Power Quality Enhancement of Micro-Grid Using DG and Power Quality Conditioner

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Abstract**—*This paper focus on specially designed DG based Power Quality Conditioner for Micro Grid applications. Three leg inverter coupled with solar PV with MPPT used as Compensator can be used for distinct DGs in the micro grid for power quality improvement of the entire system. Optimum control can be achieved to avoid detraction for voltage, current and Power flowing between Grid and DG. By adjusting power distribution among shunt connected DG for ensuring Voltage and current balance inside micro grid, the said topology able to compensate unwanted Zero sequence, positive sequence and negative sequence components of voltage, current inside the entire Grid system. The Power Quality conditioner and DG inverter have dual use for this particular purpose. Primarily used as power converter for injecting power created from DG to Grid, secondly performed as parallel Active Power Filter for compensating harmonics, unbalanced voltage, current, active and reactive power demand for the balance and unbalance burden with in the Grid and neutral conductors. All these said objectives can be achieved individually or can be achieved in grid connected mode. It can be observed that after compensation 3Φ 4 wire linear and nonlinear Burdens appears as balanced linear Burdens for the grid. The above mentioned task extensively simulated under MATLAB/Simulink platform revels that soon after compensation the THD (total harmonic distortion) Value in both supply current and supply voltage for all phases drastically reduced say within 5% well suits to IEEE519 standard.*

Keywords—Distibted Getneration, Micro grid, Inverter, Power quality Conditioner, Clarks tranformation, sequence voltages/currents.

I. INTRODUCTION

A Group of Generators connected to ac mains by means of CCVSI can be called as Micro Grid. Now a days Interfacing is a major issue. Several nonlinearity in voltage and current can be noticed due to unbalanced loads connected or by unbalanced fault in the system. Power quality issues like harmonics, unbalanced load current have significant effect on loads of end user [6].Voltage distortion at load PCC produced due to harmonic current results too much power loss in AC mains [9]. Various control procedures was introduced periodically for the Extraction of harmonic constituents from uneven distorted signals is described by sachin [8]. 3Φ APF based on ANN technique and three independent hysteresis current control for switching pulses generation on CCVSI have described by Kholy et al. [33]. For pf improvement, harmonic extenuation, load balance, compensation of reactive power and voltage regulation at load PCC can be taken care by DSTATCOM which required sophisticated control strategy for accurate functioning and must well-matched with international standards [4] [12] [16] [22] [25] [27] [29] [23] [24] [21]. A CSC based APF reported on [2] can also able to mitigate harmonics and disturbances in medium voltage transmission. Similarly VSC based STATCOM have many advantage over CSC based STATCOM [1] [33]. Active shunt compensator with sophisticated control strategy shown by Allmeling [10] can introduce to mitigation non sinusoidal current in grid. PQ theory is a back bone of an active shunt compensator [3]. Other control strategy like direct power control [13], I cos Φ [7], model predictive control [14], nonlinear control algorithm [11], instantaneous reactive power theory [19] etc. introduced time to time to overwhelm these issues in grid tied system. Similarly several other control method includes adaptive filter agreed control procedure for estimation of component currents of loads requires many approximation [20],Character of Triangle Function for distorted load currents [28], state space approach like composite observer based strategy [26] introduced for 3Φ grid tied system. Shireen and Tao have reported on DSP based controller for Active Fiters [31]. Performance of synchronous tightfitting and I cos Φ strategy for power factor modification reported by Bhuvaneswari shows I cos Φ control strategy is well suited for the mitigation of power quality issues [17]. Application of synchronous finding method using analog circuit with many methods like identical current method, equal power method and identical resistance method discussed by Lin et al. [32] but performance is not quite extraordinary for a distorted ac mains [30]. Synchronous detection method reported by Syed and Ram also not able to modify the current harmonic up to desired level [15]. So this is a common practice to connect a separate apparatus which can coupled either in series or in shunt to the utility grid. It is obvious that at these adverse situation main grid should cut out from the micro grid. Several automatic actuating device can satisfactorily operate in this prospect to isolate the fault part from healthy part. But at less unbalanced situation the auto recloser remain on. Both micro grid and main grid are intact with each other and drives their load may cause detrimental effect to the loads. Sensitive loads may show abnormal behavior. Again it is quite obvious to connect a compensator to the system to recompense these nonlinearity. Though line impedance between both the grid are very low, control of micro-grid voltages can regulate large disturbed current that will flow between micro grid and main grid [5] results overstress the interfacing inverter and the devices associated with the inverter. This problem will more noticeable for 1Φ line which are derived from a 3 Φ 4 wire line. This problem will more intricate when Zero-sequence component of current flow through both line and neutral. To

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overwhelm these complicated issue a specially designed DG incorporated with CCVSI introduced for 3Φ 4 wire micro grid. It can be noted that one prototype DG with MPPT which is a part of micro grid can able to compensate both voltage and current of entire system. This novel Power Quality conditioner can able to compensate harmonics and distortion in micro grid. This Grid-interfacing inverter can effectively transmit Active power delivered by DG inverter, support Reactive power demanded by the burdens and compensate harmonics both in current and Voltage at Load PCC. It is also able to compensate unbalanced current in neutral conductor. All these task effectively managed either independently or can be operated together to perform required task. The control strategy of UPQU and STATCOM family are quite dissimilar in all respect than the proposed Power quality conditioner and able to challenge on existing UPQC and STATCOM. A detail control strategy is presented in subsequent sections.

In this paper Clark's transformation based Power quality conditioner implemented for extraction of reference supply currents under unbalanced ac mains for improvement of power quality. The paper is organized as below:

Part .II demonstrates the proposed model for Grid tied DG system. Control Strategy discussed in section III. MATLAB simulation and a typical case study is represented in Part .IV. Part .V represents the result analysis in terms of THD Both Before compensation and after compensation and finally extensive conclusion discussed in Section VI.

II. PROPOSED MODEL

A. 3Φ 4 wire Grid Tied Power quality Conditioner.

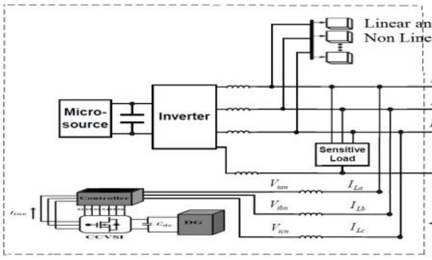

Fig. 1 Schematic diagram of DG-Grid Interfaced System

The planned model consists of a Grid tied DG interfaced scheme as shown in Fig 1. The renewable energy technologies are quite environmental friendly. For integrating DG with Grid, the CCVSI is a crucial part of the system.

The Basic eminent Distributed Generation (DGs) are SPV, Wind, Small Hydro and many more. To ensure injection of sinusoidal current a robust controlled voltage source inverter can be employed and latter depending upon load harmonic distribution in source, DG inverter should inject necessary harmonic to suppress the source harmonic content. Therefore systems need to be controlled properly. These DG systems have a poor controllability due to their seasonal characteristics. Synchronization is the most vital factor for DG integration. So information of phase angle Φ is necessary to turn on and off of static devices for accuracy and control for ensuring active and reactive power flow in Grid tied DG system.

III. CONTROL STRATEGY

Control strategy is the brain of any custom power devices. There are three steps of operation provided for any control strategy.

Step 1: PTs, CTs and other sensors feed the necessary system parameter like voltage and current.

Step 2: Necessary compensating rules in term of voltage and current can be extracted depending upon control approach for different Filter arrangement.

Step 3: Gate signal generation for power electronics device.

A. Description of Control Algorithm

The mechanism of regulating a CCVSI so to speak the output current output generated depending upon set current values. A set value is retained and is correlated with the 2 inputs of the regulator. Depending upon the glitch between the two inputs and the set value, signals can be produced.

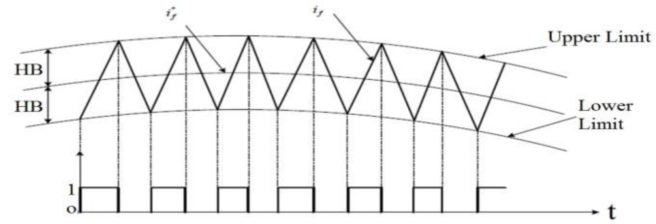

Fig. 2 Hysteresis Band

B. Instantaneous Power Calculation

The crucial part of Power quality conditioner is the calculation of compensating currents. The indicated currents are figured with P-Q theory. The scheme needs Clarke's transformation which consists of a matrix that alters 3Φ voltage and current into αβ frame of reference.

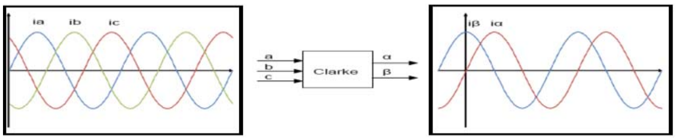

Fig. 3 Clarks Transformation

C. Clarke's Transformation & its Inverse

Using the Clarke's transformation one can convert the currents or voltages into αβ reference frame (removing the zero sequence components) and again back to *abc* frame using the inverse Clarke's transformation. We separate the apparent power (S) into real and imaginary parts using the p-q theory.

$$\begin{bmatrix} V\alpha \\ V\beta \end{bmatrix} = 0.8165 \begin{bmatrix} 1 & -0.5 & -0.5 \\ 0 & 0.866 & -0.866 \end{bmatrix} X \begin{bmatrix} V_R \\ V_Y \\ V_B \end{bmatrix} \quad (1)$$

$$\begin{bmatrix} V_R \\ V_Y \\ V_B \end{bmatrix} = 0.8165 \begin{bmatrix} 1 & -0.5 \\ -0.5 & 0.866 \\ -0.5 & -0.866 \end{bmatrix} X \begin{bmatrix} V\alpha \\ V\beta \end{bmatrix} \quad (2)$$

$$\begin{bmatrix} I\alpha \\ I\beta \end{bmatrix} = 0.8165 \begin{bmatrix} 1 & -0.5 & -0.5 \\ 0 & 0.866 & -0.866 \end{bmatrix} X \begin{bmatrix} I_R \\ I_Y \\ I_B \end{bmatrix} \quad (3)$$

$$\begin{bmatrix} I_R \\ I_Y \\ I_B \end{bmatrix} == 0.8165 \begin{bmatrix} 1 & -0.5 \\ -0.5 & 0.866 \\ -0.5 & -0.866 \end{bmatrix} X \begin{bmatrix} I\alpha \\ I\beta \end{bmatrix} \quad (4)$$

$$\begin{bmatrix} P \\ Q \end{bmatrix} = \begin{bmatrix} V\alpha & V\beta \\ V\beta & V\alpha \end{bmatrix} X \begin{bmatrix} I\alpha \\ I\beta \end{bmatrix} \quad (5)$$

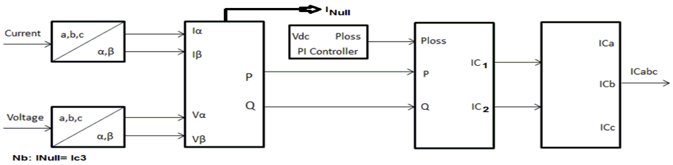

Fig. 4 Control Mechanism

$$P = (V_\alpha X I_\alpha) + (V_\beta X I_\beta)$$
$$Q = (V_\beta X I_\alpha) - (V_\alpha X I_\beta) \quad (6)$$

$$P_{LOSS} = K_P \{V_{dcref} - (V_{dc})\} + K_i \int \{V_{dcref} - (V_{dc1})\} dt \quad (7)$$

$$I_{C1} = \frac{-1}{V\alpha^2 + V\beta^2}\left(P_{Modified} \times V\alpha + Q \times V\beta\right) \quad (8)$$

$$I_{C2} = \frac{-1}{V\alpha^2 + V\beta^2}\left(P_{Modified} \times V\beta + Q \times V\alpha\right) \quad (9)$$

$Ic3 = I_{Null}$ (10)

Where $P_{MODIFIED}$ is the summation of P_{loss} and Output of Butterworth filter and subtracting P itself from the summation block to obtain IC1, IC2 and IC3 by using inverse Clarks transformation.

$$I_{CA} = \sqrt{\frac{2}{3}} \times \{I_{c1} + (0.7072 \times I_{c3})\} \quad (11)$$

$$I_{CB} = \sqrt{\frac{2}{3}} \times \left\{\frac{-I_{c1}}{2} + \frac{\sqrt{3}}{2} I_{c2} + (0.7072 \times I_{c3})\right\} \quad (12)$$

$$I_{CC} = \sqrt{\frac{2}{3}} \times \left\{\frac{-I_{c1}}{2} - \frac{\sqrt{3}}{2} I_{c2} + (0.7072 \times I_{c3})\right\} \quad (13)$$

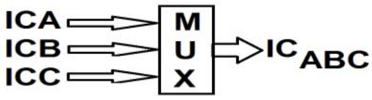

Fig. 5 Reference current Calculation

D. Operation Of Hysteresis Control Block

IC_{ABC} is consider as Reference for Hysteresis Block. If Reference Current of R phase > Inverter current of R Phase output is a pulse for Switch 1 Else Pulse will generate for Switch 2. If Reference Current of Y phase > Inverter current of Y Phase output is a pulse for Switch 3. Else Pulse will generate for Switch 4. If Reference Current of B phase> Inverter current of B Phase output is a pulse for Switch 5 Else Pulse will generate for Switch 6. The output Pulse of Hysteresis Controller Is now fed to the Gate of 3 phase Universal Bridge. PI controller is one of the most widely used controllers in applications for feedback mechanisms. PI controller is the DC Voltage manager be used for generating the signal P_{Loss} which is added to the real power calculations. Effect of PI controller is to increase the type of the system by one, decrease Band width, Increase rise time, hence speed decreases, i.e Transient response becomes slower/sluggish. Steady state error decrease i.e steady state response is improved. The 3 phase Universal Bridge is a bi- directional Converter which have a dual operation. i,.e AC to DC and DC to AC. This process is operated in cyclic fashion to give desired output. Matlab/Simulink have an automatic PI tuning feature can be used to get adjusted value of both proportional gain and integral gain precisely. These proportional gain and integral gains values automatically adjusted depending upon the variation of nonlinear loads to be used in this topology. The purpose of this DG-Grid interface terminology is to regulate power at load PCC. This power control mechanism feds or pull essential power to/ from the grid depending upon the load requirement. If the a load is highly nonlinear or uneven, the DG inverter will modify the wave shape of both current and voltage in such a manner to achieve a pure resistive load characteristic by compensating harmonics un balance neutral current which should approximately zero value irrespective of load variation, irrespective of the nonlinear burden used. The switching mechanism of DG Inverter is so adjusted depending upon load requirement and injects counter balance amount of harmonic current and as a result the grid current have to modify its shape as like a pure resistive load. The yield of DC Link Voltage which lugs figures about give-and-take of active power among DG and Grid. Phase Locked Loop is used for synchronization purposes. $I_R = Sin\Phi$, $I_Y = Sin\ \Phi - (2\pi/3)$, $I_B = Sin\ \Phi + (2\pi/3)$. DG voltages V_{DC1}, V_{DC2} can be fed to a Butterworth *LPF* circuit for removal of ripples. Output of DG voltage compared with the reference Value (V_{DC}^* a Constant value) and latter fed to an automatic PI controller for generating a fixed DC voltage irrespective of the load profile. Proper tuning of PI controller is necessary. Automatic PI controller satisfactorily do its job. In this project initially the value of Kp =0.2 and Ki=0.05 respectively taken initially.

$$I_R^* = I_m \times I_R \,;\, I_Y^* = I_m \times I_Y \,;\, I_B^* = I_m \times I_B \,;\, I_{neutral}^* = 0$$

I_R^*, I_Y^*, I_B^* and $I_{neutral}^*$ are linked with Inverter currents, I_{InvR}, I_{InvY}, I_{InvB} *and* I_{InvN} to compute the current errors and fed to a Hysteresis based regulator for generating necessary switching pulses (S1 to S6). Nonlinear load current (instantaneous Value) can be represented as below:

$$I_{Load}(t) = \sum_{har=1}^{\infty} I_{har} \sin(h_{ar}\omega t + \phi_{har}) = I_{f1}\sin(\omega t + \sum_{h=1}^{\infty} I_{har}\sin(h_{ar}\omega t + \phi_{har}) \quad (14)$$

Where I_{f1} is the Maximum Fundamental Current for Load, I_{har} is the maximum value of Load Current with Harmonic and Φf_I, Φ_{har} be the Vector angle of Both (i.e. Fundamental, Harmonic) components of Current in Load.

The instantaneous value of Total Power for load can be written as:

$$P_{Load}(t) = V_{Source}(t).I_{Load}(t) = V_m I_{f1} \sin^2 \omega t \cos(\phi f_1) + V_m I f_1 \sin \omega t \cos(\omega t) \sin(\phi f_1)$$
$$+ V_m \sin \omega t \sum_{har=1}^{\infty} I_{har} \sin(h_{ar}\omega t + \phi_{har}) = Power_{LF}(t) + Power_{LQ}(t) + Power_{LHar}(t)$$

(15)

The term $Power_{LF}(t)$ be the instantaneous value of Fundamental Load Power. Second term $Power_{LQ}(t)$ be the instantaneous value of Load reactive power and Third term represents $Power_{LHar}(t)$ be the instantaneous value of Harmonic Load Power. The above mechanism can compensate simultaneously the Load Power Factor and Current Harmonics. The overall operation of this topology can be analysed in

3 modes. (1) Forward Current Approach (2) Reverse Current approach (3) Alone DG Approach. In Forward Current Approach Both Micro Grid and Incoming DG Inverter will supply power to drive linear and nonlinear load connected to the system. In reverse Current approach Only DG drives the connected loads and surplus power can be used to improve the capacity of micro grid. In this mode Active power carrying capacity improved in the system. Lastly the incoming DG inverter with its MPPT can be operated in islanding mode in case of Grid failure. The three modes are so adjusted to achieve desired goal like load sharing, active and reactive power compensation and power quality improvement. After removal of grid imbalance the automatic switching mechanism incorporated with Relay and CBs will actuate accordingly to shift to any tied mode depending upon system requirement.

IV. *SIMULATION RESULT*

For the verification and achievement of multiple target of the proposed mechanism for 3Φ 4 wire Grid tied DG system simulated under MATLAB/Simulink platform.

Table 1 System Parameters

3 phase supply	VG=40V,50Hz
3 Phase Linear and Non Linear load in (W,VAR)	500W and 0.005 VAR
DC link capacitance	400 µF
Coupling Inductance	2.5mH (3 Nos)

The utility grid having phase to phase voltage 440V with frequency 50 Hz (with neutral). Per phase line resistance and reactance be 1Ω and 1 mH. For the investigation purposes the output of the grid fed to a phase controlled rectifier and a RL load of approximately 70%-80% of utility grid connected at load PCC. The effect of rectifier load at various firing angles can now be seen on the source. The current wave shape now changed and leads power quality issue. With proper synchronization a PV based DG with MPPT (P/O) with certain control mechanism inject counter balance amount of harmonic to the utility grid and improves the THD values and hence system power quality can now improve.

A. A Case study:

TABLE I. SYSTEM SPECIFICATION- A CASE STUDY

PV Based DG Inverter Specification	
Maximum DC Power	1200 KW
Maximum DC Input voltage	800V
Rated DC Voltage	650 V
Filter	R=1.5 mΩ, L=200µH
Transformer	$1.5{\times}10^6$ VA, 50 Hz
Rated Power	1 Mega watt
DC Link Voltage (VDC1, VDC2)	1200
DC Link Capacitance (2 Nos)	4000µF
Coupling Inductance	2mH
Sampling Frequency	5 KHz
Grid Specification	
Source Voltage	Vs=440
frequency	F=50Hz
PV Based DG Inverter Specification	
Ls	40mH
Xs/Rs	8

TABLE II. LOAD SPECIFICATION

Load Specification	
Unbalanced RL Load	Ra=50Ω,La=200mH,Rb=75Ω, Lb=225mH,Rc=25Ω,Lc=175mH
Non Linear Load1 3Φ Diode rectifier Load	Rd=125Ω Ld=300mh (on DC side)
Non Linear Load2 Control Rectfier Load	Active Power =10kW Positive VAR= 300 VAR Negative VAR= 150 VAR
Linear Load	Active Power =10kW Positive VAR= 10KVAR Negative VAR= 5KVAR

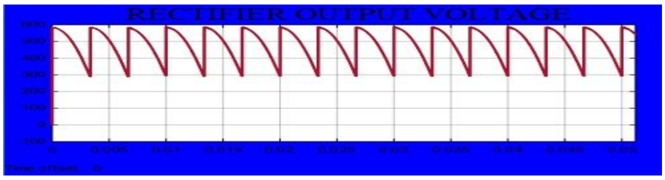

Fig. 6 Controled Rectifier Voltage at 30^0 Firing Without DG

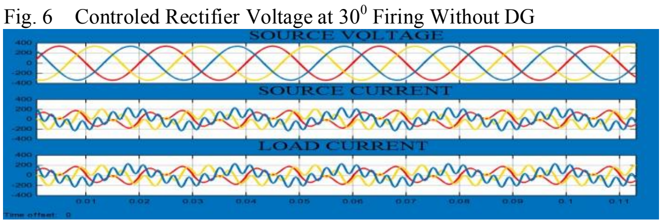

Fig. 7 Source Voltage, Source Current, Load Current Without DG

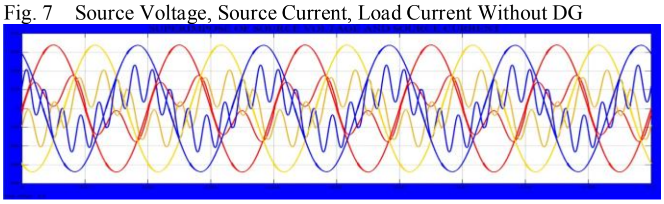

Fig. 8 Superimpose Source Voltage and Source Current Without DG

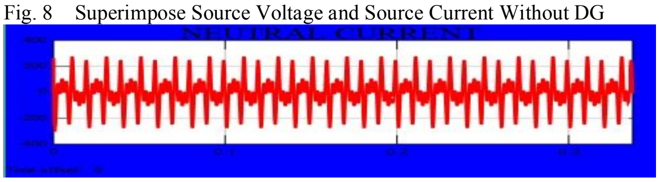

Fig. 9 Neutral Current Without DG

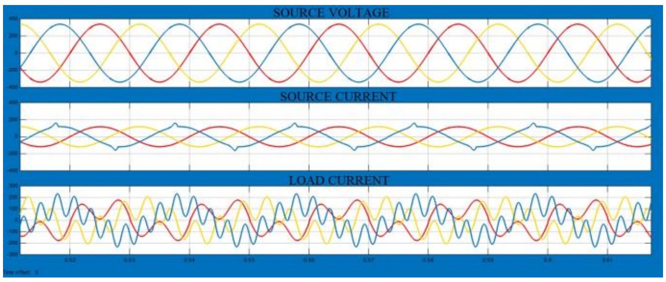

Fig. 10 Source Voltage, Source Current, Load Current With DG

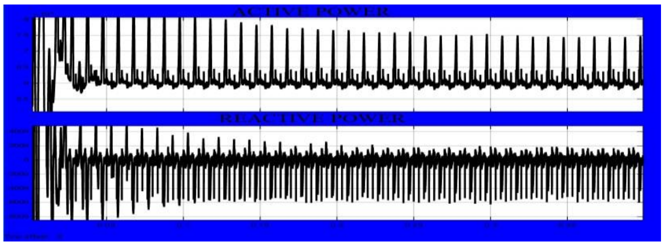

Fig. 11 Active and Reactive Power at 30^0 Firing With DG

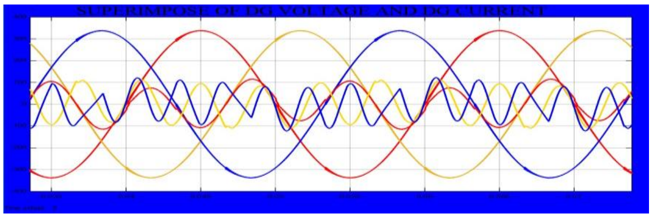

Fig. 12 Superimpose of DG Voltage and DG Current at 30^0 Firing With DG

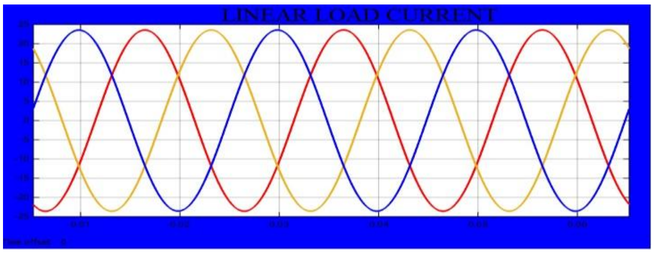

Fig. 13 Linear Load Current at 30^0 Firing With DG

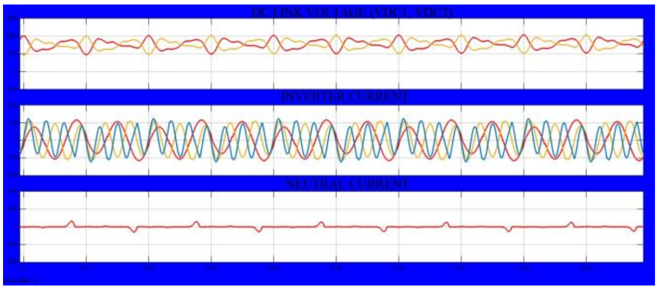

Fig. 14 Dc Link Voltage, Inverter Current and Neutral Current With DG

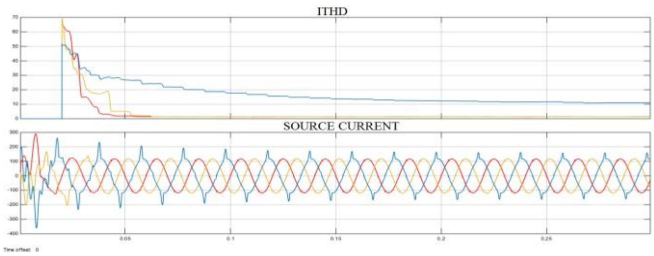

Fig. 15 ITHD Source Current at 30^0 Firing With DG

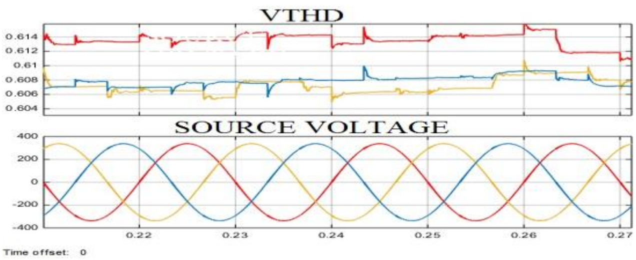

Fig. 16 VTHD Source Voltage at 30^0 Firing With DG

The waveforms shown in figure "Fig. 5,6,7,8 are Controlled Rectifier Voltage at 30^0 Firing Without DG, Source Voltage, Source Current, Load Current Without DG, Superimpose Source Voltage and Source Current Without DG, Neutral Current Without DG respectively. The waveforms shown in figure "Fig. 9,10,11,12,13,14,15 are Source Voltage, Source Current, Load Current with DG, Active and Reactive Power at 30^0 Firing With DG, Superimpose of DG Voltage and DG Current at 30^0 Firing With DG, Linear Load Current at 30^0 Firing With DG, Dc Link Voltage, Inverter Current and Neutral Current With DG, ITHD Source Current at 30^0 Firing With DG, VTHD Source Voltage at 30^0 Firing With DG

Thus, the recommended compensator surely directs any abnormality inside the system with linear and nonlinear load effectively as a result the harmonic content can be easily minimized and can be noticed from all Figures of "Dc Link Voltage, Non-Linear Load Current, Linear Load current and Source Current" at 30^0,45^0 and 60^0 firing with DG described in TABLE II. One can change the load (for Both Linear as well as Nonlinear) parameters to obtained change in the result. All the results shown in figure are for some particular loads. The entire topology is able to compensate any type of power quality issues resulted by the load change can precisely compensate and subsequently system power quality improves to a great extent.

V. *RESULTS ANALYSIS*

TABLE III. RESULT ANALYSIS

Nonlinear Loads at Different Firing angle	**VTHD Without DG**	**ITHD Without DG**	**VTHD With DG**	**ITHD With DG**
30^0	1.59%	89.55%	0.29%	1.18%
45^0	1.67%	87.84%	0.31%	1.07%
60^0	1.72%	86.78%	0.46%	1.43%

VI. *CONCLUSION*

This paper presented the Power quality issues based on the concept of power quality conditioner. Grid tied DG act as an interface between Grid and various types of linear and Nonlinear Load successfully compensate the source current, Reactive power, Active Power etc. As several nonlinear loads connected to the micro grid results harmonics and other power quality issues pollute the system. Without using distinct equipment for DG incorporation and other equipment for power quality improvement, here we incorporating DG with power quality conditioner to achieve desired goal. The DG inverter is controlled by Clarks transformation based theory integrated with hysteresis controller for generating gate pulses for DG inverter. Various simulation results are given with/ without DG incorporation. Of course automatic PI controller is employed for improving stability. The proposed compensation topology effectively compensate power quality issues extensively simulated under MATLAB/SIMULINK platform. The THD value both for current as well as voltage investigated. The proposed Power quality conditioner furthermore apposite under disturbed and wry Grid voltages too. Clark's transformation is used to reduce computational burdens. With various types of firing angle and different load condition (10% - 80% of full load approx.) the proposed compensation topology effectively compensate the power quality issue.

References

[1] B. Singh, A. Adya, A.P. Mittal and J.R.P. Gupta, “Power Quality Enhancement with DSTATCOM for Small Isolated Alternator feeding Distribution System,” IEEE International Conference on Power Electronics and Drives Systems, PEDS 2005, pp. 274-279, 2005.

[2] A. Terciyanli, T. Avci, I. Yilmaz, C. Ermis, K. N.Kose, A. Acik, A. S. Kalaycioglu, Y. Akkaya, I. Cadirci and M. Ermis “A Current Source Converter Based Active Power Filter for Mitigation of Harmonics at the Interface of Distribution and Transmission Systems,” IEEE Transactions On Industry Applications, vol. 48, pp. 1374-1386, 2012.

[3] M. Popescu, A. Bitoleanu and V. Suru, "A DSP-Based Implementation of the p-q Theory in Active Power Filtering Under Nonideal Voltage Conditions," IEEE Transactions on Industrial Informatics,vol.9, pp. 880-889, July 2013.

[4] A. Ghosh and G. Ledwich, “Power quality enhancement using custom power devices,” Springer International Edition, Delhi, 2009.

[5] M. Prodanovic and T. C. Green, "Control and filter design of three-phase inverters for high power quality grid connection," IEEE Transactions on Power Electronics, vol. 18, pp. 373-380, Mar 2003.

[6] P. Caramia, G. Carpinelli and P. Verde, "Power Quality Indices in Liberalized Markets," John Wiley & Sons, Aug-2009.

[7] B. Singh and S Kumar, "Control of DSTATCOM using IcosΦ algorithm", 35th Annual Conference of IEEE Industrial Electronics, pp. 322-327,Novemver 2009.

[8] S. K. Jain and S. N. Singh, "Harmonics estimation in emerging power system: Key issues and challenges," Electr. Power Syst. Res., vol. 81, , pp. 1754-1766, 2011.

[9] S. Rechka, E. Ngandui, J. Xu and P. Sicard, "Analysis of harmonic detection algorithms and their application to active power filters for harmonics compensation and resonance damping," Canadian Journal of Electrical and Computer Engineering, vol: 28, pp. 41 - 51, January 2003

[10] J. Allmeling, “A control structure for fast harmonics compensation in activefilters,” IEEE Transactions On Power Electronics, vol. 19, pp. 508-514, March 2004.

[11] L. Marconi, F. Ronchi and A. Tilli, "Robust nonlinear control of shunt active filters for harmonic current compensation," Automatica, vol 43, pp. 252-263, February 2007.

[12] S. Iyer, A. Ghosh and A.Joshi, "Inverter topologies for DSTATCOM applications—a simulation study," Electric Power Systems Research, vol 75, pp.161-170 August 2005.

[13] A. Chaoui , J. P. Gaubert and F. Krim, "Power quality improvement using DPC controlled three-phase shunt active filter," Electric Power Systems Research, vol 80, pp. 657-666, June 2010

[14] S. A. Verne and María I. Valla, "Active power filter for medium voltage networks with predictive current control," Electric Power Systems Research, vol 80, pp. 1543-1551, December 2010.

[15] M. K. Syed and B. V. S Ram, "Active power filtering in asymmetric power system by Modified Synchronous Detection Algorithm," IEEE Region Conference TENCON, pp. 1-4, November 2008.

[16] M. E. Meral, A. T , K. C Bayindir , M. Tumay , "Power quality improvement with an extended custom power park," Electric Power Systems Research, vol 79, pp. 1553-1560, November 2009.

[17] G. Bhuvaneswari, M.G. Nair and S. K Reddy, "Comparison of Synchronous Detection and I. Cosϕ Shunt Active Filtering Algorithms," IEEE Conference on Power Electronic, Drives and Energy Systems, pp. 1-5, December 2006.

[18] E. E. E Kholya, A. E Sabbea, A. E Hefnawya and H. M. Mharousb, "Three-phase active power filter based on current controlled voltage source inverter," International Journal of Electrical Power & Energy Systems, vol 28, pp. 537-547 October 2006.

[19] P. Salmerón, R. S. Herrera and J. R. Vázquez , "A new approach for three-phase loadscompensation based on the instantaneous reactive power theory," Electric Power Systems Research, vol 78, pp. 605-617, April 2008.

[20] B. Singh, S. R Arya, A.Chandra and K. A. Haddad, "Implementation of adaptive filter based control algorithm for Distribution Static Compensator," IEEE Conference on Industry Applications Society Annual Meeting, pp. 1-8, Ocober 2012.

[21] A. Garces , M. Molinas and P. Rodriguez,"A generalized compensation theory foractive filters based on mathematical optimization in ABC frame," Electric Power Systems Research, vol 90. pp. 1-10, September 2012.

[22] W. R. A. Ryckaert , J. A. L. Ghijselen and J. A. A. Melkebeek, "Harmonic mitigation potential of shunt harmonic impedances," Electric Power Systems Research, vol. 65, pp. 63-69, November 2002

[23] “IEEE Recommended Practice and Requirements for Harmonic Control in Electric Power Systems 519-2014,” - Redline Revision of IEEE Std 519-1992.

[24] L. Sainz and J. Balcells, "Harmonic Interaction Influence Due to Current Source Shunt Filters in Networks Supplying Nonlinear Loads," IEEE Transactions On Power Delivery, vol. 27, pp. 1385-1393, July 2012.

[25] N. K. Kummari, A. K. Singh and P. Kumar, "Comparative evaluation of DSTATCOM control algorithms for load compensation," IEEE Conference on Harmonics and Quality of Power, pp. 299-306, Decemember 2012.

[26] B. Singh and S. R. Arya, "Composite observer-based control algorithm for distribution static compensator in four-wire supply system," IET Power Electronics, vol. 6, pp. 251-260, June 2013.

[27] Y. S Jeon, N. H. Kwak and J.B. Choo, "Analysis of Voltage Regulation by DSTATCOM Using the EMTDC Program," JPE, vol. 5,pp. 329-334 October 2005.

[28] S.R. Arya and B. Singh, "CTF control algorithm of DSTATCOM for Power factor correction and zero voltage regulation," IEEE Conference on Sustainable Energy Technologies (ICSET), pp. 157-162, November 2012.

[29] G.Benysek and M. Pasko, "Power Theories for Improved Power Quality," springer, 2012

[30] H. L. Jou, "Performance comparison of the three-phase active-power-filter algorithms," IEE Proceedings - Generation, Transmission and Distribution, vol. 142,pp. 646-652, August 2002.

[31] W. Shireen and L. Taob "A DSP-based active power filter for low voltage distribution systems," Electric Power Systems Research, vol. 78, pp. 1561-1567, September 2008.

[32] C. E. Lin, C. L. Chen and C. L. Huang "Calculating approach and implementation for active filters in unbalanced three-phase system using synchronous detection method," IEEE Conference on Proceedings of International Conference on Industrial Electronics Control, Instrumentation and Automation, vol.1, pp. 374-380, August 2002.

[33] K. Anuradha, B. P. Muni and A. D. Raj Kumar, "Modeling of Electric Arc Furnace & control algorithms for voltage flicker mitigation using DSTATCOM," IEEE Conference on Power Electronics and Motion Control , pp. 1123-1129, July 2009.