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NEW EFFICIENT SINGLE PHASE&THREE PHASE HARMONICS ELIMINATION METHOD FOR INDUCTION MOTOR DRIVE APPLICATION

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ABSTRACT:
Harmonic mitigation is a key issue in industrial as well as commercial drive applications. The wide use of non-linear loads causes significant power quality degradation in power distribution networks. 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 d-q reference frame. In the proposed control algorithm, the required amount of attenuation for harmonics is determined to meet the total harmonic distortion. A complete simulation model is developed in order to observe the performance of the proposed harmonic compensator. The proposed method is further implemented by connecting induction motor to the output and performance of the motor is studied using Matlab/Simulink software.

Key Words: Total harmonic Distortion, Point of Common Coupling, Induction Motor Drive, Grid Connected Mode.

I. INTRODUCTION

Power electronic devices have become abundant today due to their capabilities for precise process control and energy savings benefits. However, they also bring drawbacks to electrical distribution systems [1]:

harmonics are a growing concern in the management of electrical systems today. The presence of harmonics in electrical systems means that current and voltage are distorted and deviate from sinusoidal waveforms.

Harmonic currents are caused by nonlinear loads connected to the distribution system. A load is said to be nonlinear when the current it draws does not have the same wave shape as the supply voltage. The flow of harmonic currents through the system impedances in turn causes voltage distortion in the distribution system [2-5]. Equipment consisting of power electronic circuits are typical nonlinear loads. Such loads are increasingly more abundant in all industrial, commercial, and residential installations and their percentage of the total load is growing steadily. Harmonic currents increase the rms current in electrical systems and deteriorate the supply voltage quality. They stress the electrical network and potentially damage the equipment [6].

They may disrupt normal operation of devices and increase operating costs. Symptoms of problematic harmonic levels include overheating of transformers, motors and cables, thermal tripping of protective devices and logic faults of digital devices. In addition, the life span of many devices is reduced by elevated operating temperatures [7-9].

In a power system, induction motors constitute the largest component of the load and are widely used in industrial, commercial and residential applications. Once the power system gets polluted with harmonics, the operation characteristics of induction motors are affected first. The use of induction motors (IMs) are increasing day by day in industry sector for high power applications [10].

The main advantages of IMs are rugged in construction, easy maintenance, less cost and sufficiently high efficiency, etc. The proposed Harmonics elimination 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 proposed method provides two main contributions. First contribution is the proposed location of the harmonics reduction unit to perform simultaneous harmonic compensation in the grid current and the PCC voltage [11].

The second contribution is the use of efficient algorithms to detect and compensate for the harmonics. Using computationally efficient algorithms allows additional functions to be performed by the harmonic compensation unit with a low-cost embedded controller [12].

The harmonics reduction unit connected in series to the line has an advantage of less power consumption.

Finally the harmonic elimination method with induction motor drive is proposed and results shown for Stator current, and Torque and Speed.

II. PLACEMENT OF HARMONICCOMPENSATION UNIT IN MICROGRID SYSTEM

In conventional methods 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,

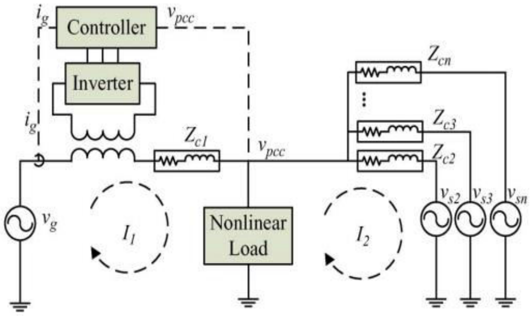

Fig.1. Conventional harmonic compensation method.

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

$$I_{n_1} Z_{n_{c1}} + V_{n_{\mathrm{inj}}} = V_{n_{\mathrm{pcc}}} \quad (1)$$

$$I_{n_2} Z_{n_{c2}} = V_{n_{\mathrm{pcc}}} \quad (2)$$

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

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

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

$$V_{n_{\mathrm{inj}}} = k_n I_{n_1} \quad (4)$$

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

$$I_{n_1} = \frac{V_{n_{\mathrm{pcc}}}}{Z_{n_{c1}} + k_n} \quad (5)$$

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

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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.

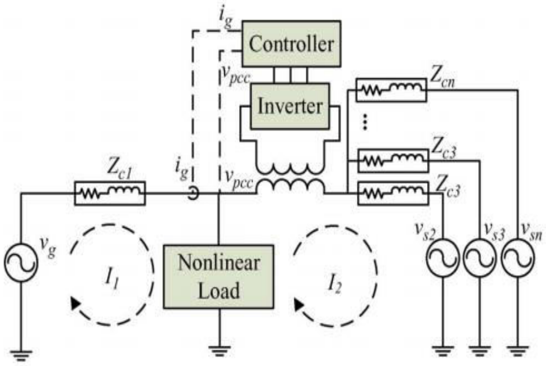


Fig.2. Proposed harmonic compensation method.

The unit makes the PCC voltage harmonic free 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:

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

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

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 the harmonics 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 micro grid. Then, the compensation unit can secure the harmonics free grid current and PCC voltage by diverting the harmonics to the side of the other sources, which can share the harmonics effectively through the techniques provided.

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.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, this dictates the amount of harmonics injection by the harmonics compensator.

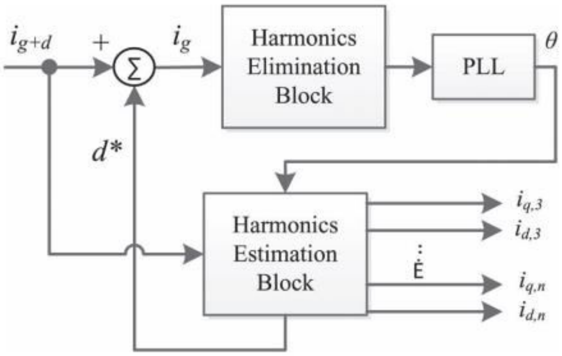


Fig.3. Overall, harmonic compensation block.

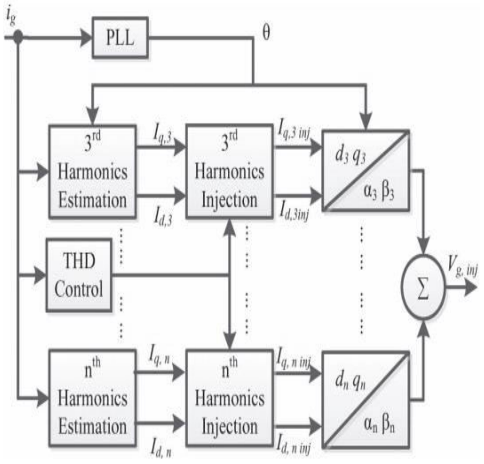


Fig.4. Harmonics elimination block diagram

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. . . n^{th} 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 at the specified harmonic frequency should be injected into the line based on the error between the actual and reference.

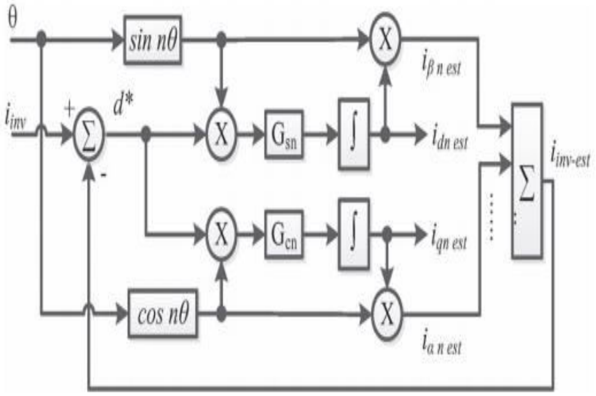


Fig.5. Harmonics estimation block

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 dq rotating reference frame for fundamental, as well as harmonics components. The transfer function for the harmonics estimation block can be written as

$$\frac{\hat{V}_{d,n}(s)}{V_{d,n}(s)} = \frac{0.5G_{sn}}{s + 0.5G_{sn}} \tag{3.8}$$

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. 3.4, should be set according to this requirement. 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 no integer harmonics or any other disturbances the measured current signal shown in Fig.3, can be expressed as

$$i_{g+d} = i_g + d \tag{9}$$

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

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

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. 3.5). Thus, $\hat{\imath}_g$can be described as

$$\hat{i} = i_{g+d} - \hat{d} = i_g + d - err - d = i_g - err. \tag{3.11}$$

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 noninteger harmonics.

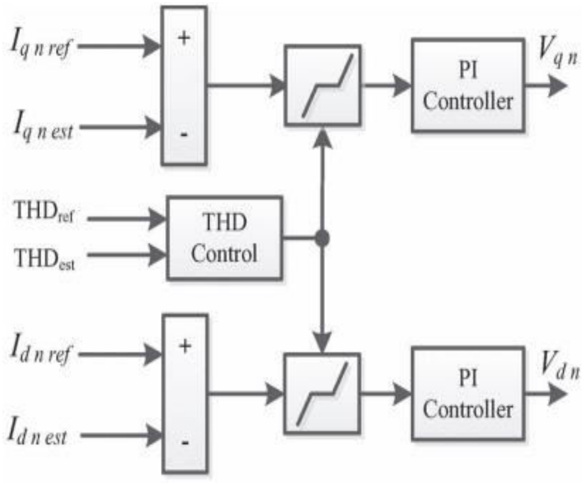


Fig.6. Harmonics injection unit

IV. CONTROLLER OPERATION

Fig.5 illustrates the block diagram of the harmonics injection unit, where the desired amounts of harmonics are commanded in *dq* 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.

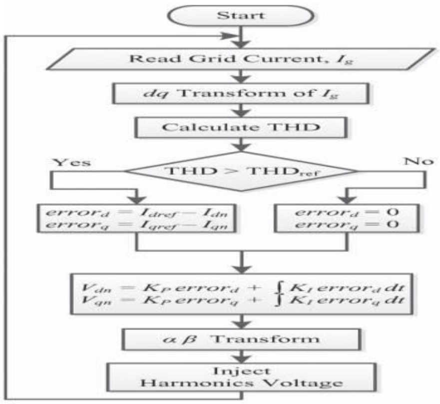


Fig.7. System Flow Diagram

The harmonic resonance condition may occur due to the capacitors connected to a micro grid. The control of harmonic resonance can be achieved through tuning the virtual impedance in the micro grid 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 *dq* rotating reference frame, as shown graphically in Fig.8. The differential 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 (3.12) and (3.13) can be written as

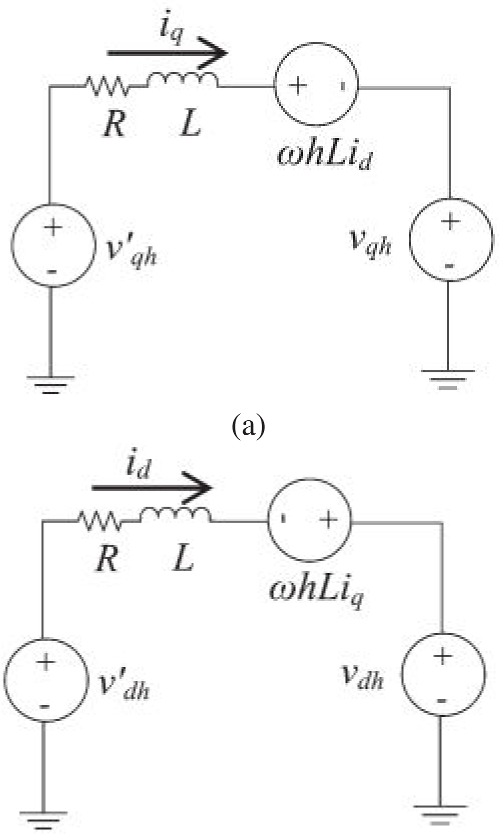
$$sLI_d = -RI_d + V'_{dh} + \omega LI_q - V_{dh} \quad (3.14)$$

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

(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

Substituting V'_{dh} and V'_{qh} from (16) to (14) and (15) we would obtain

$$sLI_d = -RI_d + \frac{k_p s + k_i}{s}\frac{G}{s+G} i_d + \omega LI_q - V_{dh} \quad (17)$$

$$sLI_q = -RI_q + \frac{k_p s + k_i}{s}\frac{G}{s+G} i_q - \omega LI_d - V_{qh} \quad (18)$$

From (17) and (18), the characteristics equation for the system can be written as

$$\left(sL + R\frac{k\left(s + \frac{k_i}{k_p}\right)}{s}\frac{G}{s+G}\right)^2 + (\omega L)^2 = 0 \quad (19)$$

However, the gain *k* is limited by available inverter dc bus voltage. If the gain is too high, it will saturate or overload the inverterof the compensating unit. Thus, proper values of *k* need to be determined to ensure stable and proper operation of the compensating unit.

V. MATLAB/SIMULINK RESULTS

Case 1: Grid Connected Mode

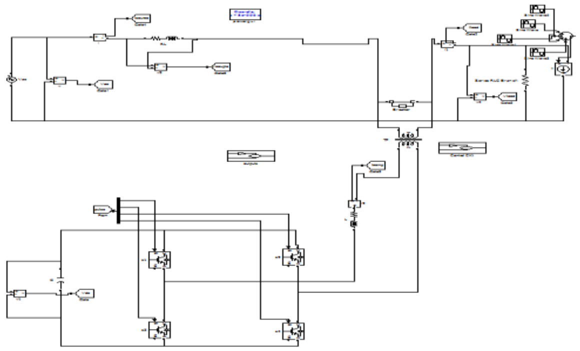


Fig.9. Matlab/Simulink Circuit for Harmonic compensator with grid connected mode

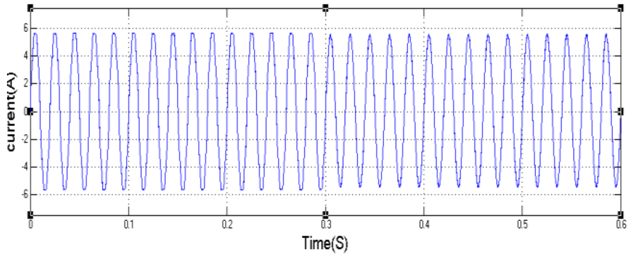


Fig.10. Grid current before and after harmonics elimination in GC mode

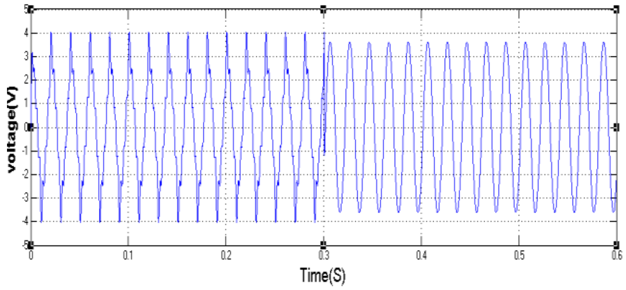


Fig.11. Voltage across coupling impedance of the line before and after harmonics elimination (GC)

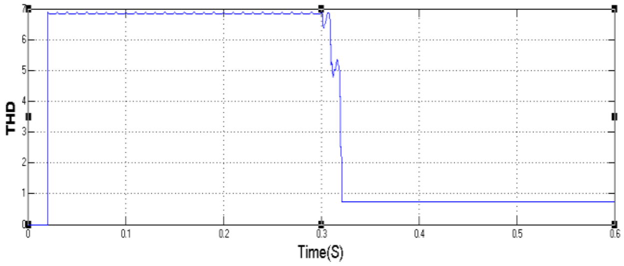


Fig.12. THD in grid current in GC mode as controller adjusts the compensation level.

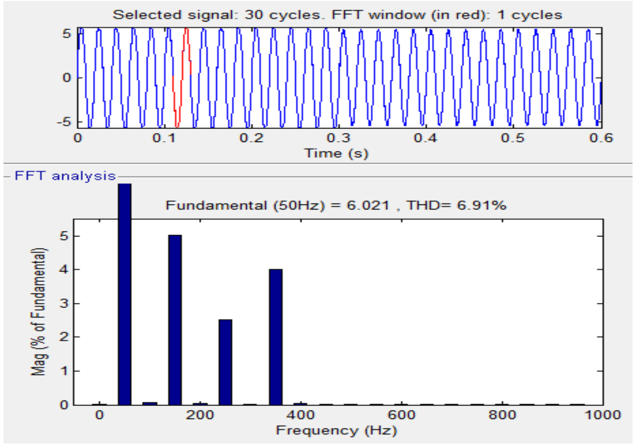


Fig.13. FFT analysis at Grid connected mode

Case 2: SA Mode

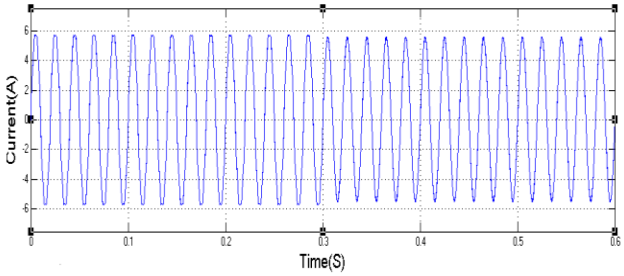


Fig.14. Grid source current in SA mode of operation

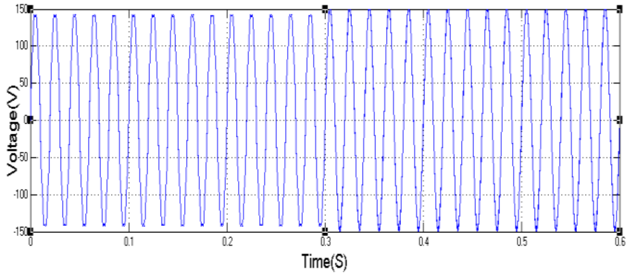


Fig.15. Voltage across coupling impedance of the line at SA mode

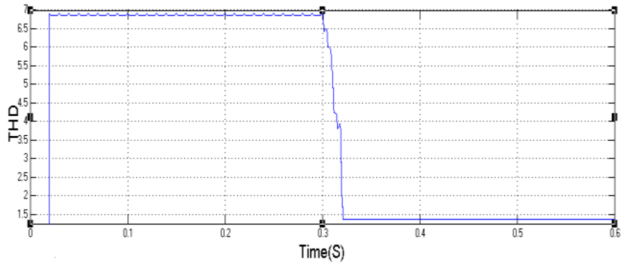


Fig.16. THD in the PCC voltage at SA mode.

Case 3: Inter harmonic Injection

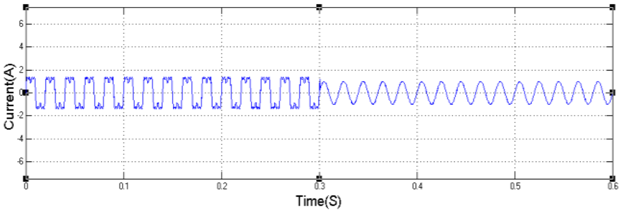


Fig.17. Interharmonic compensation for the grid current

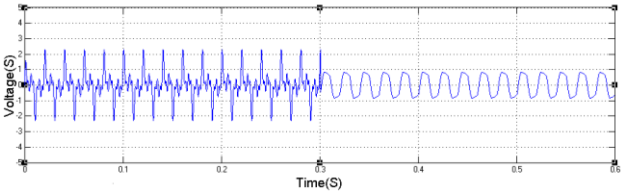


Fig. 18.Interharmonic compensation for the Voltage Couple

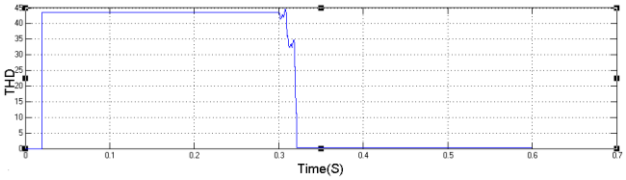


Fig.19. THD in grid current with Inter Harmonic

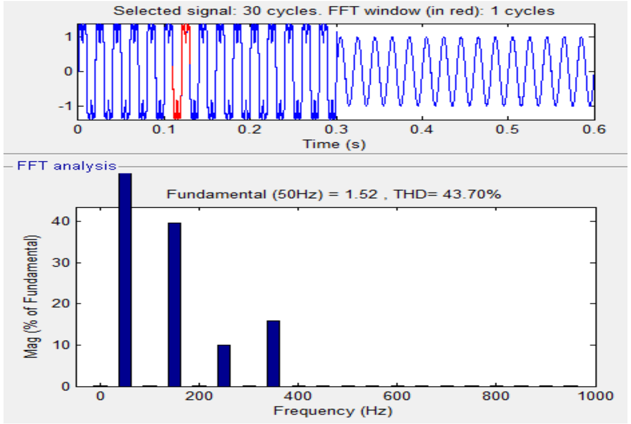


Fig.20. FFT analysis before applying interharmonic compensation for the grid current

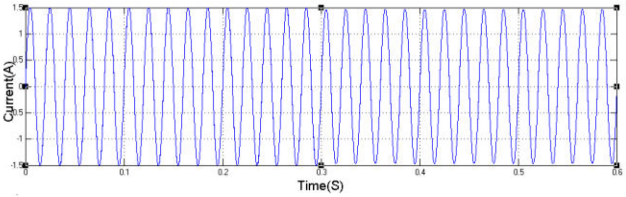


Fig.21. Current source before the compensation is applied.

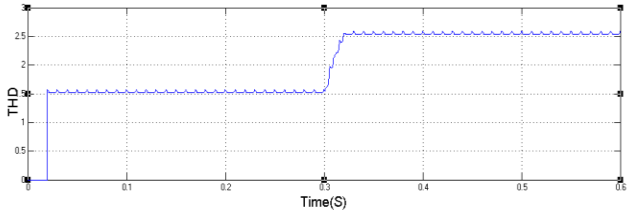


Fig.22. THD in grid current before the compensation is applied.

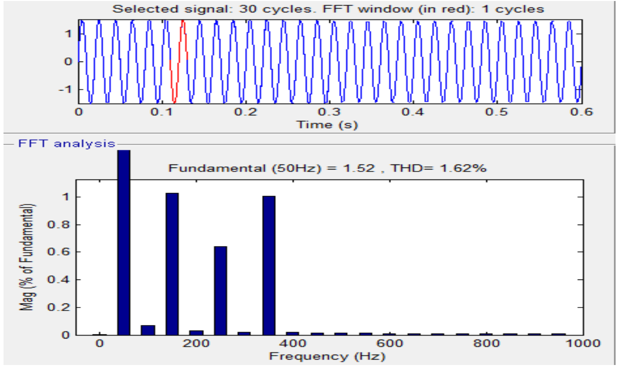


Fig.23. FFT analysis of the critical load current before the compensation is applied.

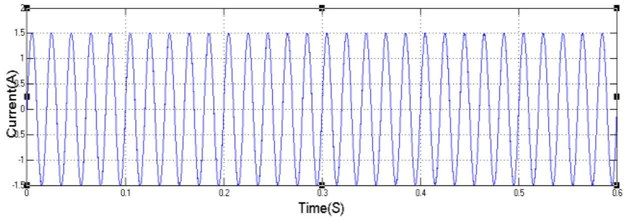


Fig.24. Current source after the compensation is applied

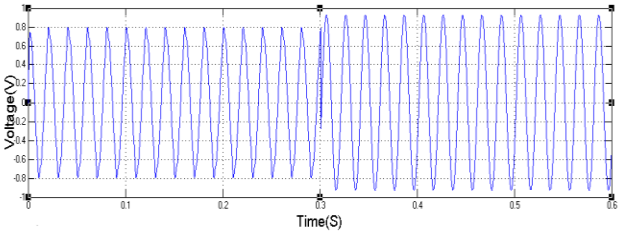


Fig.25. Voltage across coupling impedance of the line after compensation applied.

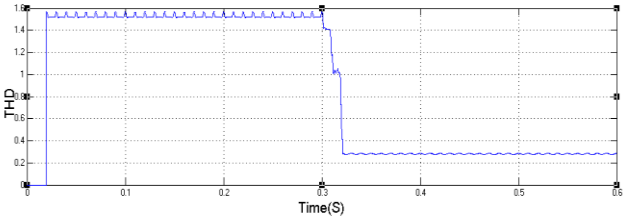


Fig.26. THD in grid current after the compensation is applied.

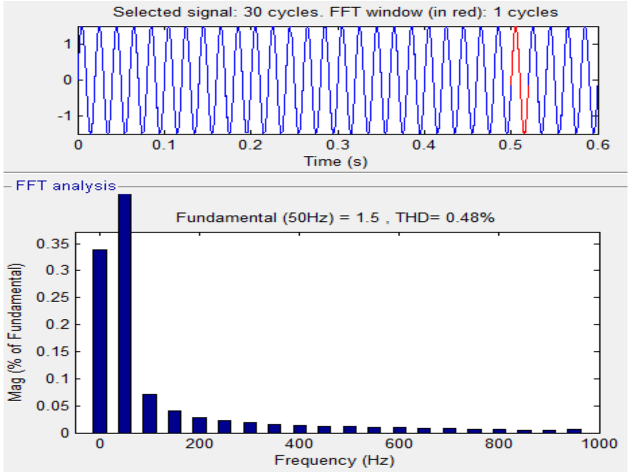


Fig.27. FFT analysis of the critical load current after the proposed compensation method is applied.

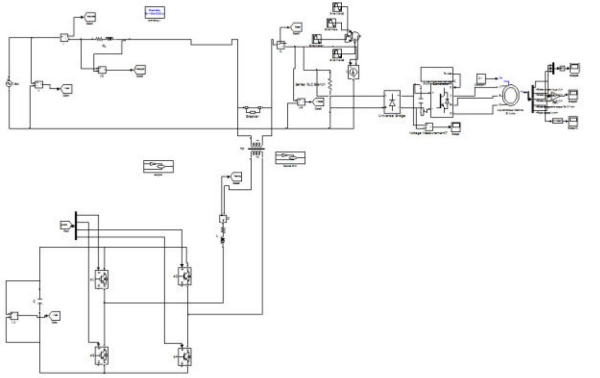
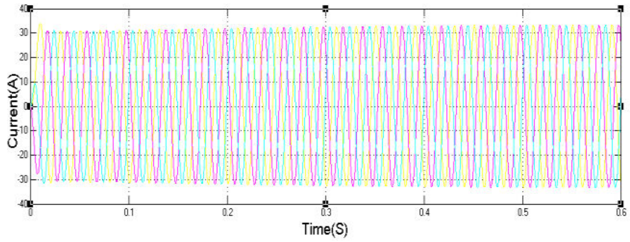
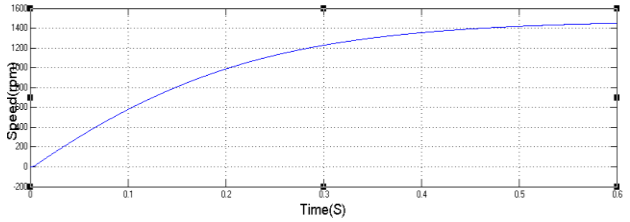


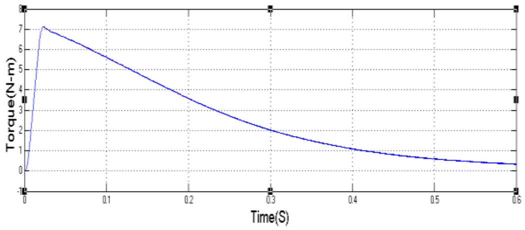
Fig.28. Matlab/Simulink Circuit for Harmonic compensator with SA mode single phase Induction motor Drive



(a) Stator Current



(b) Speed



(c) Electromagnetic Torque
Fig.29.Simulink waveform for Harmonic compensator with SA mode single phase Induction motor Drive Stator Current, Speed and Torque.

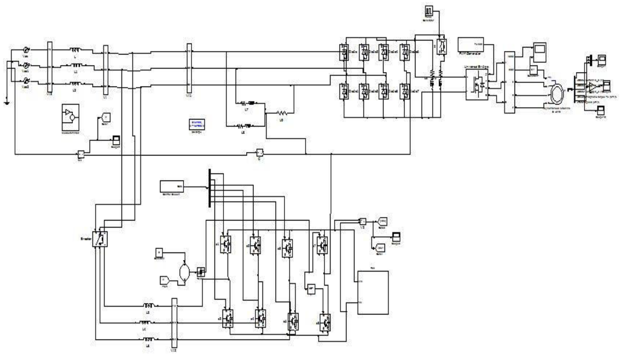
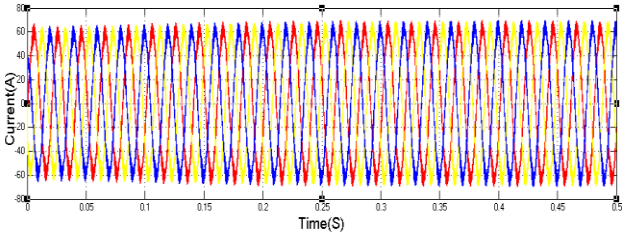
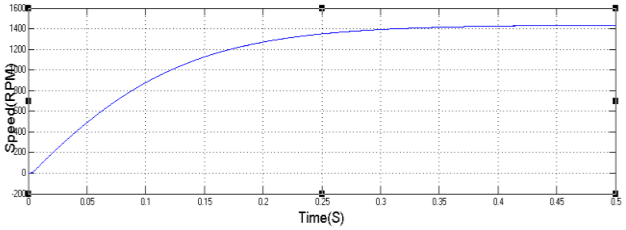


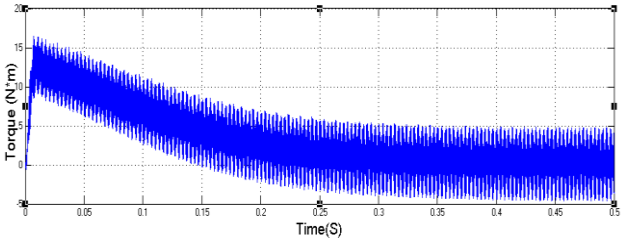
Fig.30. Matlab/Simulink Circuit for Harmonic compensator with SA mode three phase Induction motor Drive



(a) Stator Current



(a) Speed



(b) Electromagnetic Torque
(c)
Fig.29.Simulink waveform for Harmonic compensator with SA mode Three Phase Induction motor Drive Stator Current, Speed and Torque.

VI. CONCLUSION

A new method of ensuring power quality both in the grid current and PCC voltage has been proposed in this paper. Harmonic currents increase the rms current in electrical systems and deteriorate the supply voltage quality. The location of the harmonics reduction unit was selected to eliminate the harmonics in the grid current and the PCC voltage, as well. The suggested placement of the harmonic reduction unit dictates the use of a special controller structure that uses the harmonics magnitude in the d-q reference 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. The effectiveness of the proposed method is verified through simulation Results. This harmonic compensation method can be extended by connecting Induction motor drive, in this the stator current, Speed and Torque are observed to be better.

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