Enhancement of Power Quality with multilevel Inverter based IPQC for Micro-Grid

K.Chandrasekhar

M.Tech Student Scholar
Department of Electrical and Electronics Engineering
R.V.R. & J.C. College of Engineering, Guntur, Andhra Pradesh, India

P.Venkata Kishore Babu

Assistant professor
Department of Electrical and Electronics Engineering
R.V.R. & J.C. College of Engineering, Guntur, Andhra Pradesh, India

Abstract- This project presents the integrated power quality controller (IPQC) for microgrid. In current control the novel variable reactor based on the magnetic flux control is used. A transformer with air gap is selected, and the primary winding current of the transformer is detected. A voltage-sourced inverter is applied to follow the primary current to produce another current, which is injected to the secondary. While it's operational principle and dynamic performance are analyzed. Based on the developed variable reactor, a novel integrated power quality controller (IPQC) suitable for microgrid is proposed, which can cater for the peculiar requirements of microgrid power quality, such as the harmonic high penetration, frequent voltage fluctuation and over current phenomenon, and bidirectional power flow and small capacity. For the fundamental, the equivalent impedance of the primary winding is a variable reactor or capacitor. For the nth-order harmonic, the equivalent impedance is very high impedance and acts as a "harmonic isolator." The system control strategy is also analyzed in detail. A set of three-phase IPQC has been constructed. The simulation results. The proposed concept can be implemented with Multilevel based inverter by replacing conventional inverter and is simulated using Matlab/simulink software.

Keywords – Micro grid, overcurrent, power flow, power quality, transformer, variable reactor, Multilevel Inverter.

I. INTRODUCTION

Electric power quality may be defined as a measure of how well electric power service can be utilized by customers. Power Quality problem is an occurrence manifested as a nonstandard voltage, current or frequency that results in a failure or a miss-operation of end user equipment. To compensate harmonics conventional Passive Filters are used for specific number of harmonics. To compress total harmonic content Active Power Filters are used. For all types of power quality solutions at the distribution system voltage level FACTS also called as Custom Power Devices are introduced to improve Power Quality. Interline Power Flow Controller is one of the advanced controller in Flexible AC Transmission System controller it only compensates series and manages power flow in the system [5]. To simultaneously control the power flow two converter model d-q orthogonal was introduced in the microgrid. By means of transmission angle variation series voltage is inject in the control region and the system gets over compensated [6]. Microgrid leads to effective distribution in rural area all distribution includes effective power in the control region processor to control and monitor the power exchange between the grids. When such processor get fully exploited it leads to high power quality problems and power consumption by developing narrow band communication and local control algorithm full micro grid is exploited with marginal investment and mainly micro grid can be able to disconnect from the microgrid loads from the disturbance and protects the transmission from harmonics [7]. By grid interfacing converter system the conventional series and parallel structure is adapted.

Two three phase four leg inverters is tend to construct grid interfacing system to compensate harmonic current it increases the complication and losses in the system [8]-[9]. Distributed generator not only inject power to the grid it also enhance power quality. By means of droop control technique it autonomously compensates voltage unbalances active and reactive droop control [10].A flexible AC distribution system aims to improve the power quality and reliability in microgrid, the design of control algorithms and extended kalman filters is meant for frequency tracking and to extract harmonic in grid voltage and load current in micro grid. By minimizing the total system planning and operation cost and cost of load shedding co- optimization of power system is taken over to increase the economic and reliability of the grid [11].

The main advantage of multilevel inverters is that the output voltage can be generated with a low harmonics. Thus it is admitted that the harmonics decrease proportionately to the inverter level. For these reasons, the multilevel inverters are preferred for high power applications[12]. How ever ,there is no shortage of disadvantages. Their control is much more complex and the techniques are still not widely used in industry. In this paper, modeling and simulation of a multilevel inverter using Neutral Point-Clamped(NPC) inverters have been performed with motor load using Simulink/ MATLAB program. Total Harmonic Distortion (THD) is discussed in the third section. The aim is to highlight the limit at which the multilevel inverters are no longer effective in reducing output voltage harmonics [13, 14].

II. VARIABLE REACTOR PRINCIPLE

2.1. System Configuration: Fig.1 shows the 1-ϕ system configuration of the novel variable reactor based on magnetic flux control. Suppose that the turns of primary and secondary winding of the transformer are and , respectively. The turns ratio is represented by *k* = / . A transformer with air gap is selected, and its primary winding *AX* can be connected in series or in parallel with power utility. In a normal load the secondary winding *ax* is not connected but a connected to voltage-sourced inverter. The primary and secondary windings voltages are and , respectively. The primary winding current *i*1 of the transformer is detected and functions as the reference signal . *his* represented by the gain of the current sensor. is represented by the voltage of dc side of the inverter , is represented by the capacitance of the dc capacitor and *α* is a controllable parameter, which will be explained later. The current control and voltage-sourced inverter are applied to yield a controlled current , which has the same frequency as . is inversely in phase injected to the secondary winding *ax.*

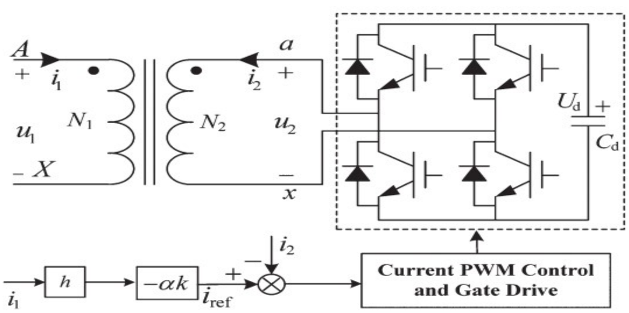

Fig.1.System configuration of the novel variable reactor

2.2. ***Equivalent T-Circuit of The transformer:*** The transformer is magnetically coupled circuit and it is central to the operation of the novel variable reactor, which is shown in Fig.2. The flow of currents in the two windings produces magneto motive forces (MMFs), which, in turn, set up the fluxes.

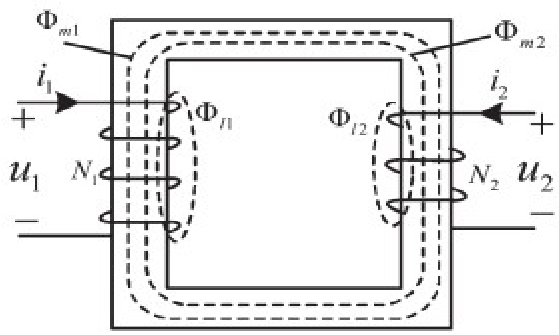

Fig.2. magnetically coupled circuit of the transformer

The total flux linking each winding may be written as

$$\psi\ 1 = \Phi l1 + \Phi m1 + \Phi m2 = \Phi\ l1 + \Phi\ m \quad (1)$$

$$\psi 2 = \Phi\ l2 + \Phi\ m2 + m1 = \Phi\ l2 + \Phi\ m \quad (2)$$

Here in, $\Phi l1$ is represented by the primary winding of the leakage flux and $\Phi l2$ is represented by the secondary winding of the leakage flux. $\Phi m1$ is the magnetizing flux produced by the primary winding, and it links all turns of the primary and secondary windings. The magnetizing flux is represented by $\Phi m2$ which is produced by the secondary winding, and it links all turns of the primary and secondary windings. Φm is represented by the resultant mutual flux. The voltage equations of the transformer can be expressed as.

$$u1 = R1i1 + d\lambda 1/dt \quad (3)$$

$$u2 = R2i2 + d\lambda 2/dt \quad (4)$$

Where $R1$ is the resistance of the primary winding and $R2$ is the resistance of the secondary winding.. $\lambda 1$ and $\lambda 2$ are the flux linkages related to the primary and secondary windings, respectively. If saturation is neglected and the system is linear, the below equations can be achieved.

) (5)

) (6)

Here in, is the leakage inductance of the primary winding and is the leakage inductance of secondary winding. And are the magnetizing inductances of the primary and secondarywindings, respectively. According to, when the quantities of the secondary winding are referred to the primary winding, (3) and (4) become.

1 (7)

u_1 : (8)

Here, the prime denotes referred quantities of secondary winding to primary winding. Equations (7) and (8) can be expressed as the following equations in phasor form:

U_1 (9)

$U'_2 = l$ (10)

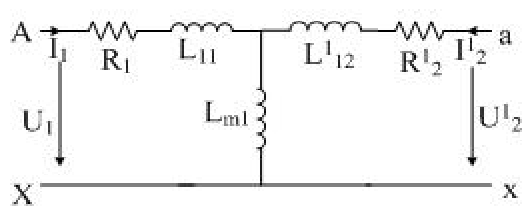

Fig.3 Equivalent T-circuit of the transformer

The voltage equations in (9) and (10) with the common suggest the equivalent T-circuit shown in Fig.3 for the two winding transformer. Note that, in some equivalent T-circuit of the transformer, a core loss resistance

, which accounts for the core loss due to the resultant mutual flux, is connected in series or in parallel with the magnetizing inductance (in the later analysis, a series core loss resistance is taken into account in theequivalent T-circuit of the transformer). Let

which is the leakage impedance of the winding. , which is the leakage impedance of the secondary winding *ax* referred to the primary winding. , which is the magnetizing impedance of the transformer. Here, ω is represented by the fundamental angular frequency. Then, the equations (9) and (10) can be written as

(11)

(12)

2.3. Variable Reactor principle: In Fig.1, the primary winding current is detected and functions as the reference signal, and to applied the voltage-sourced inverter and to track the reference signal to yield a controlled current . When controlled current and the primary current satisfy

(13)

Herein, α is a controllable parameter. The transformer is double side energized, and then, the below equations can be obtained:

(14)

(15)

In terms of (14), from the terminals *AX*, the equivalent impedance of the transformer can be obtained, i.e.

(16)

In terms of (16), the equivalent impedance of the primary winding of the transformer is a function of the controllable parameter α. When α is adjusted, the primary winding exhibits consecutively adjustable impedance. Equation (16) can be also achieved in terms of the resultant. MMFs of the two windings acting around the same path of the core. The voltage sourced inverter is produced a controlled current *i*2 and it is injected into the secondary winding of the

The Primary Winding of the Transformer
with Equivalent Impedance

α	The equivalent impedance of terminal *AX*	Impedance charateristic
$\alpha < 0$	$Z_{AX} > Z_1 + Z_m$	resistive and inductive
$\alpha = 0$	$Z_{AX} = Z_1 + Z_m$	
$0 < \alpha < 1$	$Z_1 < Z_{AX} < Z_1 + Z_m$	
$\alpha = 1$	$Z_{AX} = Z_1$	
$1 < \alpha < 1 + Z_1 / Z_m$	$Z_1 < Z_{AX} < 0$	
$\alpha = 1 + Z_1 / Z_m$	$Z_{AX} = 0$	0
$\alpha > 1 + Z_1 / Z_m$	$Z_{AX} < 0$	resistive and capacitive

Transformer and , the resultant MMF is + = $(1 - \alpha)$. Then, the resultant flux set up by the MMF of the two windings is $(1 - \alpha)$. Then, the induced voltage produced by the resultant flux can be expressed in phasor form as

$$= (1 - \alpha)j\omega \quad I \qquad (17)$$

The primary voltage equation can be achieved as (14). In terms of (16), the relation between the equivalent impedance of the primary winding and the parameter α is shown in Table I. The variable reactor features hardly producing harmonics, simple control scenario, and with consecutive adjustable impedance. Many flexible ac transmission systems (FACTS) devices can be implemented in terms of the novel principle. To control the power flow by using variable reactor and it can be used in unified power flow controller to change the line impedance between the sending and receiving ends, and it can also substitute the thyristor-controlled reactor of the thyristor-controlled series capacitor; however, any harmonics does not proposed by the variable reactor. The novel principle of the variable reactor can be used to implemented the fault current limiter. Reactive power compensation can be all realized by the novel variable reactor. In addition, it has been successfully applied the hybrid series active power filter based on fundamental magnetic flux compensation.

2.4. Dynamic Analysis of the Variable Reactor: The novel variable reactor based on the magnetic flux control is current control it is one of best technique. Nowadays, the widely used current control technique includes the hysteresis current control, the predictive and ramp comparison current control, and deadbeat control. In the digital control system based on DSP, the most widely used current control is the ramp comparison current control with the proportional–integral (PI) controller. In this case, the system block diagram of the variable reactor is shown in Fig.4. Here in, *h* is represented by the gain of current sensor; the combined transfer function of the sample and delay is represented as ; the transfer function of the voltage-sourced inverter is denotedby The transfer function of the PI controller is denoted by .

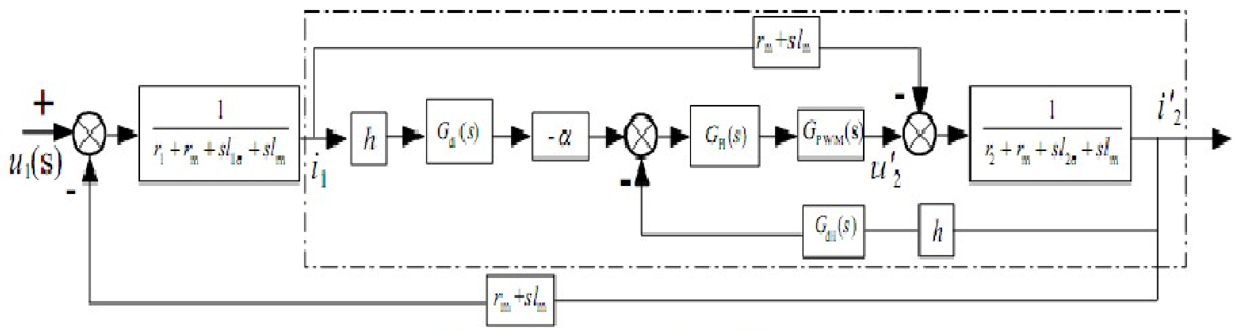

Fig. 4 System block diagram of variable reactor

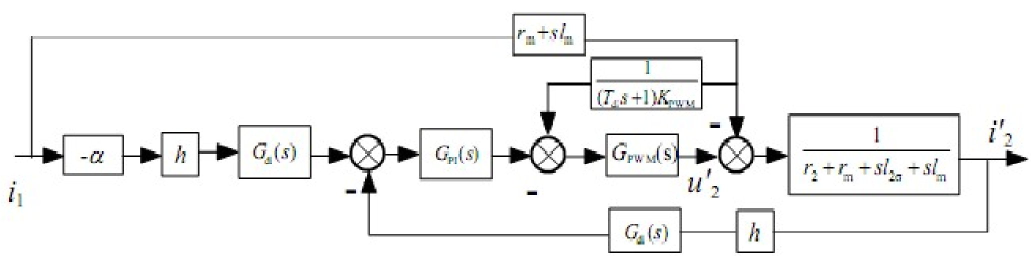

Fig. 5 Block diagram of current control with feed forward

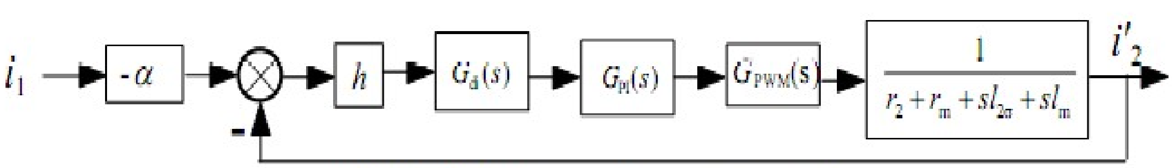

Fig. 6 Block diagram of current control

Shown at the bottom of the page the system admittance of the transfer function can be derived as (18), which means that the overall system is a five-order system. Fig.4 shows the current control component is in dash-dotted frame. In order to improve the system anti-interference performance in low-frequency band, a feed forward element is designed in the block diagram of the current control component, which is shown in Fig.5. In this case, the block diagram of the current control component becomes Fig.6. The open-loop transfer function of the current control block in Fig.6 is

$$G_Y(s) = i_1(s)/u_1(s) = \frac{hk_i(1+T_i s)K_{\mathrm{PWM}} + (r_2 + r_{\mathrm{m}} + sl_{2\sigma} + sl_{\mathrm{m}})(1+T_{\mathrm{di}}s)sT_i(1+T_{\mathrm{PWM}}s)}{hk_i(1+T_i s)K_{\mathrm{PWM}}[r_1 + r_{\mathrm{m}} + sl_{1\sigma} + sl_{\mathrm{m}} - \alpha(r_m + sl_m)] + [(r_1 + sl_{1\sigma})(r_2 + sl_{2\sigma}) + (r_m + sl_m)(r_1 + r_2 + sl_{1\sigma} + sl_{2\sigma})](1+T_{\mathrm{di}}s)sT_i(1+T_{\mathrm{PWM}}s)} \tag{18}$$

$$G_{\mathrm{open}}(s) = \frac{hk_{\mathrm{i}}(1+sT_{\mathrm{i}})K_{\mathrm{PWM}}}{(1+T_{\mathrm{di}}s)sT_{\mathrm{i}}(1+T_{\mathrm{PWM}}s)(r_2 + r_{\mathrm{m}} + sl_{2\sigma} + sl_{\mathrm{m}})} \tag{19}$$

.

Let *Ti* = (+)/(+) and *T*PWM ≈ 0.5*T*di, when combining the two elements with little time delay, (16) becomes

$$G_{\mathrm{open}}(s) = \frac{\frac{hK_{\mathrm{PWM}}k_i}{(r_2+r_m)}}{(1+1.5T_{\mathrm{di}}s)sT_i} \tag{20}$$

$$k_i = T_i(r_2+r_m)/(3T_{\mathrm{di}}K_{\mathrm{PWM}}h)$$

Here, when the current control system performance will be approximately optimum.

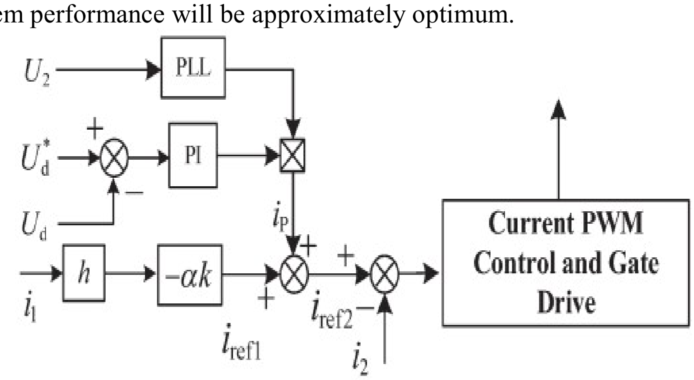

Fig.7. DC-link voltage control schematic

2.5. Dc-Link Voltage Control of The Variable Reactor: There must be some losses when the novel variable reactor system with inverter operates normally, and the inverter will absorb active power to maintain the dc voltage constant. The dc-link voltage control schematic of the variable reactor is shown in Fig.7. Here in, and represent the inverter dc reference and p to achieve a new reference signal *i*ref2. A dc-link voltage PI controller is applied to make the inverter dc practical voltage follow the dc reference voltage . The output of the voltage PI controller is multiplied by the phase-locked loop (PLL) output of to yield the active current reference .

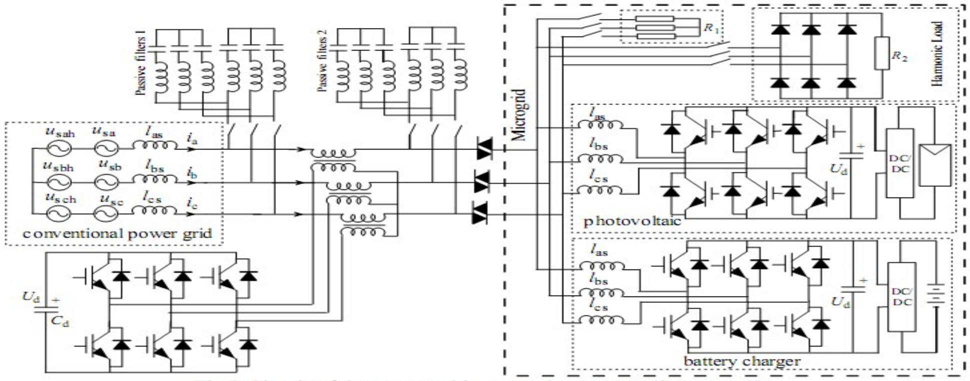

Fig.8 Circuit of the proposed integrated power quality controller

III. IPQC PRINCIPLE

3.1. System Configuration: The novel integrated power quality controller can be installed in series and parallel in point of common coupling (PCC) or micro grid. For simplicity, the IPQC is installed in PCC. Fig. 8 shows the three-phase detailed system configuration of the IPQC with transformer and inverter. and represent the source voltage and impedance of conventional power supply, respectively. The function of absorbing the harmonics by using passive filters, are shunted in both sides. The primary winding of a transformer is inserted in series between the microgrid and the conventional power utility, whereas the secondary winding is connected with a voltage-source PWM converter. is represented by the voltage of the dc side of the inverter. The microgrid contains a harmonic load, a normal load ,a photovoltaic cell system, and a battery storage system. The proposed integrated power quality controller has the following functions

.

3.2. ***Power flow Control:*** When the fault current limiter and power flow control are of concern, only the fundamental is taken into account. In terms of the preceding analysis, the primary winding exhibits adjustable impedance + (1 − *α*) . With the change in coefficient *α*, the equivalent impedance of the primary winding can be achieved, which is shown in Table I. Therefore, when the primary winding is connected in series in circuit, it can be applied to control the internal power flow of the micro grid or to control the power flow between the conventional power utility and the microgrid. Fig.9 shows the schematic of power flow control. when the novel variable reactor is connected in series between the sending and receiving ends. Suppose that the equivalent impedance + (1 − *α*) of the variable reactor is *R* + *jX*. In terms of the vector diagram in Fig.9, the below equations can be obtained.

$$U_m \sin\varphi = U_s \sin(\varphi - \delta) + XI \qquad (21)$$

$$U_m \cos\varphi = U_s \cos(\varphi - \delta) + RI \qquad (22)$$

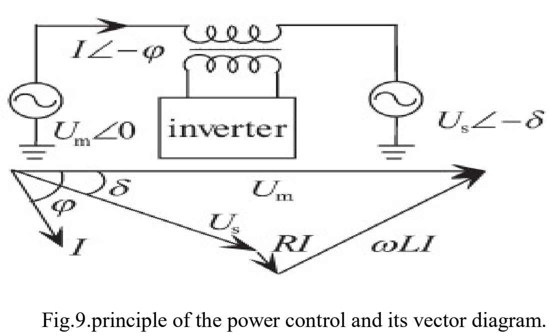

Fig.9.principle of the power control and its vector diagram.

Multiply cosϕ in both sides of (21) and multiply sin ϕ in both sides of (22), then the following equation can be obtained by adding them:

$$U_m(U_m - U_s \cos\delta) = PR + QX \quad (23)$$

Multiply sin ϕ in both sides of (21) and multiply cosϕ in both sides of (22), then the following equation can be obtained by subtracting them:

$$U_s \sin\delta = PX - QR. \quad (24)$$

In terms of (23) and (24), the active and reactive power from to are

$$P = \frac{U_m}{R^2 + X^2}\left[R(U_m - U_s \cos\delta) + XU_s \sin\delta\right] \quad (25)$$

$$Q = \frac{U_m}{R^2 + X^2}\left[-RU_s \sin\delta + X(U_m - U_s \cos\delta)\right] \quad (26)$$

In the power system with high voltage level, the inductive reactance component of the transmission line is much more than the resistance component of the transmission line, (25) and (26) become

$$P = \frac{U_s U_m}{X}\sin\delta \quad Q = \frac{U_m}{X}(U_m - U_s \cos\delta) \quad (27)$$

In microgrid with low voltage level, when the resistance component of the transmission line is much more than the inductive reactance component of the transmission line, (25) and (26) can be expressed as

$$P = \frac{U_m}{R}(U_m - U_s \cos\delta) \quad Q = -\frac{U_m U_s}{R}\sin\delta \quad (28)$$

In terms of (28), there is a striking difference in power flow control and voltage regulation between microgrid and conventional power grid.

3.3. Fault Current Limiter: When the terminal *AX* is connected in series in circuit, the coefficient α can be controlled as α = 1 + / in the normal operation state, the equivalent impedance of the primary winding *AX* is zero. Hence, in normal operation state the series transformer does not have any influence on the power system. The maximum system current of the three phases is obtained by a current-detecting circuit and compared with a reference current. In case of a short-circuit fault, maximum system current reaches the reference current, the coefficient α can be controlled between −1 and 1 in terms of the requirement of fault current, and the equivalent impedance of the primary winding *AX* is controlled between + and to limit the system current to a desired value

3.4. Voltage Compensation: In order to compensate the voltage fluctuation, the primary winding of the transformer is connected in series between the power electric utility and the load. When the load voltage is lower than the desired voltage, the coefficient α is controlled more than 1 + / , and the primary winding exhibits capacitive impedance. When the load voltages higher than the desired voltage, the coefficient α can be controlled between 0 and 1 + / , and the primary winding exhibits inductive impedance. Therefore, the load voltage can be controlled as a stable voltage.

3.4. Harmonic Isolation: The preceding function o fault current limiter, power flow control and voltage compensation is concerned with the fundamental. If there exits harmonic in the power utility, the primary current contains the fundamental current and *n*th order harmonic currents, that is to say, = + $\sum$ The fundamental component rather than harmonic is detectedfrom the primary winding current *i*1 and functions as a reference signal. To track the fundamental reference signal by applied the voltage source inverter to produce a fundamental compensation current , which has the same frequency as . is inversely in phase injected to the secondary winding *ax*. When α = 1 + / , the fundamental equivalent impedance of primary winding *AX* is zero, which is shown in Fig. 10. Meanwhile, for the *n*th- order harmonic, since only a fundamental current is injected to the secondary winding of The transformer does not include any order harmonic current other than the fundamental current, which means that the transformer is open circuit to harmonic current.

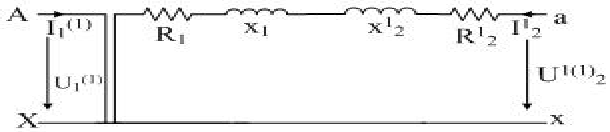

Fig.10. Fundamental equivalent circuit

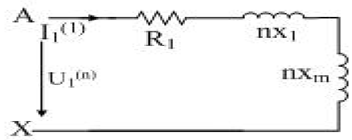

Fig.11.Harmonic equivalent circuit

Therefore, the equivalent circuit of the transformer to the *n*th-order harmonic is shown in Fig.11. Then, the harmonic equivalent impedance of the transformer is jn .From the primary winding, the series transformer exhibits very low impedance at the fundamental and simultaneously exhibits high impedance to harmonics to act as a "harmonic isolator." Then, the harmonic currents are forced to flow into the passive *LC* filter branches in both sides.

3.6. IPQC: When integrating the preceding functions of variable reactor, voltage compensation, fault current limiter, power flow control and harmonic isolation, a novel integrated power quality controller can be achieved. For fundamental and harmonic, the primary winding of the series transformer exhibits the impedance of + (1 − α) and n respectively. That is to say, the primary winding of the series transformer exhibits adjustable impedance, which plays the role of fault current limiter, power flow control, and voltage compensation to fundamental. Meanwhile, the primary winding of the series transformer exhibits high impedance n to harmonic, which can greatly improve the source impedance to harmonics, and really acts as a harmonic isolator. Therefore, it can mitigate the harmonic high penetration.

IV. MULTILEVEL INVERTERS

The general concept involves utilizing higher number of active semiconductor switches to perform the power conversion in small . There are several advantages to this approach when compared with the conventional power conversion approach. The smaller voltage steps lead to the production of higher power quality waveforms and also reduce voltage (dv/dt) stress on the load and the electromagnetic compatibility concerns. Another important feature of multilevel converters is that the semiconductors are wired in a series-type connection, which allows operation at higher voltages. However, the series connection is typically made with clamping diodes, which concerns. Furthermore, since the switches are not truly series connected, their switching can be staggered, which reduces the switching frequency and thus the switching losses .However, the most recently used inverter topologies, which are mainly addressed as applicable multilevel inverters, are cascade converter, neutral-point clamped (NPC) inverter, and flying capacitor inverter. Some applications for these new converters include industrial drives, flexible ac transmission systems (FACTS),and vehicle propulsion. One area where multilevel converters are particularly suitable is that of renewable photovoltaic energy that efficiency and power quality are of great concerns for the researchers.

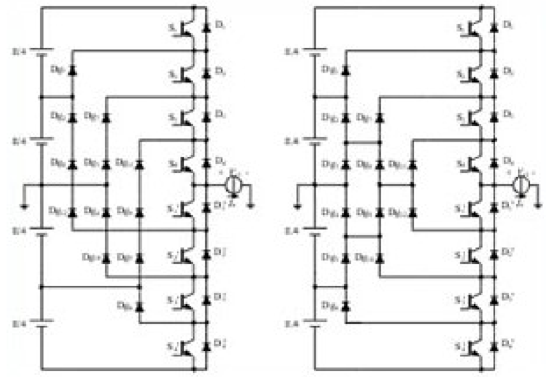

Fig.12.single leg of five level NPC inverter

V. MATLAB/SIMULINK RESULTS

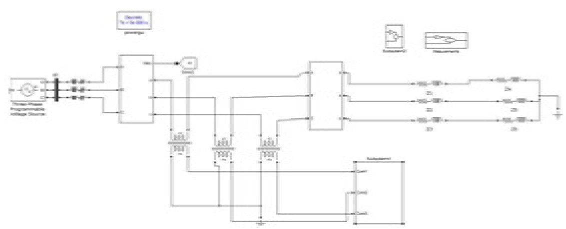

Fig.13. Conventional diagram for IPQC

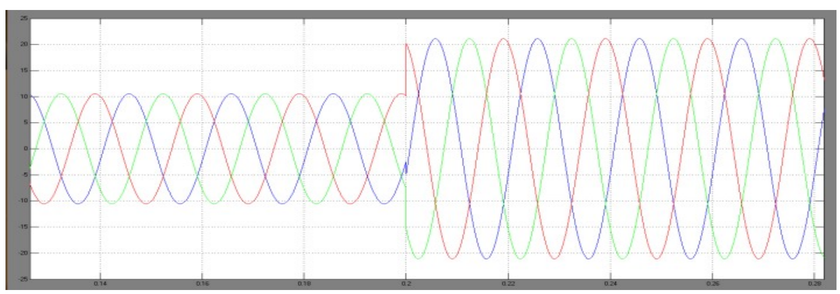

Fig.14. Current waveforms of the primary winding when α suddenly changes from 0.1 to 0.6

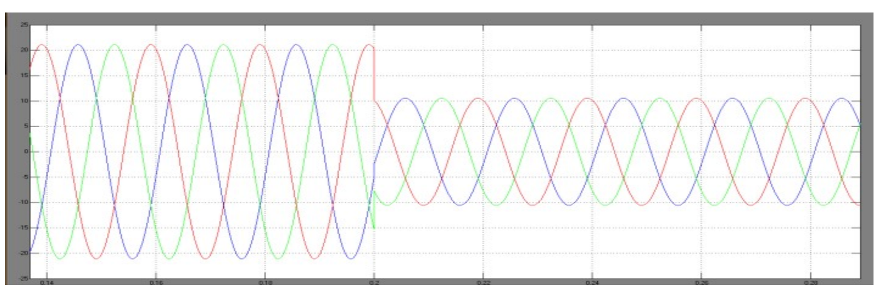

Fig.15. Current waveforms of the primary winding when α suddenly changes from 0.6 to 0.1

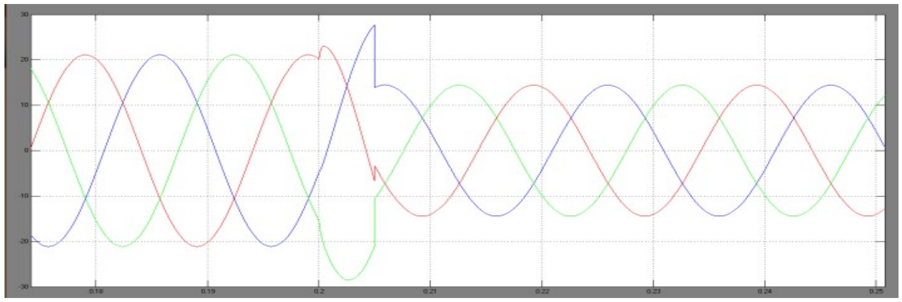

Fig.16. Current waveforms of the fault current limiter

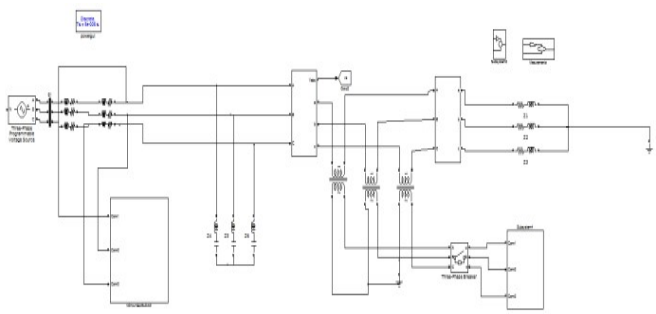

Fig.17. Simulation circuit for harmonic isolation in the first condition

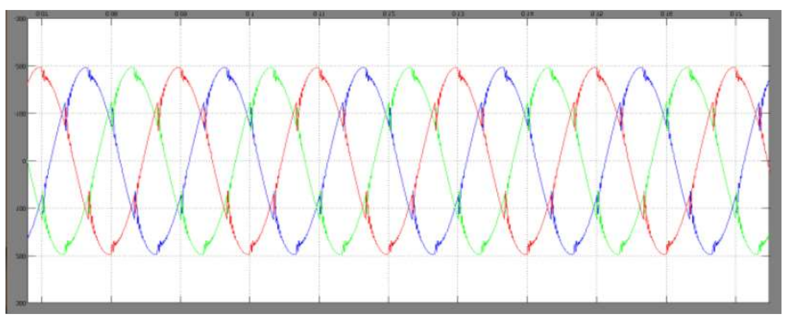

Fig.18. System voltage waveforms when the IPQC is not applied

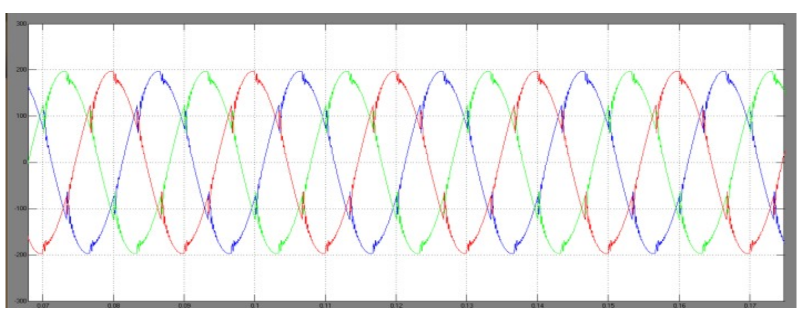

Fig.19. System current waveforms when the IPQC is not applied

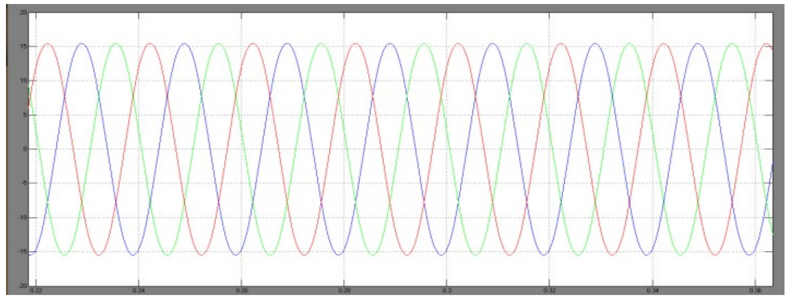

Fig.20. Current waveforms at microgrid side when the IPQC is applied

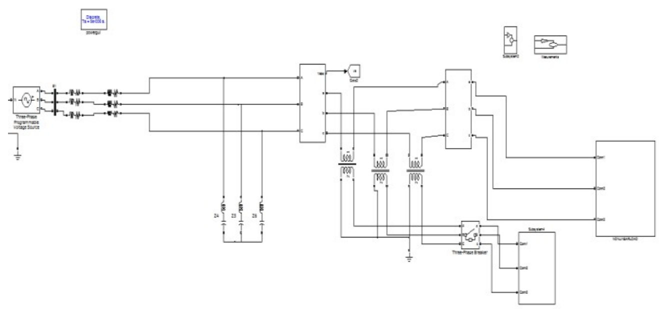

Fig. 21. Proposed circuit for harmonic isolation in the second condition

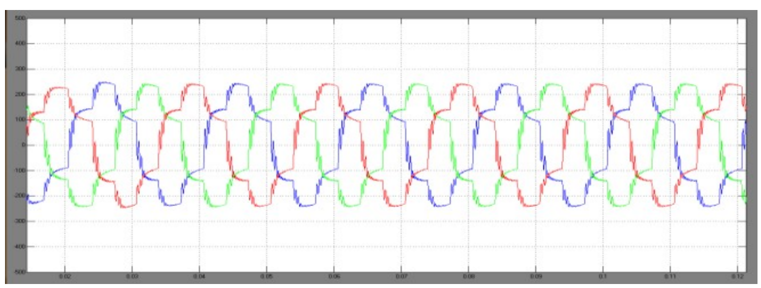

Fig.22. System voltage waveforms when the IPQC is not employed

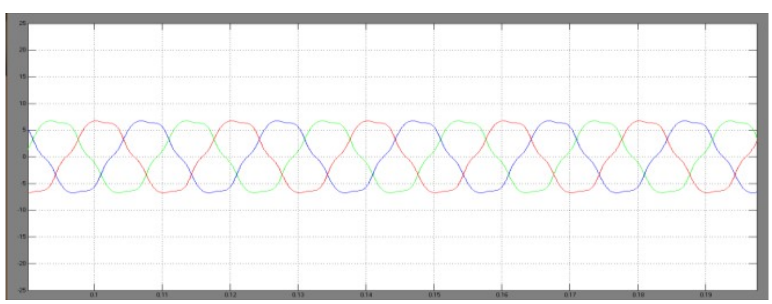

Fig. 23. System current waveforms when the IPQC is not employed

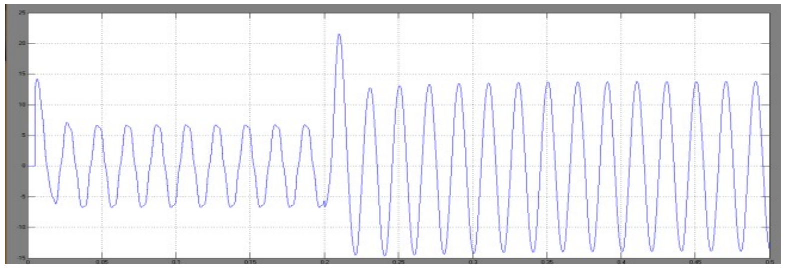

Fig .24. System current waveforms when the IPQC is employed

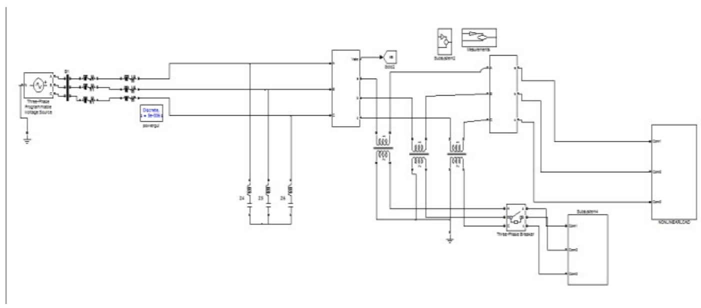

Fig.25. shows the proposed IPQC with MLI

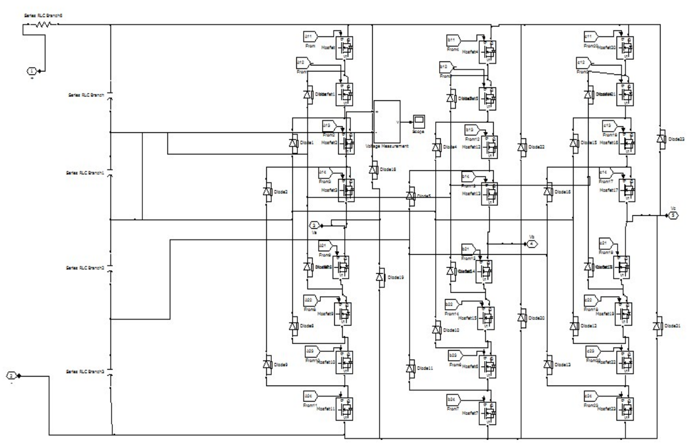

Fig.26. shows the proposed MLI system

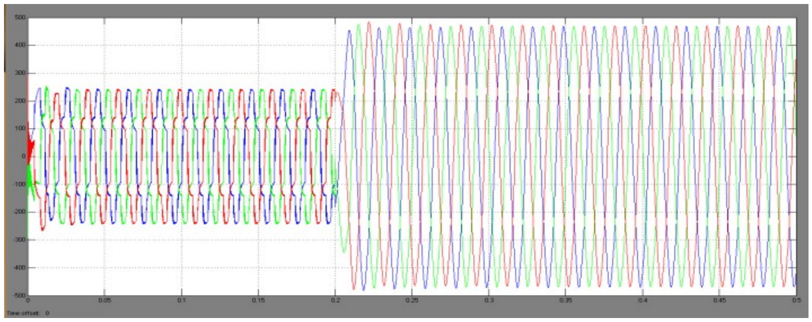

Fig.27. shows the load voltage response before and after MLI based IPQC operation

VI. CONCLUSION

The cascaded inverter switching signals are generated using triangular-sampling current controller; it provides a dynamic performance under transient and steady state conditions, THD analysis also within the IEEE standards. Instantaneous real-power theory based cascaded multilevel inverter based IPQC is connected in the distribution network at the PCC through filter inductances and operates in a closed loop. A cascaded multilevel voltage source inverter based IPQC using instantaneous real power controller is found to be an effective solution for power line conditioning to compensate harmonics, reactive power and power factor with the IRP controller reduces harmonics and provides reactive power compensation due to non-linear load currents; as a result source current(s) become sinusoidal and unity power factor is also achieved under both transient and steady state conditions. This paper has presented a novel variable reactor based on the magnetic flux control. A transformer with air gap is selected, and the primary winding current of the transformer is detected. A voltage-sourced inverter is applied to follow the primary current to produce another current, which is injected to the secondary. When the injected current is adjusted, the equivalent impedance of the primary winding of the transformer will change continuously. In terms of the novel variable reactor, a novel IPQC suitable for microgrid is proposed. The primary winding exhibits adjustable impedance, which plays the role of power flow control, fault current limiter, and voltage compensation to fundamental.

REFERENCES

[1] B. Lasseter, "Microgrids [distributed power generation]," in Proc. IEEE Power Eng. Soc. Winter Meet., 2001, vol. 1, pp. 146–149.
[2] C. Marnay, F. J. Robio, and A. S. Siddiqui, "Shape of the microgrid," in Proc. IEEE Power Eng. Soc. Winter Meet., 2001, vol. 1, pp. 150–153.
[3] R. H. Lasseter et al., Integration of Distributed Energy Resources: The CERTS Microgrid Concept. Berkeley, CA, USA: Consortium for Electric Reliability Technology Solutions, 2002.
[4] C. Marnay and O. Bailey, "The CERTS micro grid and the future of the macrogrid," Lawrence Berkeley National Laboratory, Berkeley, CA, USA, Rep. LBNL-55281, Aug. 2004.
[5] N. Hatziargyriou, H. Asano, R. Iravani, and C. Marnay, "Micro grids," IEEE Power Energy Mag., vol. 5, no. 4, pp. 78–94, Jul./Aug. 2007.
[6] R. H. Lasseter, "Smart distribution: Coupled micro grids," Proc. IEEE, vol. 99, no. 6, pp. 1074–1082, Jun. 2011.
[7] H. Akagi, E. H. Watanabe, and M. Aredes, Instantaneous Power Theory and Applications to Power Conditioning. Piscataway, NJ, USA: IEEE Press, 2007, pp. 1–17.
[8] C. Sankaran, Power Quality. Boca Raton, FL, USA: CRC Press, 2002, pp. 133–146.
[9] R. C. Dugan, Electrical Power Systems Quality. New York, NY, USA: McGraw-Hill, 2003, pp. 167–223.
[10] A. Baggini, Handbook of Power Quality. Hoboken, NJ, USA: Wiley, 2008, pp. 187–257.
[11] B. Singh, K. Al-Haddad, and A. Chandra, "A review of active filters for power quality improvement," IEEE Trans. Ind. Electron., vol. 46, no. 5, pp. 960–971, Oct. 1999.
[12] F. Z. Peng, "Application issues of active power filters," IEEE Ind. Appl. Mag., vol. 4, no. 5, pp. 21–30, Sep./Oct. 1998.
[13] K. M. Smedley, L. Zhou, and C. Qiao, "Unified constant-frequency integration control of active power filters—Steady-state and dynamics," IEEE Trans. Power Electron., vol. 16, no. 3, pp. 428–436, May 2001.
[14] H. Rudnick, J. Dixon, and L. Moran, "Delivering clean and pure power," IEEE Power Energy Mag., vol. 1, no. 5, pp. 32–40, Sep./Oct. 2003.