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A THREE-PHASE HARMONICS ELIMINATION METHOD FOR MICRO-GRID OPERATIONS

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Abstract- There are many ongoing researches in the field of harmonic compensation using active and passive power filters or the combination of the two, which are known as hybrid power filters. These filters can be implemented as series or shunt units. For shunt compensation, the voltage rating of the components is usually higher, and the impedance of the filtering unit should be very high to block the flow of the fundamental harmonic. For the series compensation, the impedance for the fundamental components should be minimal. In order to improve the power quality, many control algorithms have been proposed for automatic and selective harmonic compensation.In this project to ensuring power quality both in the grid current and PCC by harmonic elimination is presented. The proposed method is developed to take care of harmonics in grid-connected (GC) mode, as well as in the islanded or standalone (SA) mode of operation, where the main objective is to remove the harmonics from the grid current and the point of common coupling (PCC) voltage. The suggested placement of the harmonic reduction unit dictates the use of a special controller structure that uses the harmonics magnitude in the dq reference frame. In the proposed control algorithm, the required amount of attenuation for harmonics is determined to meet the total harmonic distortion. Fast and efficient algorithm for phase detection irrespective of the presence of harmonics has been utilized for the system. The effectiveness of proposed method .The proposed method can be implemented to Three-phase using Matlab/simulink software.

Index Terms—Adaptive compensation, distributed renewableenergy sources, grid-connected microgrid, harmonics, power quality, standalone microgrid.

I. INTRODUCTION

Electrical power demand within a micro grid power system requires reliable functionality, storage of energy, diagnostics, remote device control and monitoring as important functions of modern Distributed Power Generation (DPG) modules. Renewable energy sources like solar, wind, and micro-hydropower can be interfaced through the DPG modules with the microgrid system which can operate in islanded mode (off-grid) and grid connected mode. The microgrid operation needs to respond to the load demand under any circumstances therefore back-up with energy storage elements is essential. The microgrid presented in this paper is a low voltage application and it is comprised of DPG modules, distributed energy storage elements, electrical distribution gear and controllable loads. DPG modules are critical components within the micro grid systems and need to have flexible features in order to respond for a wide range of applications. DPG are designed to operate in islanded mode, utility grid-connected or genset-connected (diesel, liquid propane generators). DPG converter modules may have the following modes of operation: voltage-controlled source, current controlled source, active rectifier and active power filter mode. The converted energy produced can be delivered to the local loads within the micro grid structure or exported to the utility grid. In active rectifier mode, with ac to dc energy conversion the DG has a multi loop embedded control with power factor correction and dc voltage and current are controlled typically for battery charging [1]. In active power filter mode selective ac current harmonics are generated to cancel out the load current harmonics from the fundamental line frequency [2]. WIND inverters are typically DPG operating in current controlled mode, with dc to ac energy conversion where ac current is controlled in magnitude and phase [3], [4]. Transformerless WIND inverters represent an attractive solution due to higher efficiency, smaller size and weight, reduced cost [5], [6].In many industrial applications, usually, DC motors were the work horses for the regulating Speed Drives [7] (ASDs) because of their excellent speed and torque response. But, they have inherent disadvantage of commutator and mechanical brushes, which go through wear and tear with the passage of time. Generally [9], AC motors are preferred to DC motors, in particular, an induction motor because to its low cost, low maintenance, lower weight, low maintenance, higher efficiency, improved ruggedness and reliability. All these features make the use of induction motors a mandatory in many areas of industrial applications. The improvement in Power electronics [10] and semi-conductor technology has triggered the growth of high power and high speed semiconductor devices in order to get a smooth, continuous and step less variation in motor speed. Applications of solid state converters/inverters for adjustable speed induction motor drive are well-known in electromechanical systems for a large spectrum of industrial systems. Comparison of basic and high frequency carrier based techniques for NPC inverters is given by Feng, 2000. Influence of number of stator windings on the characteristics of motor is given by Golubev, 2000. Modified CSI based induction motor drive is given by Gopukumar, 1984. Multilevel inverter modulation schemes to eliminate common mode voltage is given by Zhang, 2000. Modulation schemes for six phase induction motor are given by Mohapatra, 2002. Improved reliability in solid state ac drives is given by Thomas, 1980. Multilevel converters [11] for large electric drives are given by Peng, 1999. Active harmonic elimination for multilevel inverters is given by Tolbert, 2006. The inverters are either Current Source Inverter (CSIs) or Voltage [8] Source Inverters (VSIs). Current source inverters are widely used for the implementation of fully generative induction machine variable speed drives. An important and attractive feature of CSI is its good fault protection capability and the inherent regeneration capability.

II. PLACEMENT OF HARMONIC COMPENSATION UNIT IN MICROGRID SYSTEM

In conventional methods [13], [14], the series harmonics reduction units are placed at the grid side, as shown in Fig.1 where the objective is to make the line impedance at the harmonic frequency as high as possible. From Fig.1,

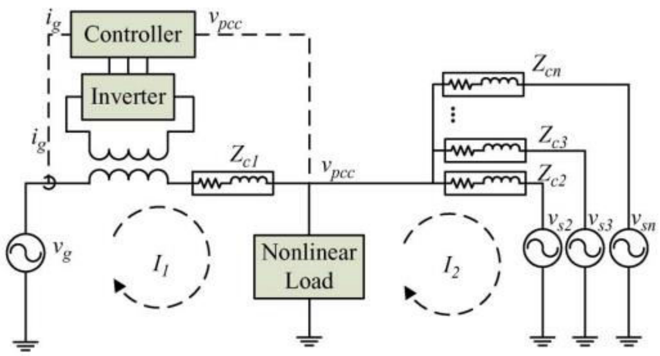


Fig.1.Conventional harmonic compensation method.

The mesh equations for the overall system for harmonic components can be written as follows:

$$I_{n_1} Z_{n_{c1}} + V_{n_{\text{inj}}} = V_{n_{\text{pcc}}} \tag{1}$$

$$I_{n_2} Z_{n_{c2}} = V_{n_{\text{pcc}}} \tag{2}$$

Where$V_{n_{pcc}}$,$V_{n_{inj}}$, $I_{n_1}Z_{n_{c1}}$represents the nth harmonic PCC voltage, injected voltage, grid current, and coupling impedance, respectively. The grid current can be expressed as

$$i_g = I_1 = \sum_{n=1}^{N} A_{n_1} \sin(n\omega t + \theta n) \tag{3}$$

The injected harmonic voltage in series with the grid is proportional to the grid current such as

$$V_{n_{\text{inj}}} = k_n I_{n_1} \tag{4}$$

Where gain of $k_n$is related to the coupling impedance and the transformer turns ratio. Based on (1) and (4), I_{n_1}can be determined as

$$I_{n_1} = \frac{V_{n_{\text{pcc}}}}{Z_{n_{c1}} + k_n} \tag{5}$$

The compensation unit pushes voltage harmonics to make the grid current harmonics free; however, this voltage harmonics distort the PCC voltage. Moreover, during the SA mode of operation, the grid branch is disconnected making the compensation unit idle.The proposed placement for the harmonics injection unit in this research is the distributed generation side, as shown in Fig.2. In this case, the objective of the harmonic compensation unit is to make the impedance in the sources of the microgrid side as small as possible to divert all the current harmonics far from the grid side. This way, if the grid voltage is harmonics free, the PCC voltage will become harmonics free. Moreover, when the grid is disconnected the harmonics reduction unit can continue to operate. The unit makes the PCC voltage harmonicfree by providing harmonic voltage at its output that counteracts the harmonics results from the voltage drop at the coupling impedances away SA operation. For the harmonic components, the equation for mesh current I$_1$ and I_2 can be written as follows:

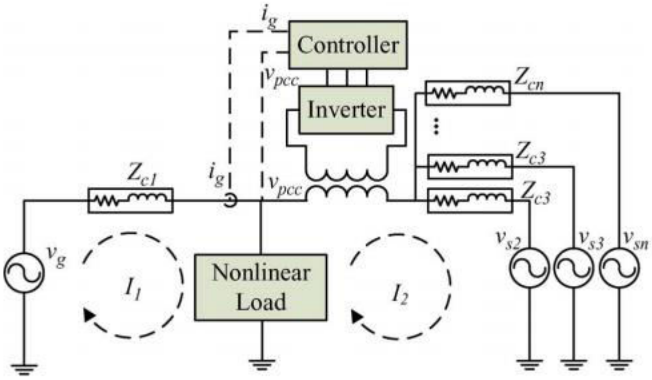


Fig.2. Proposed harmonic compensation method.

$$I_{n_1} Z_{n_{c1}} = v_{n_{\text{pcc}}} \tag{6}$$

$$V_{n_{\text{inj}}} + I_{n_2} Z_{n_{c2}} = V_{n_L} \tag{7}$$

From (6) it is clear that if $I_{n_1}$is close zero then $V_{n_{pcc}}$will be close to zero also. In literature, the inverters in the microgrid are controlled to share the current harmonics such that theharmonics in the PCC can be reduced. This approach can help in distributing the harmonics production across the sources, but it cannot insure that the total harmonic distortion(THD) at the grid current or at the PCC voltage is below the required limit. Having the compensation unit close to the PCC allows an easy access to the PCC voltage and the grid current, whereas the accessibility could be impractical for other sources due to the geographical spread of the microgrid. Then, thecompensation unit can secure the harmonics free grid currentand PCC voltage by diverting the harmonics to the side of the other sources, which can share the harmonics effectively through the techniques provided in.

III. CONTROLLER STRUCTURE

The overall block diagram of the controller structure is shown in Fig.3. The block diagram for the harmonics elimination unit is shown in Fig. 3.4. The harmonics elimination unit mainly consists of two major blocks—harmonics estimation block and harmonics injection block. Efficient and effective harmonics estimation and the harmonics elimination methods, suggested and illustrated in Fig. 4, are used for phase detection and harmonics component estimation. As the existence of the harmonics affect the PLL accuracy, the first stage is used to eliminate the harmonics from the sampled grid signal ensuring accuracy of the PLL. The second stage provides fast and accurate harmonics estimation as the PLL produces an accurate phase. The harmonics injection block, which dictates the amount of harmonics injection by the harmonics compensator.

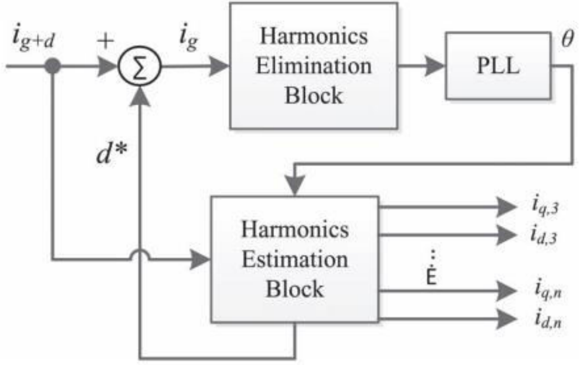


Fig.3. Overall, harmonic compensation block.

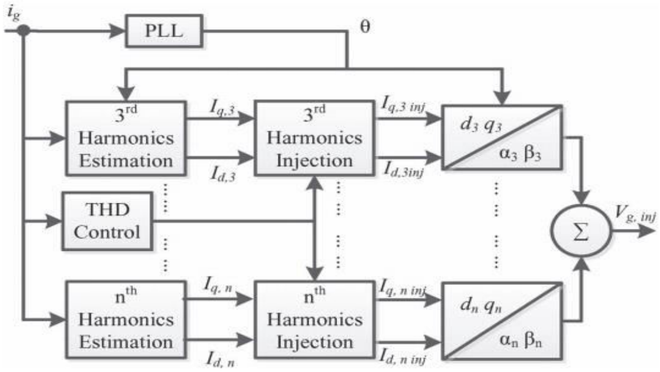


Fig.4. Harmonics elimination block diagram

The grid current and/or the PCC voltage are fed to the phase locked look (PLL) block. The PLL lock extracts the phase of the fundamental component. Then, using the PLL output,the 3rd, 5th. . . nth harmonics of these signals are estimated. The $d_q$components of the estimated harmonics are sent to the harmonics injection block to determine how much voltage atthe specified harmonic frequency should be injected into the line based on the error between the actual and reference.

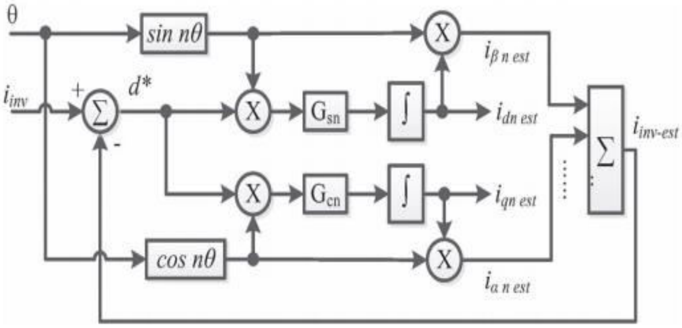


Fig.5. Harmonics estimation block.

The harmonics estimation block is used to estimate the amount of harmonics needed to be injected from the compensator. The block diagram for harmonics estimator is shown in Fig.5. The harmonics estimation is performed based on the phase provided by the PLL block. The closed-loop system provides the estimated voltage in both $\alpha\beta$ and $d_q$rotating reference frame for fundamental, as well as harmonics components. The transfer function for the harmonics estimation block can be written as

$$\frac{\hat{V}_{d,n}(s)}{V_{d,n}(s)} = \frac{0.5G_{\mathrm{sn}}}{s+0.5G_{\mathrm{sn}}}. \qquad (8)$$

According to IEEE 519, the individual harmonic components should be less than 3% and the THD should be less than 5% to ensure power quality. The reference value of THD in the THD control block, as shown in Fig.4, should be set according to these requirements. When the overall harmonics is reduced below the recommended THD, the amount of the injection for individual harmonics component is kept constant. This also ensures the system to operate in stable condition.In the presence of non-integer harmonics or any other disturbances the measured current signal shown in Fig. 3.3, can be expressed as

$$i_{g+d} = i_g + d \qquad (9)$$

Where i_g is the grid current and d is the disturbance. The estimated disturbance can be expressed as

$$\hat{d} = i_{g+d} - \hat{i}_g = i_g + d - \hat{i}_g = err + d \qquad (10)$$

Where, $\hat{\imath}_g$is the estimated value of the current and *err* is the estimation error. The estimation error is expected to be much smaller than the disturbance (*err* << *d*). The error *err* reflects the effect of *d* on the estimation of $\hat{\imath}_g$which is attenuated significantly by the filters of the estimators (see Fig.5). Thus, $\hat{\imath}_g$can be described as

$$\hat{i} = i_{g+d} - \hat{d} = i_g + d - err - d = i_g - err. \qquad (11)$$

Since *err* will go to zero after a couple iterations, $\hat{\imath}_g$will become error free. Thus, PLL will not be affected by the presence of non-integer harmonics.

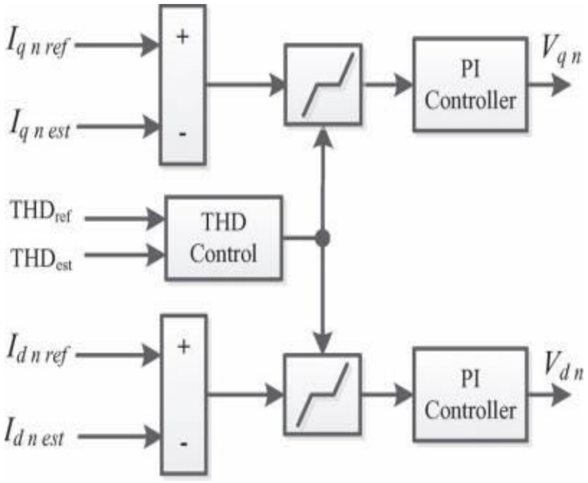


Fig.6. Harmonics injection unit.

IV.CONTROLLER OPERATION

Fig.5 illustrates the block diagram of the harmonics injection unit, where the desired amounts of harmonics are commanded in $d_q$reference frame. Desired THD level is also provided as a reference into the controller block. The THD control block receives the commanded THD and actual THD of the grid current or voltage at PCC. The THD reference is usually set according to the required power quality. The *d* and *q* component of the harmonic current or voltage should be reduced to eliminate harmonics from the system.This scheme ensures that in the absence of any particular harmonics, the compensation unit will not inject any extra harmonics to the system (see Fig.6). The PI controller is responsible for reducing the harmonics components below the specified limit. After the THD level reaches below the allowable limit, the PI controller output stabilizes and continues to inject the particular amount of harmonics. The flow diagram of the overall harmonics elimination process of grid current and PCC voltage is provided in Fig.7.

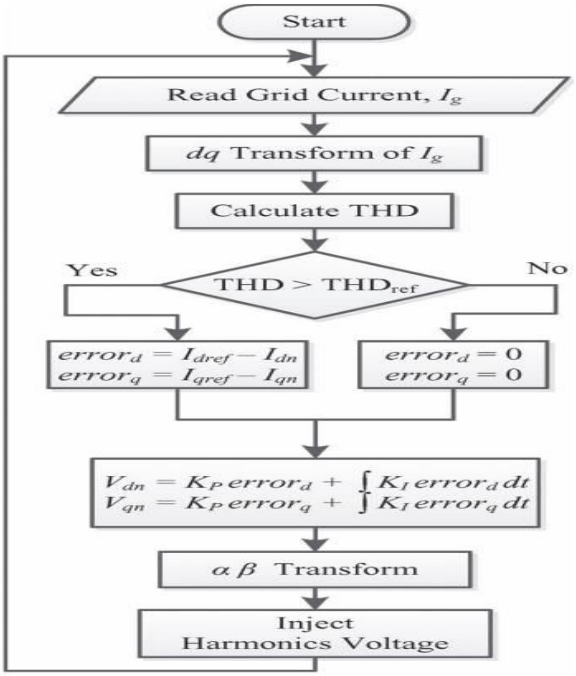


Fig.7. System Flow Diagram.

The harmonic resonance condition may occur due to the capacitors connected to a microgrid. The control of harmonic resonance can be achieved through tuning the virtual impedance in the microgrid controller. Increasing the virtual impedance will result in limiting the harmonic current flow. To design a PI controller for harmonic compensation, an approximate model for the equivalent system is derived in $d_q$rotating reference frame, as shown graphically in Fig.8. Thedifferential equations for the systems can be written as

$$L\frac{di_d}{dt} = -Ri_d + v'_{dh} + \omega Li_q - v_{dh} \tag{12}$$

$$L\frac{di_q}{dt} = -Ri_q + v'_{qh} + \omega Li_d - v_{qh}. \tag{13}$$

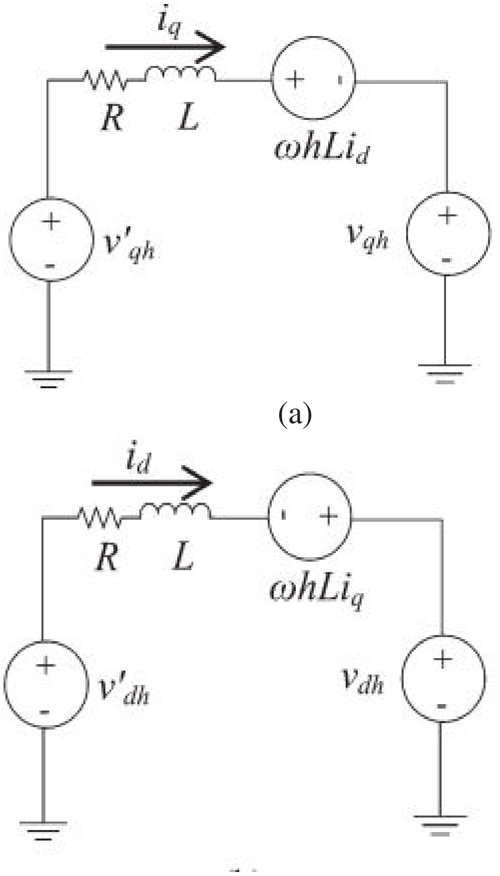
In the Laplace domain (12) and (13) can be written as

$$sLI_d = -RI_d + V'_{dh} + \omega LI_q - V_{dh} \tag{14}$$

$$sLI_q = -RI_q + V'_{qh} + \omega LI_d - V_{qh} \tag{15}$$

The transfer function can be expressed in terms of the PI controller (*kp,ki*) and harmonics estimation gain, *G*, as shown in Fig.5, as

$$V'_{xh} = \frac{k_p s + k_i}{s}\frac{G}{s+G}i_x. \tag{16}$$



(a)

(b)

Fig.8. Equivalent (a) *q* component (b) *d* component circuit for PI controller design.

V.MICRO GRID

A grid-connected photovoltaic power system or grid-connected WIND system is an electricity generating solar WIND system that is connected to the utility grid. A grid-connected WIND system consists of solar panels, one or several inverters, a power conditioning unit and grid connection equipment. They range from small residential and commercial rooftop systems to large utility-scale solar power stations. Unlike stand-alone power systems, a grid-connected system rarely includes an integrated battery solution, as they are still very expensive. When conditions are right, the grid-connected WIND system supplies the excess power, beyond consumption by the connected load, to the utility grid.Residential, grid-connected rooftop systems which have a capacity less than 10 kilowatts can meet the load of most consumers. They can feed excess power to the grid where it is consumed by other users. The feedback is done through a meter to monitor power transferred. Photovoltaic wattage may be less than average consumption, in which case the consumer will continue to purchase grid energy, but a lesser amount than previously. If photovoltaic wattage substantially exceeds average consumption, the energy produced by the panels will be much in excess of the demand. In this case, the excess power can yield revenue by selling it to the grid. Depending on their agreement with their local grid energy company, the consumer only needs to pay the cost of electricity consumed less the value of electricity generated. This will be a negative number if more electricity is generated than consumed. Additionally, in some cases, cash incentives are paid from the grid operator to the consumer.

Connection of the photovoltaic power system can be done only through an interconnection agreement between the consumer and the utility company. The agreement details the various safety standards to be followed during the connection.Solar energy gathered by photovoltaic solar panels, intended for delivery to a power grid, must be conditioned, or processed for use, by a grid-connected inverter. Fundamentally, an inverter changes the DC input voltage from the WIND to AC voltage for the grid. This inverter sits between the solar array and the grid, draws energy from each, and may be a large stand-alone unit or may be a collection of small inverters, each physically attached to individual solar panels. See AC_Module. The inverter must monitor grid voltage, waveform, and frequency. One reason for monitoring is if the grid is dead or strays too far out of its nominal specifications, the inverter must not pass along any solar energy. An inverter connected to a malfunctioning power line will automatically disconnect in accordance with safety rules, for example UL1741, which vary by jurisdiction. Another reason for the inverter monitoring the grid is because for normal operation the inverter must synchronize with the grid waveform, and produce a voltage slightly higher than the grid itself, in order for energy to smoothly flow outward from the solar array.

VI.MATLAB/SIMULATION RESULTS

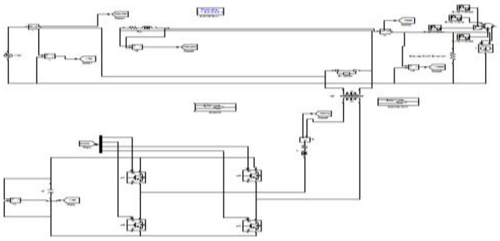


Fig 10 Matlab/simulation circuit of Conventional harmonic compensation method.

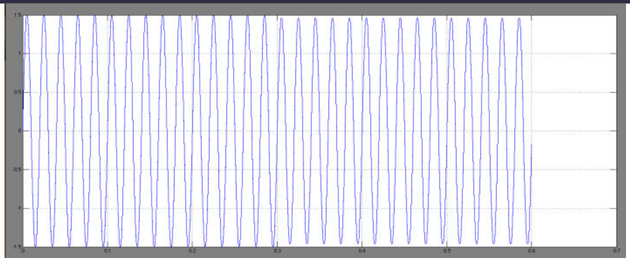


Fig 11 simulation wave form of current source

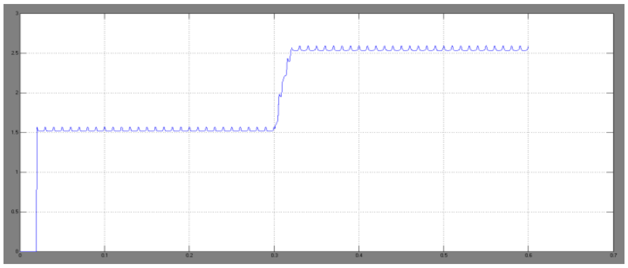


Fig 12 simulation wave form of Total Harmonic Distortion source current

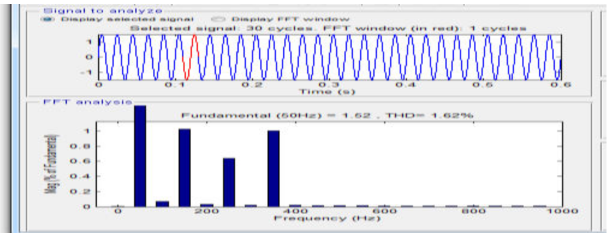


Fig 13 FFT analysis of the critical load current before the compensation is applied

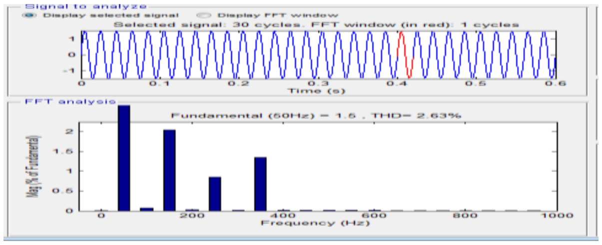


Fig 14 FFT analysis of the critical load current after the conventional compensation method is applied.

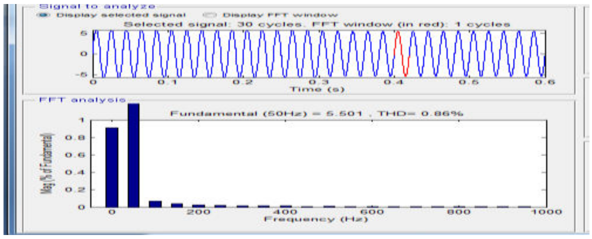


Fig 15 Grid current in conventional method before and after applying harmonic compensation.

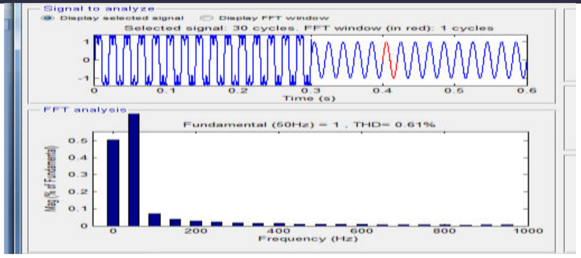


Fig 16FFT analysis of the critical load current after the proposed compensation method is applied.

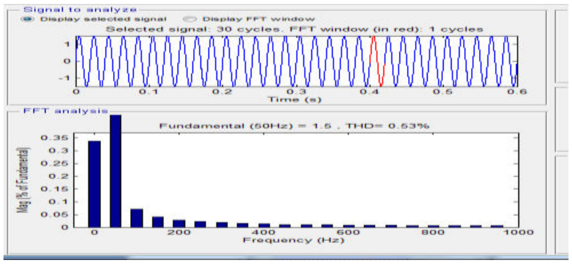


Fig 17 FFT analysis of the critical load current before the compensation is applied.

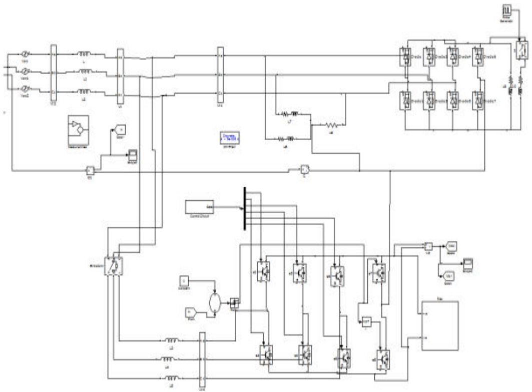


Fig 18 Matlab/simulation circuit of harmonic compensation method with three phase source industrial application

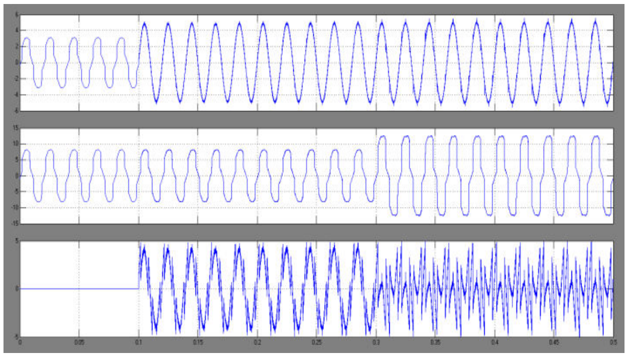


Fig 19 simulation wave form of voltage and current source

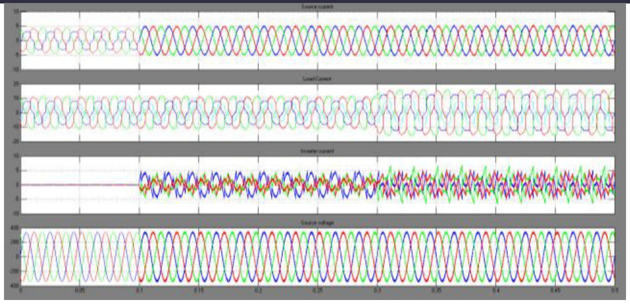


Fig 20 simulation wave form of source and load current ,inverter current and source voltage

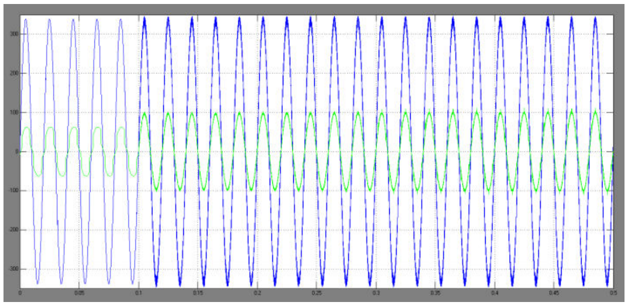


Fig 21 simulation wave form of power factor correction

VII.CONCLUSION

The power converter system integration with renewableenergy sources and interaction within a microgrid structure is presented with applicability in off grid islanded, grid-connected and genset-connected for residential and commercial installations. The system architecture presented incorporates DPG modules with flexible modes of operation in order to control the power flow for energy prioritization and system efficiency maximizationThe suggested placement of the harmonic reduction unit dictates the use of a special controller structure that uses the harmonics magnitude in the dqreference frame. An effective and efficient method is used to estimate the harmonics in the line. The proposed injects a voltage to counteract the harmonics in the system and reduce the THD to desired levels.An improved based harmonic elimination technique has been applied in this paper for control of induction motors and the various simulations has been performed on Simulink.

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