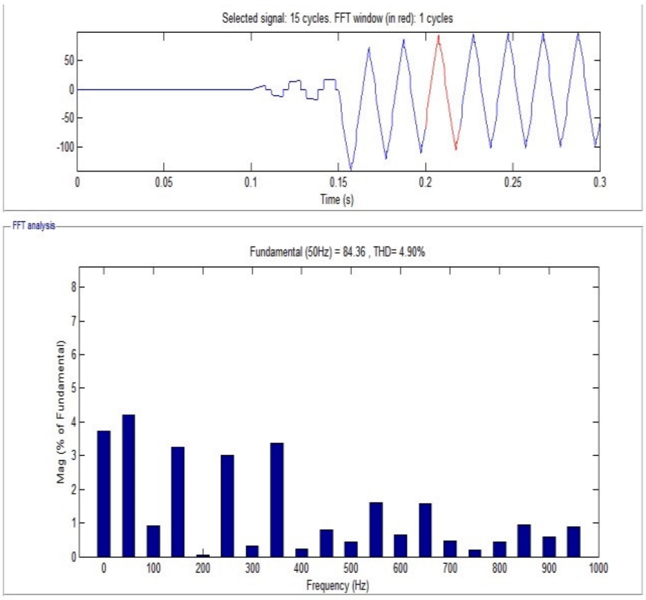

Figure 13. THD Waveforms of Voltage at PCC

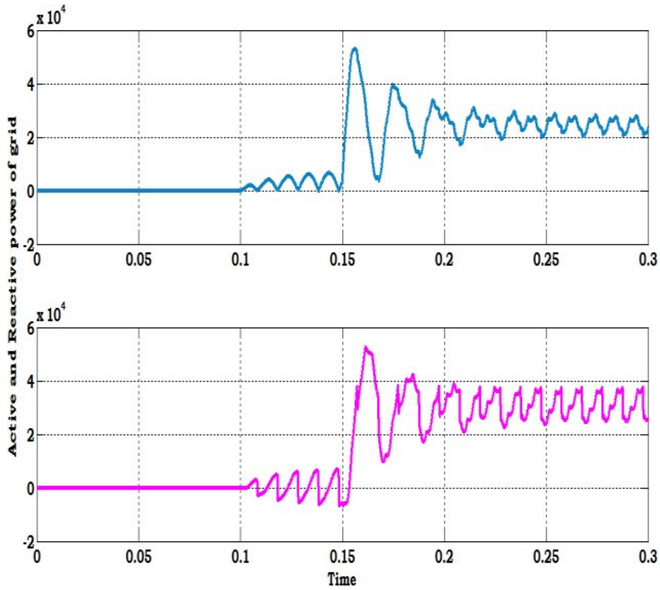

Figure 15. Active and Reactive Power of Grid

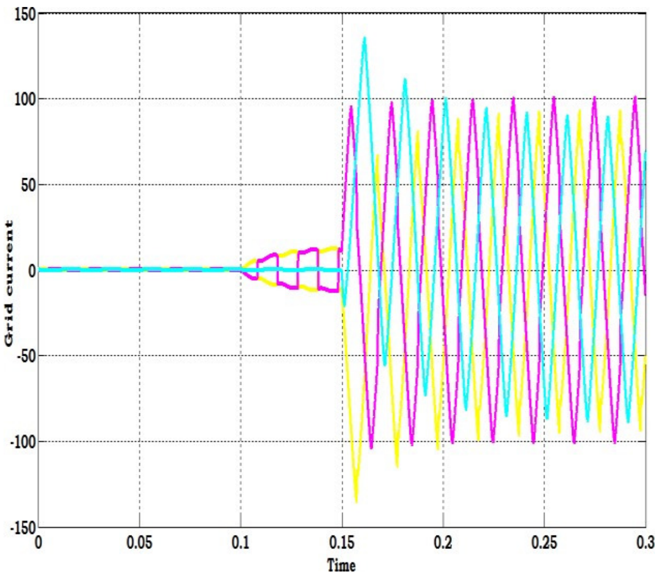

Figure 14. Waveform of Current at PCC

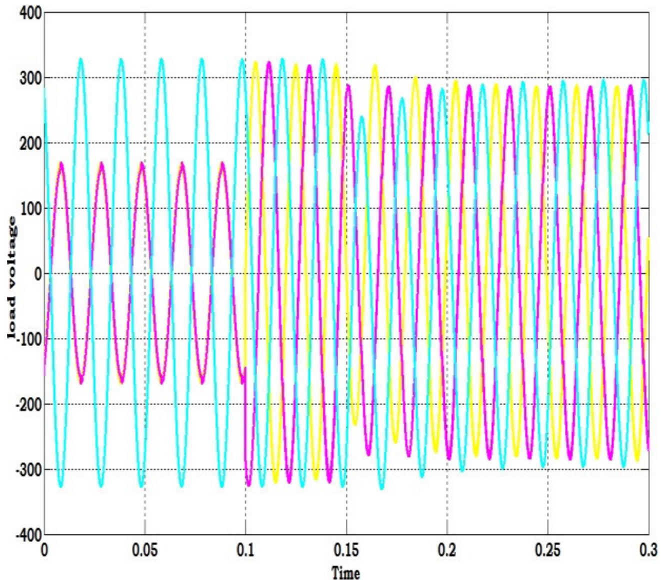

Figure 16. Waveform of Load Voltage

t=0.1s whose values are 1000W, 1000VAR and and with switching of DG system at t=0.15s, it was maintained at 3000W, 3800VAR showing injection of power.

The above figure shows three phase load voltage which was not sinusoidal with switching of 1-phase nonlinear load at t=0.1s whose value is 310V and with switching of DG system at t=0.15s, it was maintained near to sine wave and also its value has been increased to 300V which was maintained constant irrespective of variations.

The above figure shows three phase load current which was not sinusoidal with switching of 1-phase nonlinear load at t=0.1s and with switching of DG system at t=0.15s, it was maintained near to sine wave and also its value has been increased to 12A due to sudden switching of load.

The figure 18 shows active power and reactive power of load whose value is near to zero from t=0 to t=0.1s and with switching of 1-phase nonlinear load at t=0.1s whose values are 0W, 0VAR and with switching of

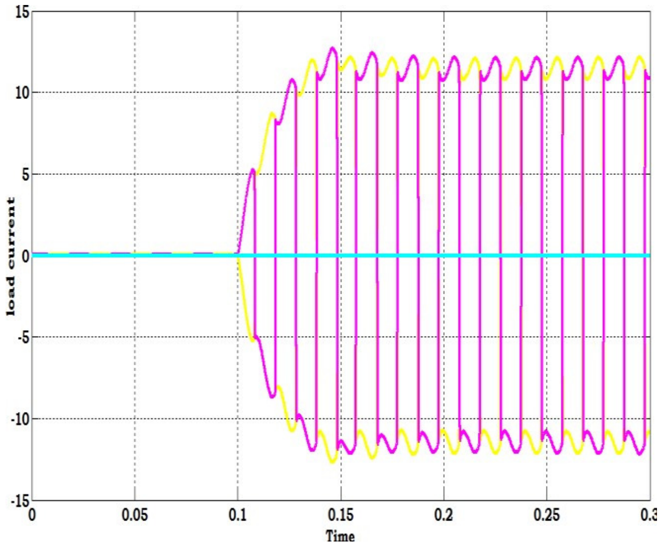

Figure 17. Waveform of Load Current

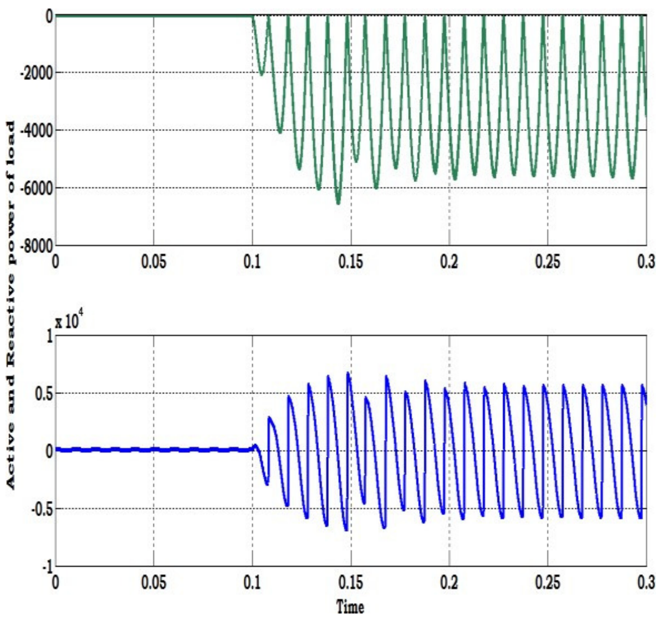

Figure 18. Active Power and Reactive Power of Load

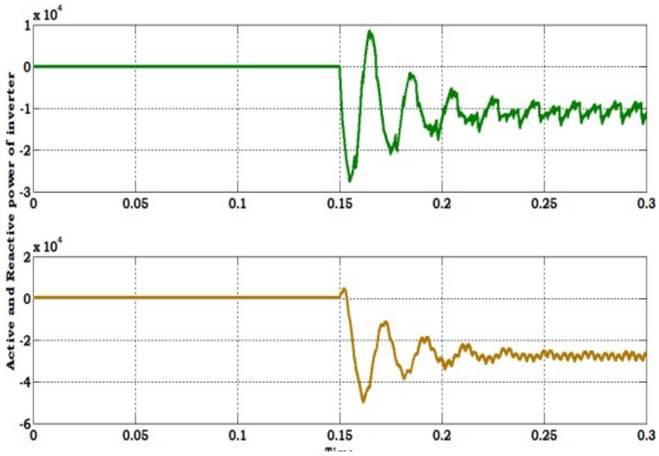

Figure 19. Active Power and Reactive Power of Inverter

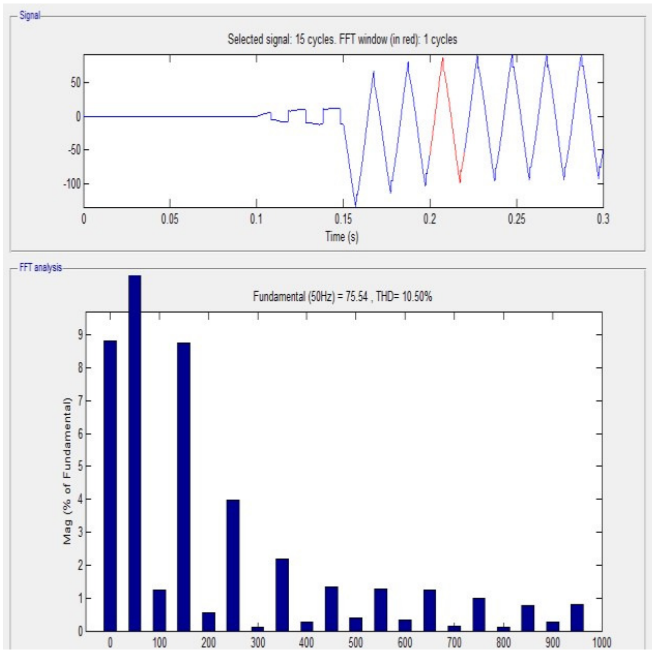

Figure 20. Waveforms of THD of Voltage at PCC

DG system at t=0.15s, it was maintained at 48000W, 500VAR showing injection of power.

The figure 19 shows active power and reactive power of inverter whose value is near to zero from t=0 to t=0.1s and with switching of 1-phase nonlinear load at t=0.1s whose values are 0W, 0VAR and with switching of DG system at t=0.15s, it was maintained at 1000W, 2600VAR showing injection of power.

The figure 20 shows the total harmonic distortion grid voltage with the switching of DG system.

The sample rate is chosen based on the highest frequency in the signal that is present in a meaningful amount. We may have frequencies over 50kHz for audio transmissions, but we only want to respond to 20kHz and lower. Filtering would be required in this situation

Table 1. Comparison Table of the Proposed System with PI and Fuzzy Controller

		THD	Power factor
With PI Controller	3-ϕ	6.56	0.99
	1-ϕ	11.36	0.99
With Fuzzy Controller	3-ϕ	4.90	0.99
	1-ϕ	10.50	0.97

Table 2. Specifications Table of the proposed system

sl.No	Parameter	Value
1	Source Voltage	400V
2	Frequency	50Hz
3	Voc of solar panel	700V
4	Isc of solar panel	23A
5	Duty cycle of boost converter	0.6
6	DC link voltage	400V

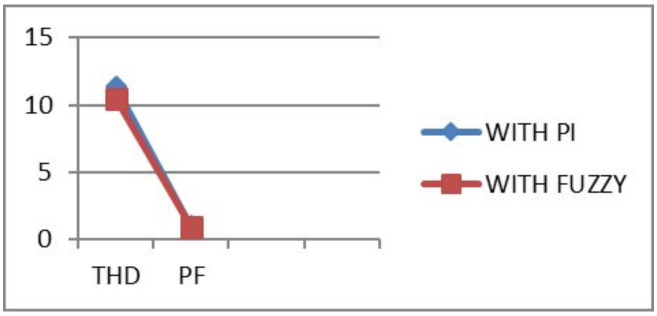

Figure 21. Comparision graph of PI and fuzzy controller

to eliminate the high frequencies before sampling. The number of samples obtained at one time of maximum frequency is determined by the strategy used.

5. Conclusions

The design of distributed generation system for reducing power quality problems in the distribution system and grid side supply has been presented in this paper. The design of distributed generation using renewable energy source and also reverse voltage technique based multilevel inverter for integration into the grid has also been presented. A fuzzy controller based modified synchronous rotating frame theory for regulating the DC link voltage and multilevel inverter currents has been used in this paper. The system was simulated using MATLAB Simulink and the results are verified with single phase and three phase non-linear loads and also comparison has been made with PI controller based distributed generation where the fuzzy controller shows the better performance in terms of power factor, THD, active power , reactive power, voltage, current.

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