International Journal of Advanced Technology & Engineering Research (IJATER)
National Conference on Recent Trends in Science, Technology & Management (NCRTSTM-2018)

DEVELOPMENT OF UPQC USING CASCADED MULTILEVEL INVERTER : COMPARISON WITH SHUNT AND SERIES ACTIVE POWER FILTERS

Sureshkumar sahu, S.S.P.B.K. PRASAD
sureshkumar.sahu@gmail.com
Assistant Professor in EEE department, GIET, Baniatangi

Abstract

Power quality is related to the ability of utilities to provide electric power without interruption. One of the major concerns in electric industry today is power quality problems to sensitive loads. Power quality problems such as sag, swell, harmonic distortion, unbalance, transient and flicker may have impact on customer devices, cause malfunctions and also cost on loss of production. Unified Power Quality Conditioner is a series element and shunt element connected in the power system. In this project, a UPQC with cascaded multilevel inverter is proposed. Voltage sag, unbalance in generation system is mitigated using proposed multilevel UPQC. There is no need of using transformer and filter when multilevel UPQC is applied and it is one of its advantages. Conventional Fundamental switching scheme is used for pulse generation to control the switches in the multilevel inverter. The main objective of my project is to regulate the voltage at source side against any power quality issues like under voltages; over voltages. The total harmonic distortion was reduced by using Multilevel UPQC.

Keywords— Active filters, harmonics, power quality, multilevel inverter, pq-theory, MATLAB/Simulink.

INTRODUCTION

Because of the increased number of nonlinear loads in the power systems we need an efficient and cost effective solution to improve the power quality. As the conventional passive filters fails at resonant condition we can adopt the active power filters to improve the transient as well as steady state stability of our system [1]-[3].

To do this we need voltage and current source inverters. We can reduce the cost of our system by a proper design and selection of inverter topology from the wide range of available options [5]. The cascaded multilevel inverter is a cost effective solution [11] and it reduces harmonics in the system [4], [10].

The unified power quality conditioner (UPQC) provides better characteristics than compared to individual series and shunt active power filters [6]-[9].

The operation of the proposed UPQC was verified through simulations with MATLAB software.

I. ACTIVE POWER FILTER

Filters are often the most common solution that is used to mitigate harmonics from a power system. Unlike other solutions, filters offer a simpler inexpensive alternative with high benefits. There are three different types of filters each offering their own unique solution to reduce and eliminate harmonics. These harmonic filters are broadly classified into passive, active and hybrid structures. The choice of filter used is dependent upon the nature of the problem and the economic cost associated with implementation.

An active filter is implemented when orders of harmonic currents are varying. One case evident of demanding varying harmonics from the power system are variable speed drives. Its structure may be either of the series of parallel type. The structure chosen for implementation depends on the type of harmonic sources present in the power system and the effects that different filter solutions would cause to the overall system performance.

Active filters use active components such as IGBT-transistors to inject negative harmonics into the network effectively replacing a portion of the distorted current wave coming from the load.

Active filters can be classified based on the connection scheme as Shunt active filters, series active filters and Unified power quality conditioners.

A. *Shunt Active Filters*

The active filter concept uses power electronic equipment to produce harmonic current components that cancel the harmonic current components that cancel the harmonic current components from the non-linear loads. In this configuration, the filter is connected in parallel with the load being compensated. Therefore the configuration is often referred to as an active parallel or shunt filter.

Fig. 3 illustrates the concept of the harmonic current cancellation so that the current being supplied from the source is sinusoidal. The voltage source inverter used in the active filter makes the harmonic control possible. This inverter uses dc capacitors as the supply and can switch at a high frequency to generate a signal that will cancel the harmonics from the non-linear load. The current compensation characteristic of the shunt active power filter is shown in fig. 4.

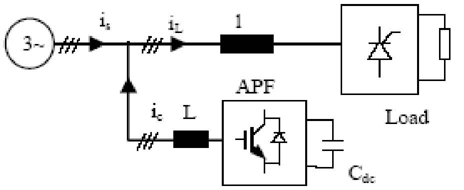

Fig. 3: shunt active power filter

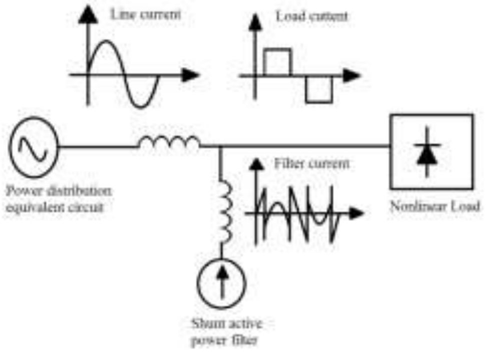

Fig. 4: Compensation characteristics of a shunt active power filter.

B. *Series Active Filters*

In Shunt Active Power Filtering, the Inverter injects harmonic currents required for elimination of harmonics in the source current and injects it at the node where the load is connected. The current drawn by the inverter is forced to contain a small in-phase sinusoidal component in order to draw enough active power from source to supply losses in the APF and to maintain the D.C side capacitor voltage constant. Series APF is the dual of Shunt APF.

In series APF the Inverter injects a voltage in series with the line which feeds the polluting load through a transformer. The injected voltage will be mostly harmonics with a small amount of sinusoidal component which is in-phase with the current flowing in the line. The small sinusoidal in-phase (with line current) component in the injected voltage results in the right amount of active power flow into the Inverter to compensate for the losses within the Series APF and to maintain the D.C side capacitor voltage constant. Obviously the D.C voltage control loop will decide the amount of this in-phase component.

Series active power filter compensate current system distortion caused by non-linear load by imposing a high impedance path to the harmonic current. By forcing high impedance it makes the high frequency currents to flow through the LC passive filter connected in parallel to the load. The high impedance imposed by the series active filter is created by generating a voltage of same frequency in such a way that the current harmonic component is eliminated. It should be noted that when series active filter used for the harmonic elimination it would be working in combination with the passive filter as shown in Fig 5.

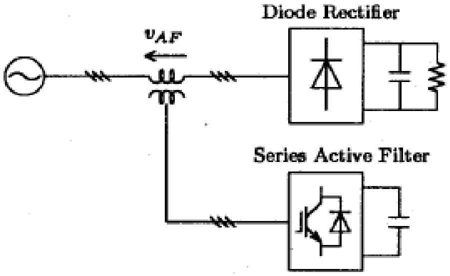

Fig 5: Series active filter.

C. *Unified Power Quality Conditioner*

The UPQC consisting of the combination of a series active power filter (APF) and shunt APF can also compensate the voltage interruption if it has some energy storage or battery in the dc link. The two types of UPQC are:

1. Right shunt UPQC.
2. Left shunt UPQC.

In this paper right shunt UPQC configuration was selected. This UPQC consists of two voltage source inverters connected back to back with each other sharing a common dc link. One inverter is controlled as a variable voltage source in the series APF, and the other as a variable current source in the shunt APF. Fig.6 [2] shows a basic system configuration of a general UPQC consisting of the combination of a series APF and shunt APF.

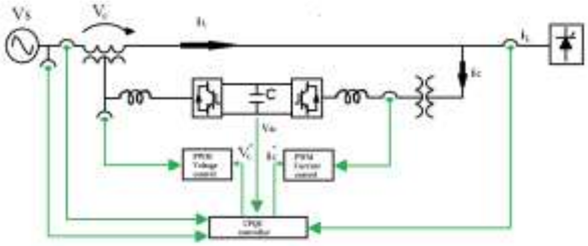

Fig. 6: Block diagram of UPQC

A simulation circuit diagram is shown in fig. 7.

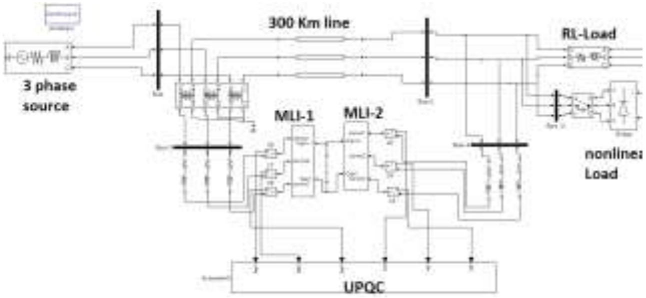

Fig. 7: MATLAB circuit diagram of the UPQC connected to the 3p line.

The function of the series APF is to compensate the voltage disturbance in the source side, which is due to the fault in the distribution line at the PCC. The series APF control algorithm calculates the reference value to be injected by the series APF transformers, comparing the positive-sequence component with the load side line voltages. The shunt APF described in this paper used to compensate the current harmonics and reactive power generated by the nonlinear load. The instantaneous reactive power (p-q) theory is used to control of shunt/series APF in real time.

MULTILEVEL INVERTER

It is generally accepted that the performance of an inverter, with any switching strategies, can be related to the harmonics contents of its output voltage. Power electronics researchers have always studied many novel control techniques to reduce harmonics in such waveforms. Up-to date, there are many techniques, which are applied to inverter topologies. In multilevel technology, there are several well-known topologies as follows:

1. Diode clamped multilevel inverter (DCMI).
2. Flying-capacitor multilevel inverter (FCMI).
3. Cascaded multilevel inverter with separate DC sources.

A. Cascaded Multilevel Inverter

Cascaded multilevel inverters are based on a series connection of several single-phase inverters. This structure is capable of reaching medium output voltage levels using only standard low-voltage mature technology components. Typically, it is necessary to connect three to ten inverters in series to reach the required output voltage. A basic structure of a cascaded multilevel inverter is shown in Fig. 8.

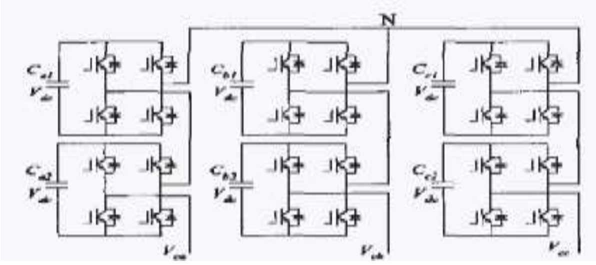

Fig. 8: Three-phase H-Bridge cascaded MLI.

Each inverter uses a dc-link voltage to generate a modulated voltage at the output terminals. The total output voltage is obtained by the sum of each individual output voltage as shown. Each inverter is able to produce three output voltage levels, namely, +*v*dc, −*v*dc, and 0. The maximum number of voltage levels of the phase voltage *L*ph is given by [11]

$L_{ph} = 2N_{inv} + 1$
Where $2N_{inv}$ is the number of inverters.

B. Phase Shifted Carrier PWM Method

A so-called phase-shift sinusoidal pulse width modulation (PS-SPWM) switching is proposed to operate the switches in the system as shown in fig.9.

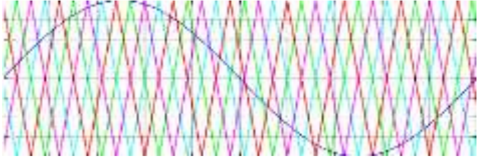

Fig. 9: Phase Shifted PWM.

Optimum harmonic cancellation is achieved, phase shifting each carrier by (k-1) π/n, where k is the kth inverter; n=(L-1)/2, where n is the number of series-connected single phade inverters. Where L is the number of switched DC levels thet can be achieved in each phase leg.

C. Multilevel inverter simulation diagram:

Fig. 10 shows an example of a multilevel inverter formed with MOSFETs. Fig. 11 shows the three terminals of the three phase multilevel inverter.

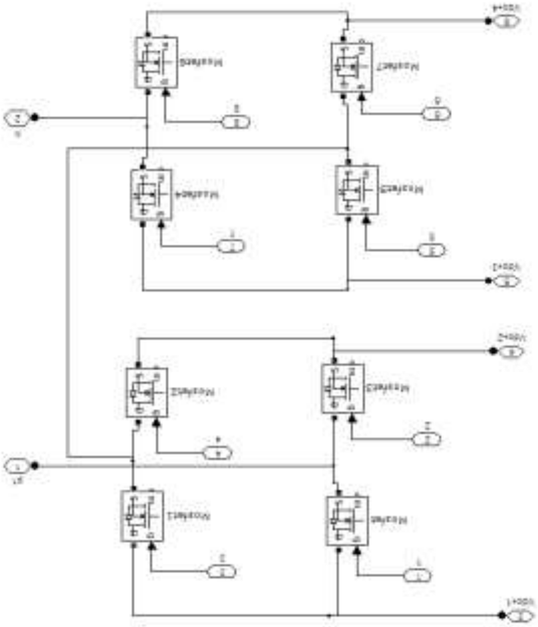

Fig. 10: One phase of a multilevel inverter MATLAB circuit diagram.

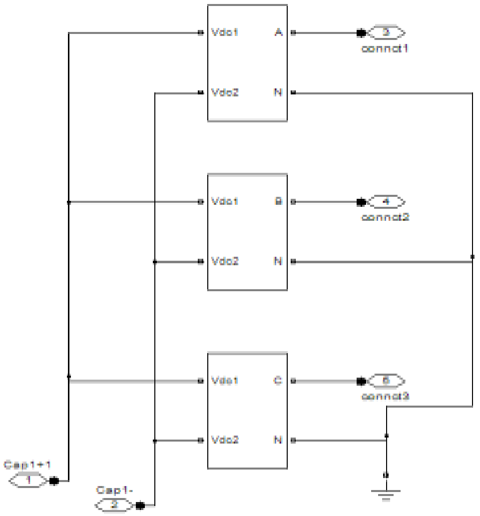

Fig. 11: Three phase output terminals of the 3 Phase MLI

INSTANTANEOUS REACTIVE POWER PQ-THEORY

Different techniques have been applied to obtain a control signal for the active filter. One such is the generation of a voltage proportional to the source current harmonics. With this control algorithm, the elimination of series and/or parallel resonances with the rest of the system is possible. The active filter can prevent the passive filter becoming a harmonics drain on the close loads. Additionally, it can prevent the compensation features depending on the system impedance.

The PQ-theory consists of an algebraic transformation (Clarke transformation) of the three-phase voltages and currents in the a-b-c coordinates to the α-β-0 coordinates, followed by the calculation of the p-q theory instantaneous power components:

$$\begin{bmatrix} V_\alpha \\ V_\beta \\ V_0 \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & \frac{-1}{2} & \frac{-1}{2} \\ 0 & \frac{\sqrt{3}}{2} & \frac{-\sqrt{3}}{2} \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \end{bmatrix} \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix}$$

(1)

$$\begin{bmatrix} i_\alpha \\ i_\beta \\ i_0 \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & \frac{-1}{2} & \frac{-1}{2} \\ 0 & \frac{\sqrt{3}}{2} & \frac{-\sqrt{3}}{2} \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix}$$

(2)

Instantaneous zero-sequence power is given by,

$$Po = vo.io \qquad (3)$$

Instantaneous real power is given by,

$$P = (V_\alpha .\, i_\alpha + V_\beta .\, i_\alpha)$$

(4)

Instantaneous imaginary power by definition is given by,

$$Q = (-V_\alpha .\, i_\beta + V_\beta .\, i_\alpha) \qquad (5)$$

CONTROL STRATEGY

The parameters required for the control of the compensator are shown in [3].

In order to obtain the reference compensation currents in a-b-c coordinates to the shunt-inverter we can write,

$$\begin{bmatrix} i^*_{ca} \\ i^*_{cb} \\ i^*_{cc} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1/\sqrt{2} & 1 & 0 \\ 1/\sqrt{2} & -1/2 & \sqrt{3}/2 \\ 1/\sqrt{2} & -1/2 & -\sqrt{3}/2 \end{bmatrix} . \begin{bmatrix} i^*_{co} \\ i^*_{c\alpha} \\ i^*_{c\beta} \end{bmatrix}, \qquad (6)$$

$$i^*_{cn} = (i^*_{ca} + i^*_{cb} + i^*_{cc}) \qquad (7)$$

In the same way the reference compensation voltages in the a-b-c coordinates to the series-inverter are given by,

$$\begin{bmatrix} v^*_{ca} \\ v^*_{cb} \\ v^*_{cc} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & 0 & 0 \\ \frac{1}{\sqrt{2}} & \frac{-1}{\sqrt{2}} & \frac{\sqrt{3}}{2} \\ \frac{1}{\sqrt{2}} & \frac{-1}{\sqrt{2}} & \frac{-\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} v^*_{c0} \\ v^*_{c\alpha} \\ v^*_{c\beta} \end{bmatrix} \qquad (8)$$

$$v^*_{cn} = (v^*_{ca} + v^*_{cb} + v^*_{cc}) \qquad (9)$$

OUTPUTS WITHOUT AND WITH UPQC

The following figures show the typical characteristics in different conditions.

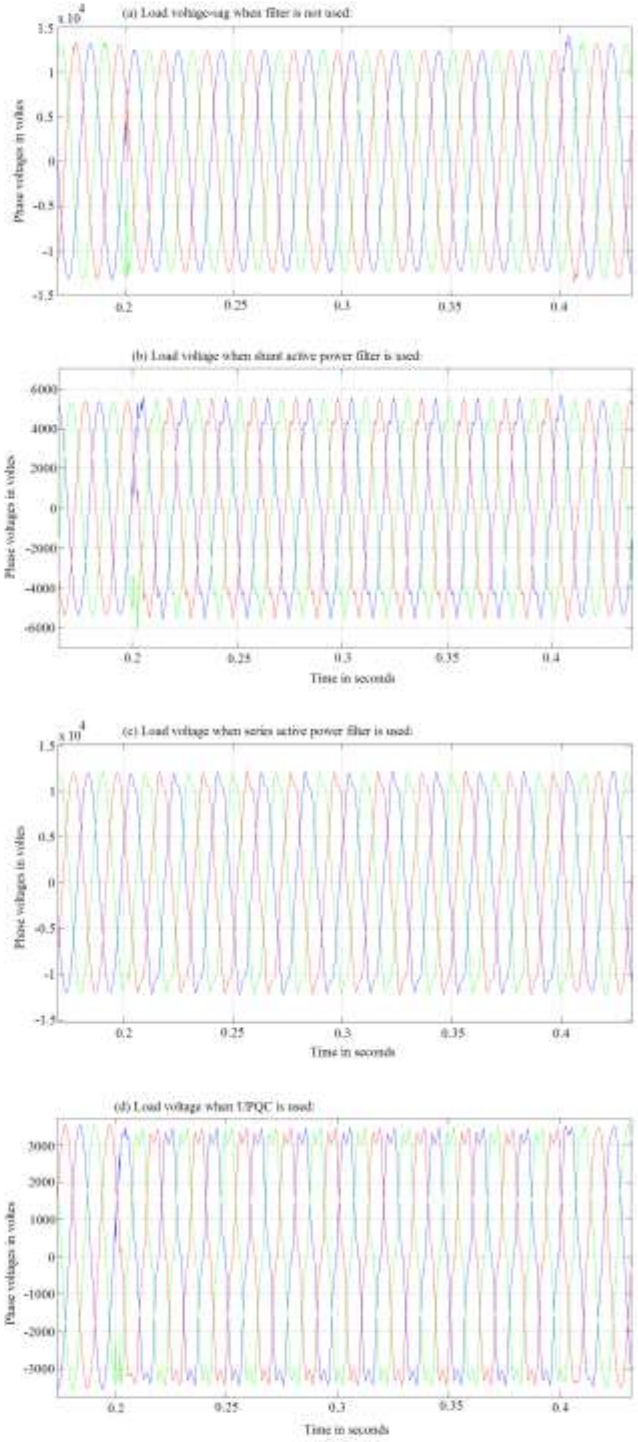

Fig. 12: Load voltage waveforms at different cases.

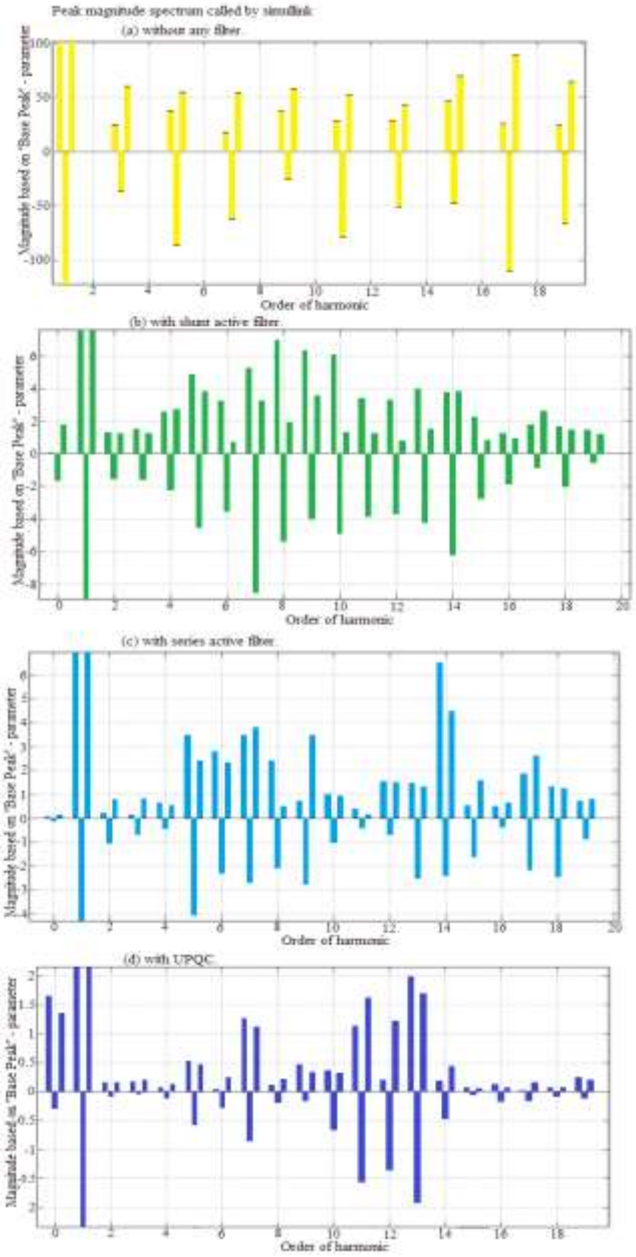

Fig. 13: Harmonics in the system at different cases.

CONCLUSION

The UPQC reduced harmonics in the system. Also voltage sag / voltage swell characteristics due to sudden application / removal of load is compensated. It does this well than that of shunt and series active power filters.

Its cost is also less compared to other inverter topologies [11]. And the load power factor tends to unity.

This paper has used a new configuration of UPQC, applying multilevel inverter. The proposed UPQC can be directly connected to the distribution system without any injection transformer as it struggles with core saturation and voltage drop.

The effectiveness of the proposed UPQC was verified by simulation of multilevel UPQC with MATLAB7.8.0 (R2009a).

REFERENCES

[1] Hirofumi Akagi, "New trends in active filters for power conditioning", IEEE transaction on industry applications, vol. 32, no 6, nov/dec 1996.

[2] Mauricio Aredes, Klemens Heumann, Edson H. Watanabe, "An Universal Active Power Line Conditioner" , IEEE Transactions on Power Delivery, Vol. 13, No. 2, April 1998.

[3] Hideaki Fujita, Hirofumi Akagi, "The Unified Power Quality Conditioner: The Integration of Series- and Shunt-Active Filters",IEEE transactions on power electronics, vol. 13, no. 2, march 1998.

[4] N.Farokhnia, S.H.Fati, H.R.Toodeji, "Voltage sag and unbalance mitigation in distribution systems using multi-level UPQC"IEEE.

[5] Vinod Khadkikar, "Enhancing Electric Power Quality Using UPQC: A Comprehensive Overview", IEEE transactions on power electronics, vol. 27, no. 5, may 2012.

[6] Walid G.Morsi, M.E.El-Hawary, "Defining power components in non-sinusoidal unbalanced polyphase sustems: the issues", IEEE power delivery, October 2007.

[7] Fang Zheng Peg, "Application issues of active filters".

[8] Fang Zheng Peng, George W. Ott, jr., and Donald J.Adams, "Harmonic and reactive power compensation based on the generalized instantaneous reactive power theory for three-phase four-wire system", IEEE power electronics v-13 n-6, 1998.

[9] Joao Afonso, Mauricio Areds, Edson Watanabe, Julio Martins, "Shunt active filter for power quality improvement", international conference UIE 2000 – electricity for a sustainable urban development.

[10] B.P.McGrath, Donald G.Holmes, "Multicarrier PWM strategies for multilevel inverters", IEEE industrial electronics, August 2002.

[11] Mariusz Malinowski, Jose Rodriguez, "A survey on csascaded multilevel inverter", IEEE TRANSACTIONS ON INDUSTRIAL ELECTRONICS, VOL. 57, NO. 7, JULY 2010

sureshkumar sahu completed his B.Tech from JITM parlakemundi affiliated to BPUT University in 2008 in Electrical and Electronics Engineering. He completed his M.Tech in AITAM college of Engineering affiliated to JNTUK in 2013 specialisation in Power Electronics and Electric Drives. His areas of interest are network theory and synthesis, control systems, power electronics and Drives.