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Development of Efficient PV System using SEPIC Converter and DVR for Power Quality Improvement

J.R.Maglin[1*] and R.Ramesh[2]

[1]Department of Electrical Engineering, Anna University, Guindy, Chennai*
E-mail: kkani712@gmail.com
[2]Department of Electrical Engineering, Anna University, Guindy, Chennai
E-mail: rramesh@annauniv.edu

Abstract

Photovoltaic energy source is an attractive alternate electrical energy source in the future. The main aim is to develop an efficient photovoltaic model with SEPIC based MPPT technique to track maximum power. Multilevel inverters are used to provide the power to grid with high power capacity and lower harmonics to improve the power quality of the grid. The power quality issues such as sag and swell in the distribution system has been minimized by using PV based dynamic voltage restorer. The work reported tested with IEEE-33 bus with the objective of identifying the optimal location and amount of voltage to be injected for the particular bus.

Keywords: Dynamic Voltage Regulator (DVR), Continuous Pulse Width Modulation (CPWM), Secondary Ended Primary Inductance Converter (SEPIC), Sine Pulse Width Modulation (SPW) and Multilevel Inverter (MLI).

Introduction

The research work aims in the improvement of power quality in the distribution system. The term power quality is referred to maintaining a near sinusoidal power distribution bus voltage at rated magnitude and frequency. When power quality becomes poor, it affects almost all consumers. In addition to the power utilized from the grid to provide the DVR for the purpose of improving the power quality, the solar power has been utilized as the input to the DVR to improve the power quality.

The efficiency of the DVR depends on the performance of the control technique involved in switching of the inverters. During the occurrence of the fault in the distribution system, DVR is activated and the voltage is injected in to the system to improve the system stability. Here IEEE-33 is analyzed for fault condition and optimal amount of voltage to be provided by the PV based DVR.

2. OBJECTIVES OF THE RESEARCH

In this research work, efficient PV module is used for synchronizing solar power with ac grid. Nowadays due to increase in power quality disturbances, it is necessary to improve the power quality in distribution system. Here DVR is used as a compensator to maintain the stability of the system. The load flow analysis of IEEE-33 bus system is analyzed to find out the weak bus and to improve the power quality by using proposed PV module with DVR. The main objectives of the research work are

- To design and analysis of SEPIC converter based MPPT for Solar power system with CPWM.
- To study the behavior of PV system and to design efficient system with Multi level inverter.
- To model and implement the PV array based Dynamic Voltage Restorer.
- To improve the power quality in distribution system using proposed PV system with DVR.

3. SEPIC CONVERTER BASED MPPT FOR SOLAR PV MODULE WITH CPWM

Solar power is a renewable energy source that might one day soon replace fossil fuel dependent energy sources. However, for that to happen, solar power cost per kilowatt-hour has to be competitive with fossil fuel energy sources. Currently, solar panels are not very efficient with only about 12-20% efficiency in their ability to convert sunlight to electrical power. The efficiency can drop further due to other factors such as solar panel temperature and load conditions. In order to maximize the power derived from the solar panel, it is important to operate the panel at its optimal power point. To achieve this, a type of charge controller called a maximum power point tracker will be designed and implemented.

The MATLAB/PSPICE model of the PV module is developed to study the effect of temperature and insolation on the performance of the PV module.

4. MATLAB MODEL OF L1235-37W SOLAR PV MODULE

A solar cell is a kind of p-n junction semiconductor device and converts light energy into electrical energy. The output characteristics of the solar PV module depend on the irradiance and the operating temperature of the cell.

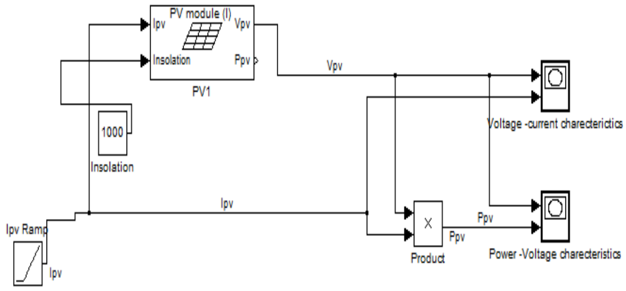

Figure 4.1 MATLAB model for PV module

The solar PV module is modeled in MATLAB shown in Figure 4.1 which is used to enhance and predict the V-I characteristics and to analyze the effect of temperature and irradiation variation. If irradiance increases, the fluctuation of the open-circuit voltage is very small. But the short circuit current has sharp fluctuations with respect to irradiance. However, for a rising operating temperature, the open-circuit voltage is decreased in a non-linear fashion.

The power electronics interface is connected between a solar panel and a load or battery bus, is a pulse width modulated dc-dc converter or their derived circuits is used to extract maximum power from solar PV panel. I–V characteristic curve of photovoltaic generators based on various dc-dc converters was proposed and concluded that SEPIC converter is the best alternative to track maximum power from PV panel.

The maximum power tracking for PV panel using dc-dc converter is developed without using micro controller. The nominal duty cycle of the main switch in the SEPIC converter is adjusted to a value, so that the input resistance of the converter is equal to the equivalent output resistance of the solar panel at the MPP. This approach ensures maximum power transfer under all atmospheric conditions. The analogue chaotic PWM is used to reduce the EMI in boost converter. The conversion efficiency is increased when CPWM is uses as a control technique. The chua's diode and chua's oscillator may be used to generate chaotic PWM. The spectral performance has been improved in induction drives when CPWM is used.

This work proposes to implement CPWM as a control method to improve the steady state performance of the dc-dc SEPIC converter based MPPT system for solar PV module. The nominal duty cycle of the main switch of dc-dc SEPIC converter is adjusted so that the solar panel output impedance is equal to the input resistance of the dc-dc converter which results better spectral performance in the tracked voltages when compared to conventional PWM control. The conversion efficiency of the proposed MPPT system is increased when CPWM is used.

5. SIMULATION RESULTS

The closed loop simulink model of SEPIC dc-dc converter based maximum power tracking using CPWM is shown in Figure 5.1.

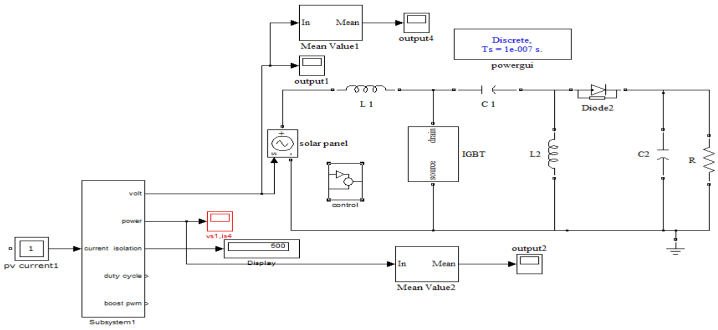

Figure 5.1 Closed loop simulation of MPPT system using CPWM for solar PV module

The Figure 5.2 shows the circuit model to generate chaotic PWM in MATLAB/Simulink.

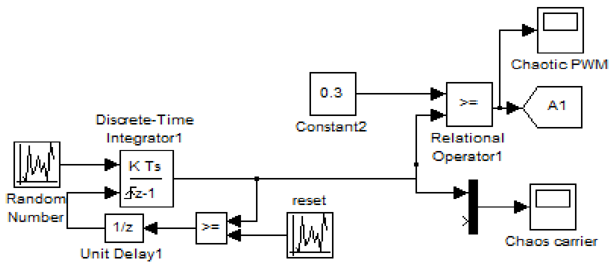

Figure 5.2 MATLAB model to generate Chaotic PWM

The generated Chaotic carrier and Chaotic PWM and conventional PWM are shown in Figures 5.3, 5.4 and 5.5

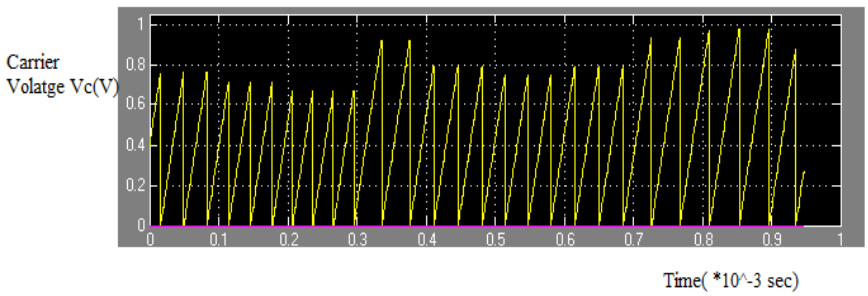

Figure 5.3 Chaotic Carrier

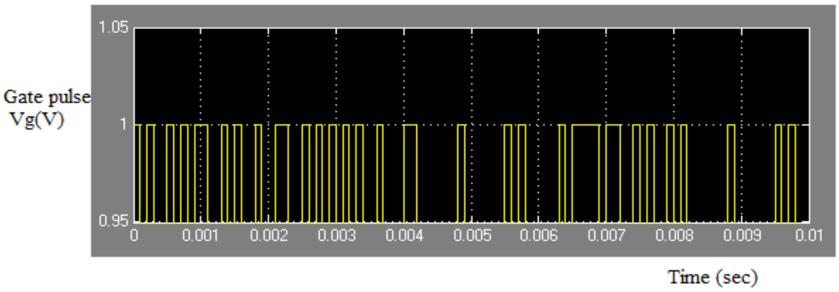

Figure 5.4 Chaotic PWM

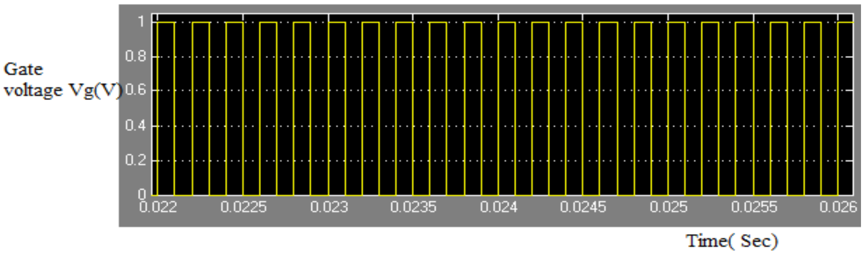

Figure 5.5 Conventional PWM

The Figure 5.6 shows the tracked power from the solar PV module is 36.5W corresponds to 1000W/m^2 and 13W corresponds to 500W/m^2. The tracking efficiency is 98.6%. The duty cycle of the main switch of the SEPIC converter is 45%. Without considering the efficiency of the solar PV module, the converter conversion efficiency is increased from 86% to 92.15% when CPWM is used as a control technique.

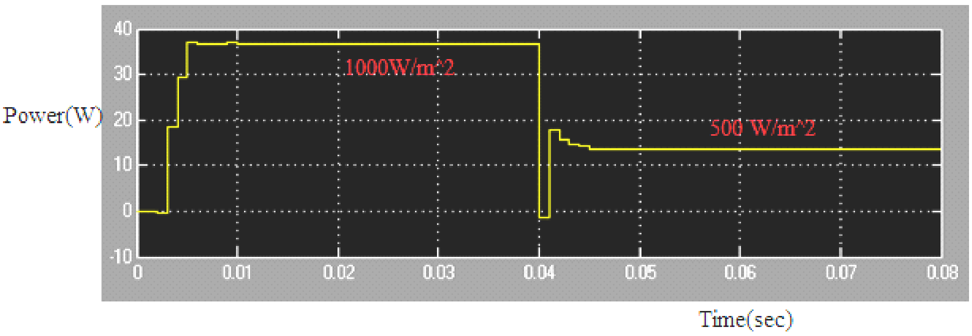

Figure 5.6 Tracked power using DC-DC SEPIC converter

Hence maximum power is extracted from solar PV module using CPWM. The convention converter efficiency is increased from 86% to 92% when CPWM is used. The spectrum performance is improved when CPWM control is used for MPPT purposes.

6. PV BASED SIMPLIFIED MULTILEVEL INVERTER WITH SEPIC CONVERTER

In this section PV array fed ac load is proposed with SEPIC converter and simplified multilevel inverter as interface circuits. As the photovoltaic cell exhibits the nonlinear behavior, while matching the load to the photovoltaic modules, dc-dc power converters are needed. The SEPIC converter should operate with high switching frequency. However, as the switching frequency increases, the reverse recovery current of the output diode affects the switching devices in the form of additional switching losses. Other adverse effects of the reverse-recovery problem include electromagnetic interference noises and additional thermal management.

Multilevel converters offer high power capability, associated with lower output harmonics and lower turn-off losses. The main disadvantage associated with the multilevel inverter configurations is their circuit complexity, requiring a high number of power switches that must be commutated in an exactly determined sequence by a dedicated control circuit. To overcome these problems, simplified multilevel inverter has been developed to reduce the number of switches. There are a large number of control techniques developed so far to control the operation of multilevel inverters such as SVPWM, SPWM, OHPWM, SHE-PWM, Hybrid modulation. In these techniques SPWM is the easy to increase the number of levels in the output waveform with lower harmonic content. In SPWM control technique the gate pulses generated by comparing the sinusoidal reference waveform with the Triangular carrier waveforms.

The simulation results of a simplified multilevel inverter with SPWM control technique for PV applications are presented. The function of an inverter is to change a dc input voltage to a symmetric ac output voltage of desired magnitude and frequency. To drive the ac load, the output dc voltage of SEPIC converter is converted into ac by means of multilevel inverter. The SPWM technique is employed for the control of multilevel inverter.

The proposed single-phase nine-level inverter power circuit with auxiliary switches is shown in Figure 6.1. It includes a single-phase conventional H-bridge inverter, two bidirectional switches, and a capacitor voltage divider formed by C_1, C_2, C_3 and C_4. The auxiliary switches, formed by the controlled switches S5, S6 and S7 and with twelve diodes, D_1 to D_{12}.

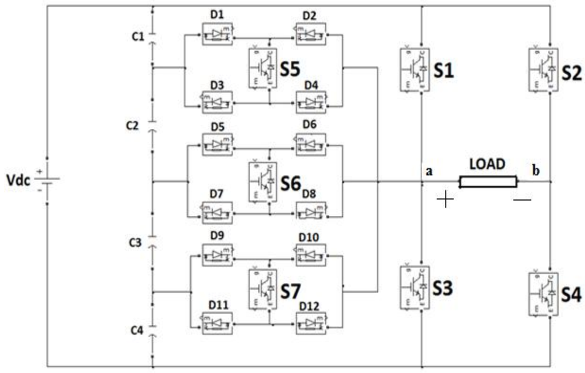

Figure 6.1 Single-phase nine-level inverter circuit

Proper switching of the single-phase nine-level inverter circuit can produce nine different levels of output-voltage from the dc supply voltage V_{dc}. The single-phase nine-level inverter circuit attains 56.25% drop in the number of main power switches are required. Figure 4.3 illustrates the comparison of the number of devices required for the four different types of single-phase nine-level inverters configuration.

7. EXPERIMENTAL SETUP AND RESULTS

The single-phase nine-level power circuit was fabricated using seven insulated gate bipolar transistor, ICs CT60. The IGBT has advantages of both MOSFET and BJT, lesser power requirement and absence of secondary breakdown phenomenon.

The whole experimental setup of the single-phase nine-level circuit fed induction motor is shown in Figure 7.1.

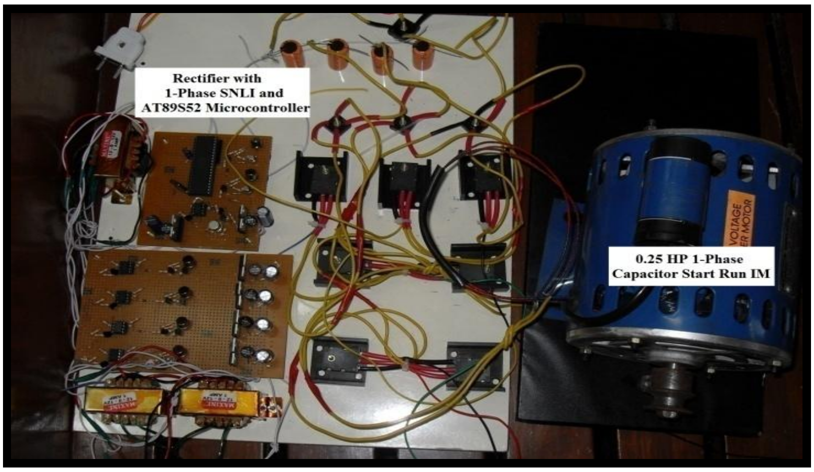

Figure 7.1 Experimental setup of the single-phase simplified nine-level circuit fed IM

The experimental result of nine-level output voltage of single-phase simplified nine-level circuit fed IM is shown in Figure 7.2. The fundamental output frequency is 50Hz. The measured nine different voltage levels are

V_{dc} = 324V, $3V_{dc}/4$ =243V, $2V_{dc}/4$ = 162V, $V_{dc}/4$ = 81V, 0V, - $V_{dc}/4$ = -81V, -$2V_{dc}/4$ = -162V, -$3V_{dc}/4$ = -243V, -V_{dc} = -324V.

The results were taken from the experimental circuit using a two channel, 50 MHz, DSO from GW Instek. The output waveform measured in the experimental setup may be close to the predicted simulation results.

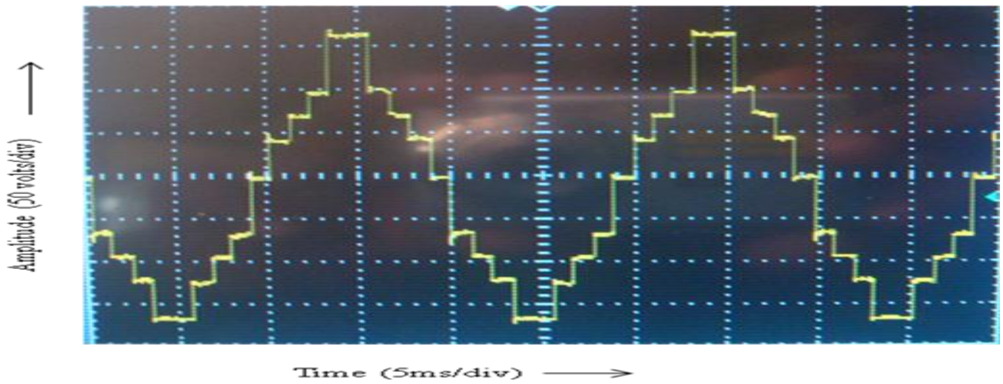

Figure 7.2 Experimental result of single-phase simplified Nine-level circuit

Thus the simulation work of a Photovoltaic array feeding a induction motor load. SEPIC converter and simplified nine-level inverter were used as interface between PV module and the induction motor. The voltage level of the PV panel is improved using SEPIC converter and simplified nine-level inverter. The simulation works of these circuits were carried out in the MATLAB software. The proposed SEPIC nine-level inverter is to reduce THD of the inverter. The 230v output voltage is obtained with above proposed topology in simulation. The boosted DC voltage of the SEPIC converter circuit output and inverted AC output waveforms were shown in the results.

8. PV ARRAY BASED DYNAMIC VOLTAGE RESTORER

Due to rapid developments in the industry, power quality plays a crucial role. Power quality is a measure of how well a source of electrical power meets the energy-supply needs of the connected load. If the load does not experience any operational problems, then by this measure, power quality is adequate. The term power quality refers to maintaining a near sinusoidal power distribution bus voltage at rated magnitude and frequency. When power quality becomes poor, it affects almost all consumers. Any variation in the supply voltage for duration not exceeding one minute is called a short duration variation. Short duration voltage variations are usually caused by faults in the power system

Dynamic voltage restorer is the one of the custom power devices which has excellent dynamic capabilities. It is well suited to protect sensitive loads from short duration voltage sag or swell. DVR is basically a controlled voltage source installed between the supply and a sensitive load. It injects 3 phase voltages to the system in order to compensate any disturbance affecting the load voltage. The amplitude and phase angle of the injected voltages are variable, thereby allowing control of real and reactive power exchange between DVR and distribution system. DVR is capable of generating or absorbing reactive power but the reactive power injection of the device must be provided by an external energy source or energy storage system.

DVR is a series connected device which is used for mitigating voltage disturbances in the distribution system. DVR maintains the load voltage at a nominal magnitude and phase by compensating the voltage sag/swell, voltage unbalance and voltage harmonics. The basic idea of DVR is to inject a control voltage generated by a forced commuted converter in series to the bus voltage by means of an injecting transformer.

The block diagram of the proposed PV-DVR is shown in Figure 8.1. It consists of a PV array, step-up dc-dc converter with adaptive P&O MPPT algorithm, battery, PWM inverter, super capacitor, series injection transformer and z-source inverter. When the grid fails or PV array generates excess power, then the switches are activated and the inverter supplies the load.

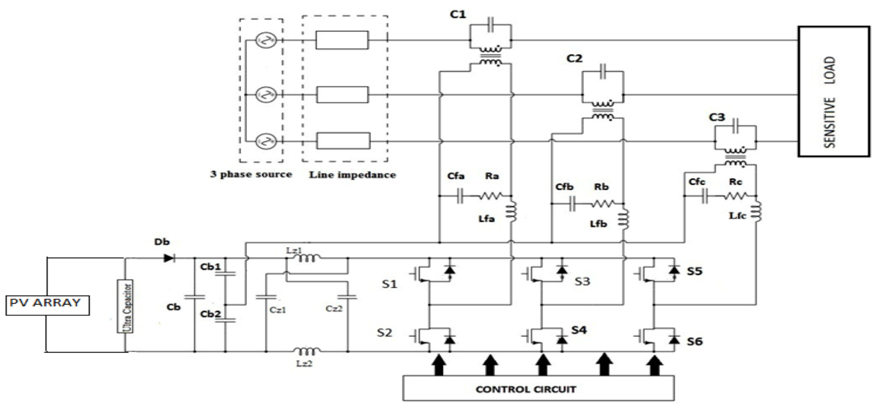

Figure 8.1 Circuit diagram of the proposed system

The Total Harmonics Distortion for non linear load without filter is shown in Figure 8.2 The harmonic distortion due to the presence of nonlinear load is 27.61%.

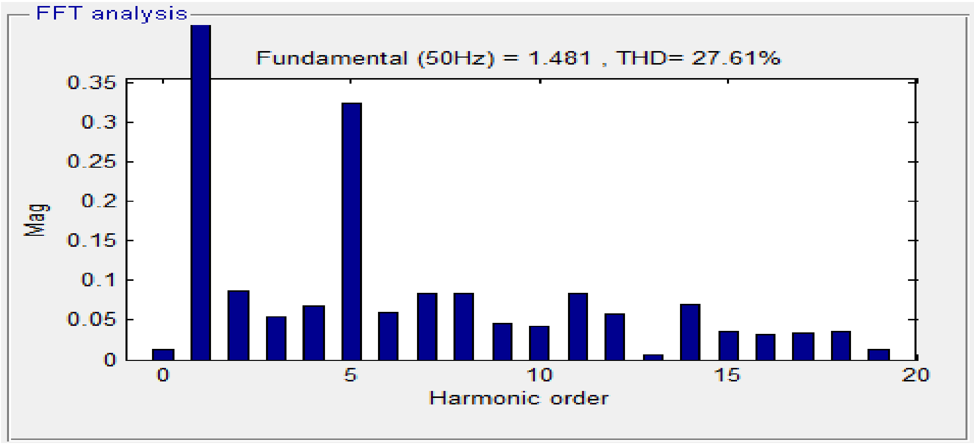

Figure 8.2 THD for non linear load without filter

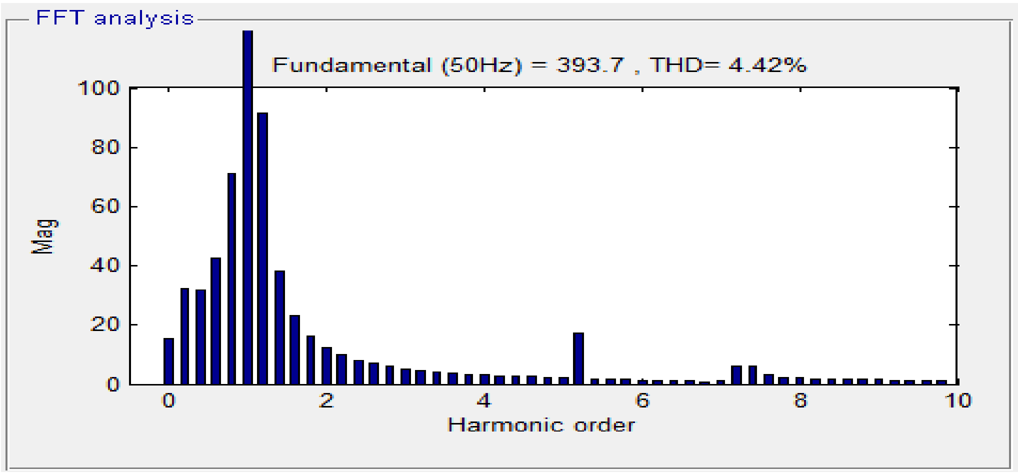

Figure 8.3 THD for non linear load with filter

The Total Harmonic Distortion for non linear load with filter is shown in Figure 8.3. The harmonic distortion due to the presence of nonlinear load is 4.42%.

This work has proposed a DVR that compensate voltage sag, voltage swell and harmonics. Based on the design procedure, DVR is designed and implemented by simulation results.

In this work, addition of load during the interval 0.15s to 0.25s. During this time voltage distortion takes place, which regained by DVR. The DVR gets activated at 0.15s and injects the distorted voltage up to 0.25s. During voltage sag condition, the supply voltage 100V dipped to 50% (50V) at 0.15s. With the help of DVR compensator, the dipped voltage gets increase to supply voltage 100V. Similarly, in voltage swell condition the supply voltage increased to 10% (110V) at 0.15s. With the help of DVR compensator, the voltages above the normal supply voltage are absorbed from 0.15s to 0.25s. Similarly addition of nonlinear load causes the waveform to get distorted and dipped to 50V, with the help of DVR this voltage is compensated to normal supply voltage 100V and voltage harmonic distortion due to the presence of nonlinear load is 27.61%, using DVR it is compensated to 4.42%. The voltage regulation is achieved using these proposed P&O MPPT algorithm based DVR. The simulations for the DVR is carried out, under different conditions including distorted supply voltage and distorted voltage sags, distorted voltage swell and harmonics have validated the operation of the proposed DVR.

9. POWER QUALITY IMPROVEMENT IN DISTRIBUTION SYSTEMS USING PROPOSED PV WITH DVR

The load flow of a distributed network provides the steady state solution of various parameters like voltages, currents and losses to be calculated. The power flow is important for the analysis of distribution system, to investigate the issues related to planning, design, operation and control. Application like optimal capacitor placement in distribution and automation system requires repeated load flow solution.

10. LOAD FLOW OF DISTRIBUTION SYSTEM

The method to carry out the load flow for distribution system under balanced operating condition employing constant power load model can be under stood through equivalent current injection method, formation of BIBC matrix, formation of BCBV matrix.

- Equivalent current injection.
- Formulation of BIBC matrix.
- Formulation of BCBV matrix.

In equivalent current injection at bus i, the complex Power S_i is specified and the corresponding equivalent current injection at the K-th iteration of the solution is computed as

$$S_i = P_i + jQ_1 \quad i = 1, 2, 3, ...N \tag{10.1}$$

$$I_i^k = I_i^r * V_i^k + j * I_i^k * V_i^k = \frac{P_i + jQ_i}{V_i^k} \tag{10.2}$$

The formulation of Bus-Injection to Branch-Current (BIBC) matrix is explained with the help of simple distribution system. The test system is a 33 node radial distribution system with one main feeder and three laterals are shown in Figure 10.1.

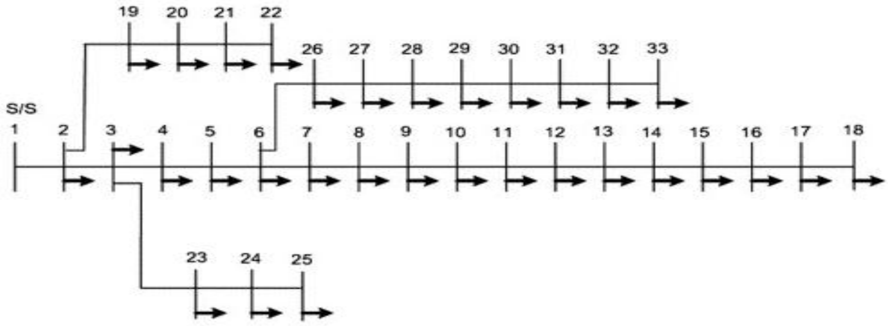

Figure 10.1 IEEE 33 Bus radial distribution system

From the above equation of BIBC matrix can be obtained

$$\begin{pmatrix} B_1 \\ B_2 \\ B_3 \\ B_4 \\ B_5 \end{pmatrix} = \begin{pmatrix} 1 & 1 & 1 & 1 & 1 \\ 0 & 1 & 1 & 1 & 1 \\ 0 & 0 & 1 & 1 & 0 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} I_1 \\ I_2 \\ I_3 \\ I_4 \\ I_5 \end{pmatrix}$$

The Branch-Current to Bus-Voltage (BCBV) matrix summarizes the relation between branch current and bus voltages. The relations between the branch currents and bus voltages can be obtained easily. As shown in Figure 10.1, the voltages of Bus 2, 3, and 4 are expressed as

$$\begin{aligned} V_2 &= V_1 - B_1 Z_{12} \\ V_3 &= V_2 - B_2 Z_{23} \\ V_4 &= V_3 - B_3 Z_{34} \end{aligned} \qquad (10.3)$$

The DVR reacts to the sag/swell events and injects the compensating voltage V_{dvr} with the supply voltage to restore the voltage at its nominal value. This method is simple to implement and very fast, especially in calculating the DVR compensating voltage. The simulation model is shown in the Figure 10.2

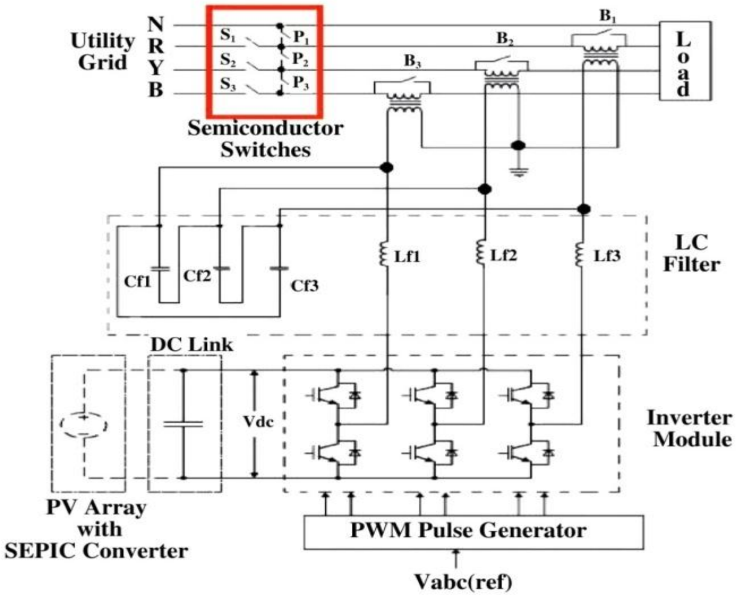

Figure 10.2 Simulation model for Comparison study

A new distribution device DVR with PV is aimed to improve the successful implementation of this device quality of power. Three different test systems (Normal, Capacitor placement, DVR with PV placement) are used to illustrate the successful improvement of this voltage. Voltage sensitivity analysis is used to employed the week busses for the location and size of the capacitor and DVR with PV. Using DVR with PV the voltage profile of the total system is improved. Particularly the nearby node voltage is improved very much. Also the total loss of the system is reduced. From the results obtained it is clear that, by the location and sizing of capacitor and DVR with PV the power quality has been improved. The loss reduction is better in DVR with PV rather than the capacitor placement method.

REFERENCES

1. Abdel-Salam, T S, Chikhani, A Y & Hackam, R 1994, 'A new technique for loss reduction using compensating capacitors applied to distribution systems with varying load condition', Power Delivery, IEEE Transactions, vol. 9, no. 2, pp. 819-827.
2. Antoneta Iuliana Bratcu, Iulian Munteanu, Seddik Bacha, Damien Picault & Bertrand Raison 2011, 'Cascaded DC–DC converter photovoltaic systems, power optimization issues', IEEE transactions on industrial electronics, vol. 58, no. 2, pp. 403-411.
3. Bhim Singh, Brij N. Singh, Ambrish Chandra, Kamal Al-Haddad, Ashish Pandey, & Dwarka Kothari, P 2003, 'A review of single-phase improved

power quality AC-DC converters', IEEE transactions on industrial electronics, vol. 50, no. 5, pp. 962-981.

4. Chiang, S J, Hsin-Jang Shieh & Ming-Chieh Chen 2009, 'Modeling and control of PV charger system with SEPIC converter', IEEE transactions on industrial electronics, vol. 56, no. 11, pp.4344-4353.
5. Cobben, J F G, Kling, W L & Myrzik, J M A 2005, 'Power quality aspects of a future micro grid', Proceedings of the International Conference on Future Power Systems, pp. 5, Available from:< http://ieeexplore.ieee.org/xpls/abs_all.jsp?arnumber=1600555>.
6. David Hamil, C, Jonathan Deane, H B & David Jefferies, J 1992, 'Modeling of chaotic DC-DC converters by iterated nonlinear mappings', IEEE transactions on power electronics, vol. 7, no. 1, pp. 26-36.
7. Esram, T & Chapman, P L 2007, 'Comparison of photovoltaic array maximum power point tracking techniques', IEEE Transactions on Energy Conversion , vol. 22, no. 2 , pp. 439-449.
8. Jindal, Amit Kumar, Arindam Ghosh & Avinash Joshi 2008, 'Critical load bus voltage control using DVR under system frequency variation', Electric Power Systems Research, vol. 78, no. 2, pp. 255-263.
9. Jing Huang & Keith Corzine, A 2006, Extended operation of flying capacitor multilevel inverters, IEEE transactions on power electronics, vol. 21, no. 1, pp. 140-147.
10. Tse, K K, Ho, M T, Chung, H S H & Hui, S Y R 2002, 'A novel maximum power point tracker for PV panels using switching frequency modulation', IEEE transactions on Power Electronics, vol. 17, no. 6, pp. 980-989.
11. Villalva, M G, Gazoli, J R & Filho, E R 2009, 'Comprehensive approach to modeling and simulation of photovoltaic arrays', Power Electronics, IEEE Transactions, vol. 24, no. 5, pp. 1198-1208.
12. Walid Omran, A 2011, 'Investigation of methods for reduction of power fluctuations generated from large grid-connected photovoltaic systems', IEEE transactions on energy conversion, vol. 26, no. 1, pp. 318-327.
13. Wang Jianqiang & Li Jingxin 2008, 'Design and experience of grid-connecting photovoltaic power system' work was supported in part by Beijing YOKU S.G.C. Technology Co., Ltd. and the government of Dingbian county of Shan' xi province of China. Availablefrom<http://ieeexplore.ieee.org/xpls/abs_all.jsp?arnumber=4747079 >.
14. Yuanxiong Guo, Miao Pan & Yuguang Fang 2012, 'Optimal power management of residential customers in the smart grid', IEEE transactions on parallel and distributed systems, vol. 23, no. 9, pp. 1593-1606.
15. Zhigang Liang, Rong Guo, Jun Li & Alex Huang, Q 2011, 'A high-efficiency PV module-integrated DC/DC converter for PV energy harvest in FREEDM systems', IEEE transactions on power electronics, vol. 26, no. 3, pp. 897-909.