MITIGATION OF LOWER ORDER HARMONICS IN A GRID CONNECTED THREE PHASE PV INVERTER APPLIED TO LOAD

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Abstract-In this paper simple single-phase grid connected photovoltaic (PV) inverter topology consisting of a boost section, a low voltage Three- phase inverter with an inductive filter and a step-up transformer interfacing the grid is considered. Ideally, this topology will not inject any lower order harmonics into the grid due to high-frequency pulse width modulation operation. However, the non ideal factors in the system such as core saturation-induced distorted magnetizing current of the transformer and the dead time of the inverter, etc., contribute to a significant amount of lower order harmonics in the grid current. A novel design of inverter current control that mitigates lower order harmonics is presented in this paper. An adaptive harmonic compensation technique and its design are proposed for the lower order harmonic compensation. In addition, a proportional-resonant-integral (PRI) controller and its design are also proposed. This controller eliminates the dc component in the control system, which introduces even harmonics in the grid current in the topology considered. The dynamics of the system due to the interaction between the PRI controller and the adaptive compensation scheme is also analyzed. The output is analyzed with load application.

***Keywords*—adaptive filter, harmonic distortion, Inverters, Solar energy.**

INTRODUCTION

Renewable sources of energy such as solar, wind and geothermal have gained popularity due to the depletion of conventional energy sources. Hence, many distributed generation (DG) systems making use of the renewable energy sources are being designed and connected to a grid. In this paper, one such DG system with solar energy as the source is considered. The topology of the solar inverter system is simple. It consists of the following three stages:

1) A boost converter stage to perform maximum power point tracking (MPPT).
2) A low-voltage Three-phase H-bridge inverter.
3) An inductive filter and a step-up transformer.

The switches are all rated for low voltage which reduces the cost and lesser component count in the system improves the overall reliability. This topology will be a good choice for low-rated PV inverters of rating less than a kilowatt. The disadvantage would be the relatively larger size of the interface transformer compared to topologies with a high- frequency link transformer. The basic circuit will not have any lower order harmonics in the ideal case. However, the following factors result in lower order harmonics in the system: The distorted magnetizing current drawn by the transformer due to the nonlinearity in the B– H Curve of the transformer core, the dead time introduced between switching of devices of the same leg, on-state voltage drops on the switches, and the distortion in the grid voltage itself. There can be a dc injection into the transformer primary due to a number of factors. These can be the varying power reference from a fast MPPT block from which the ac current reference is generated, the offsets in the sensors, and A/D conversion block in the digital controller.

II REVIEW OF LITERATURE

1. Adaptive harmonic compensation technique in three phase PV Inverter: PWM inverters ideally shift the output voltage spectrum around the switching frequency. Thus ideally PWM inverters do not introduce any significant lower order harmonics. However, in real systems, due to dead-time effect, device drops and other non-idealities lower order harmonics are present. In order to attenuate these lower order harmonics and hence to improve the quality of output current, this paper presents an adaptive harmonic elimination technique.

2. Review of Three-Phase Grid-Connected Inverter for Photovoltaic Modules

This review focuses on inverter technologies for connecting photovoltaic (PV) modules to a single- phase grid. The inverters are categorized into four classifications: The number of power processing stages in cascade. The type of power decoupling between the PV module(s) and the single phase grid.

3. Compensation Method Eliminating Voltage Distortions in PWM Inverter

The switching lag-time and the voltage drop across the power devices cause serious waveform distortions and fundamental voltage drop in pulse width-modulated inverter output. These phenomenon are conspicuous when both the output frequency and voltage are low. To estimate the output voltage from the PWM reference signal it is essential to take account of these imperfections and to correct them. In this paper, on-line compensation method is presented.

4. Systematic Method for Damping of the LCL Filter for Three-Phase Grid-Connected PV Inverters

The Proportional Resonant (PR) current controller provides gains at a certain frequency (resonant frequency) and eliminates steady state errors. Therefore, the PR controller can be successfully applied to single grid-connected PV inverter current control. On the contrary, a PI controller has steady- state errors and limited disturbance rejection capability. Compared with the L- and LC filters, the LCL filter has excellent harmonic suppression capability, but the inherent resonant peak of the LCL filter may introduce instability in the whole system.

5. A strategy for harmonic reduction using complete Solution:

One of the major problems in electric power quality is the harmonic contents. There are several Methods of indicating the quantity of harmonic contents. These parameters of power quality measurement are four in number, of which Total Harmonic Distortion is most widely used. In electrical systems, harmonics increase business operating costs by increasing downtime, placing burden on the electrical infrastructure, making power factor correction difficult and causing poor total power factor. Harmonics are a circumstance of progress, and they affect all the operating systems.

6. Harmonic Reduction in Cascaded Multilevel Inverter

It presents method of selecting switching angles of a cascaded multilevel inverter so as to produce required fundamental voltage along with improved staircase waveform in terms of harmonics. Cascaded multilevel inverter uses number of DC sources, for k sources number of levels will be 2k+1 and leads to k number of non-linear equations to be solved.

III.CONVENTIONAL POWER CIRCUIT TOPOLOGY

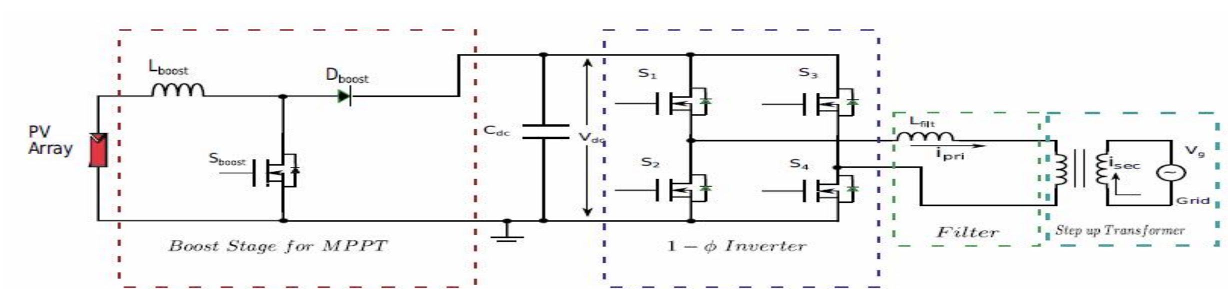

Fig.1 Power circuit topology of the single phase PV system connected to grid

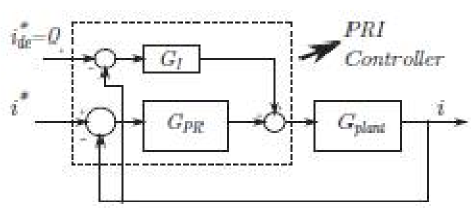

Fig.2 fundamental controller with PRI Controler

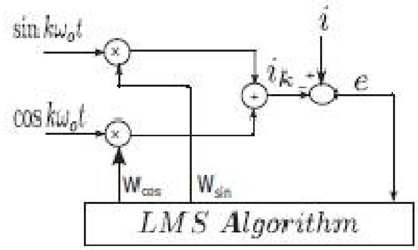

Fig.3 adaptive Estimation of a particular harmonic of grid current

Adaptive Harmonic Compensation

The LMS adaptive filter discussed previously can be used for selective harmonic compensation of any quantity, say grid current. To reduce a particular lower order harmonic (say *ik*) of grid current:
1) *ik* is estimated from the samples of grid current and phaselocked loop (PLL) [38] unit vectors at that frequency;
2) a voltage reference is generated from the estimated valu of *ik* ;
3) generated voltage reference is subtracted from the mai controller voltage reference.
block diagram of the adaptive filter that estimates the *k*th harmonic *ik* of the grid current *i*. The adaptive block takes in two inputs sin($k\omega o\ t$) and cos($k\omega o\ t$) from a PLL. These samples are multiplied by the weights *W*cos and *W*sin. The output is subtracted from the sensed grid current sample, which is taken as the error for the LMS algorithm. The weights are then updated as per the LMS algorithm and the output of this filter would be an estimate of the *k*th harmonic of grid current. The weights update would be done by using the equations given next, where *Ts* is the sampling time, *e*(*n*) is the error of *n*th sample, and μ is the step size

$$e(n) = i(n) - ik\ (n)$$

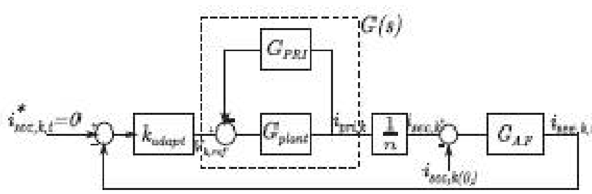

Fig.4 kadapt calculating representation

IV. Matlab /Simulink Circuit with Results

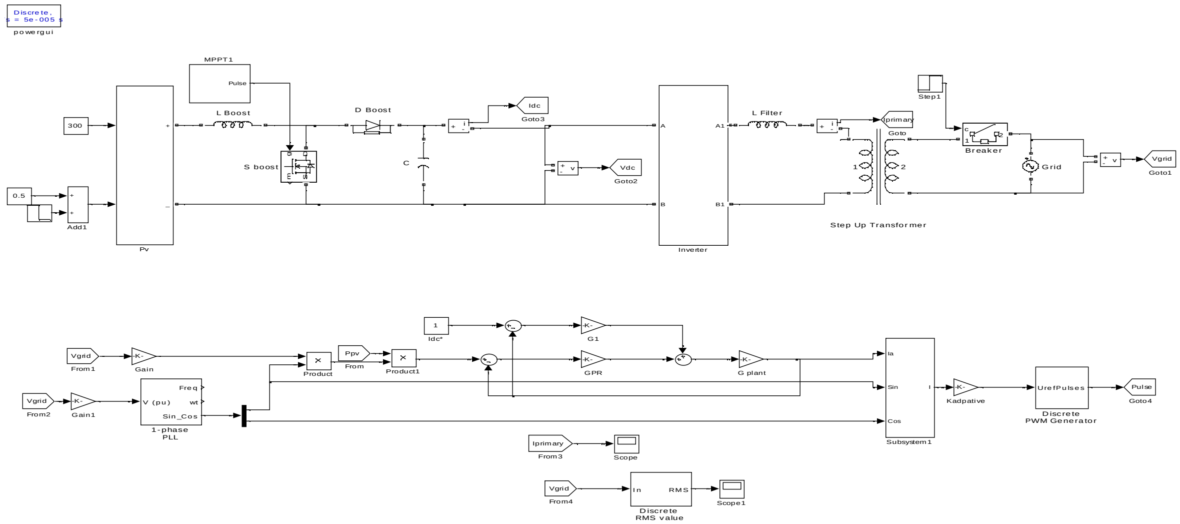

Fig.5 matlab/simulink circuit representation

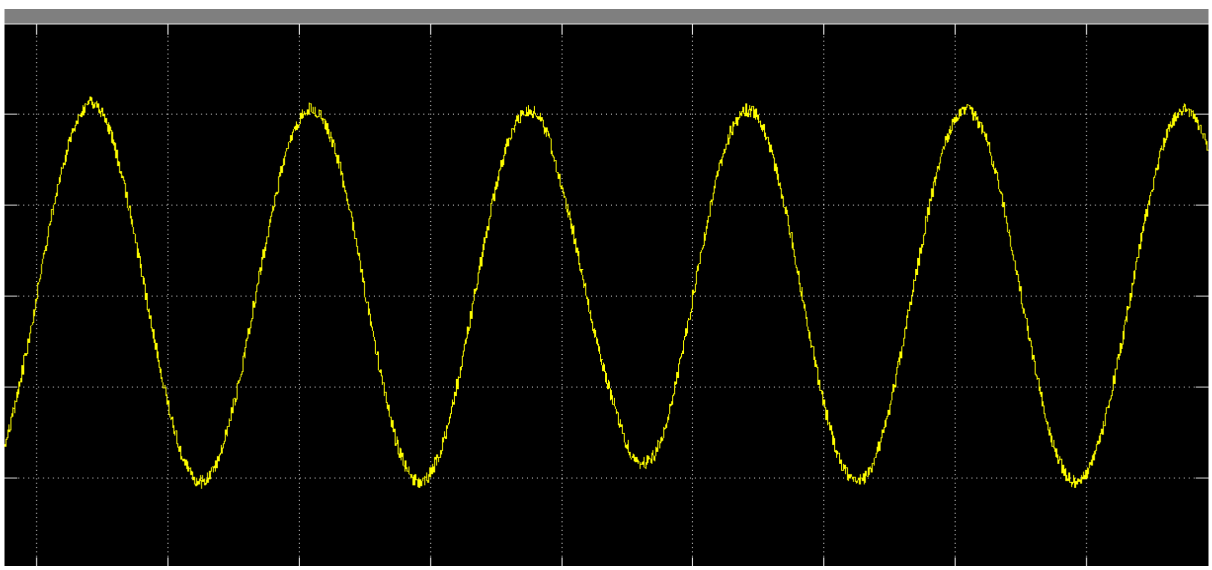

Fig.6 Case : 1 No dc offset compensation and no adaptive harmonic compensation

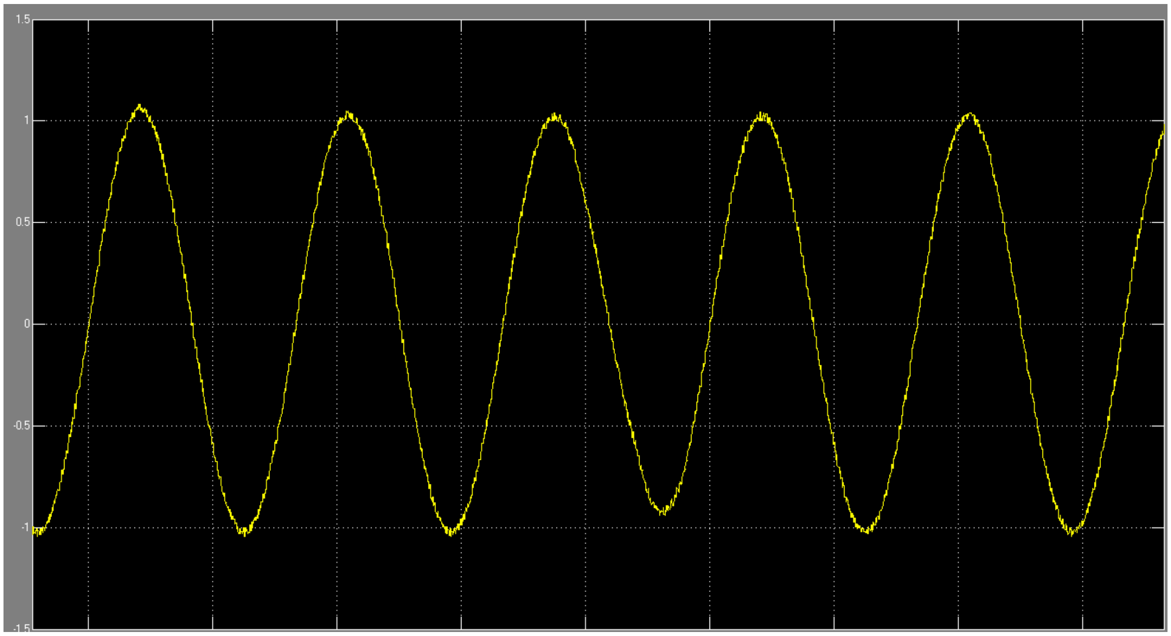

Fig.7 Case: 4 both dc offset compensation and adaptive harmonic compensation are implemented

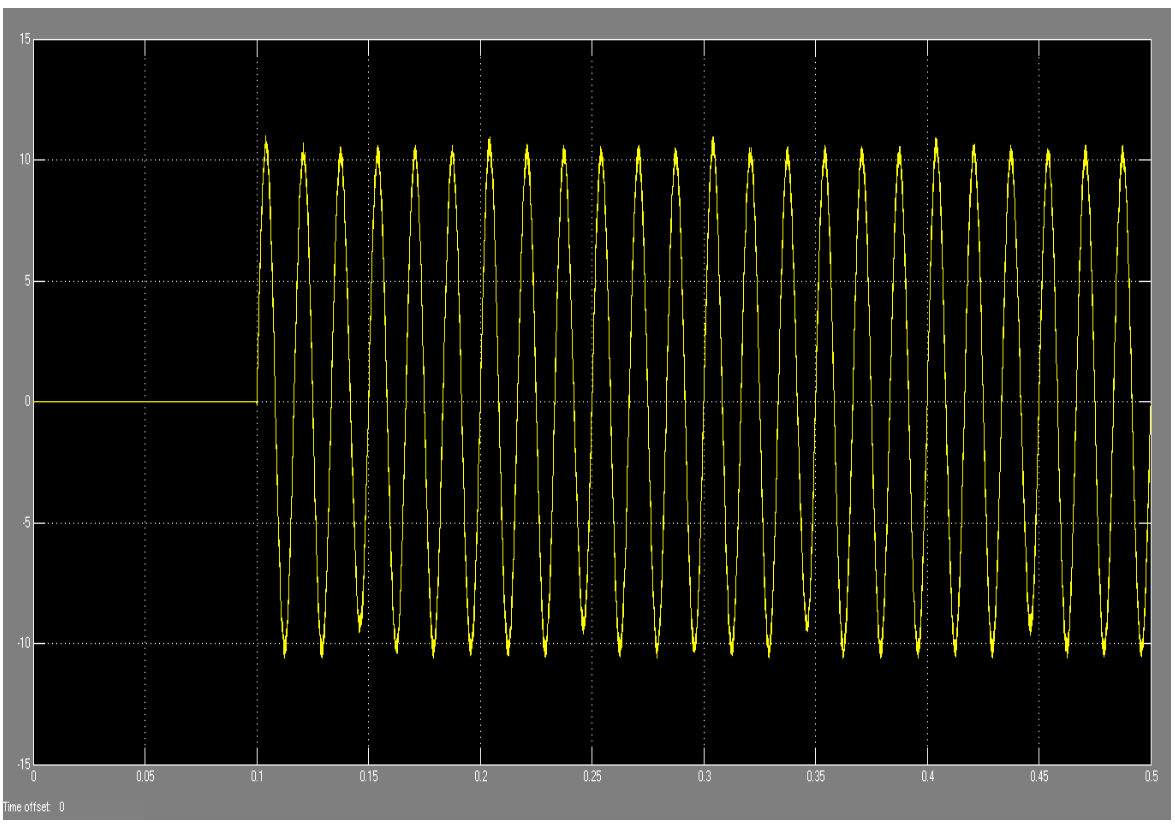

Fig.8DC offset compensation is implemented but no adaptive harmonic compensation.

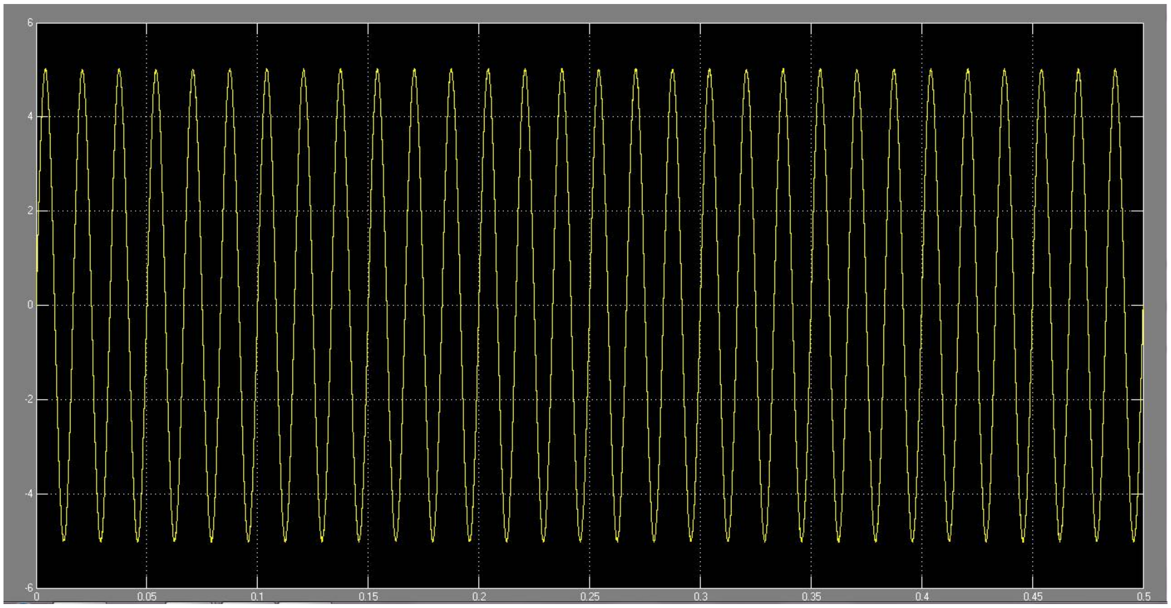

Fig.9 grid voltage waveform

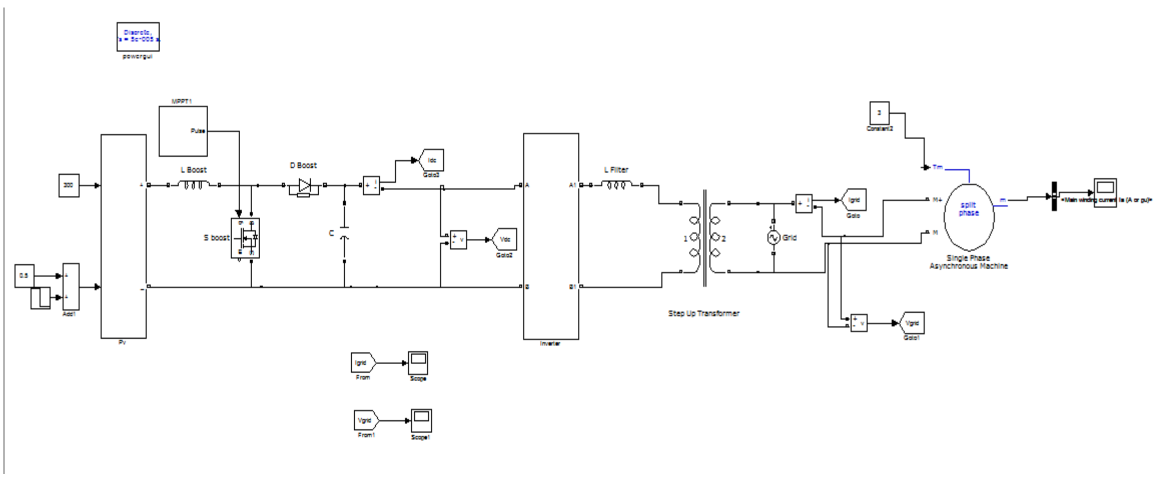

Fig.10 matlab/simulink representation with load applied representation

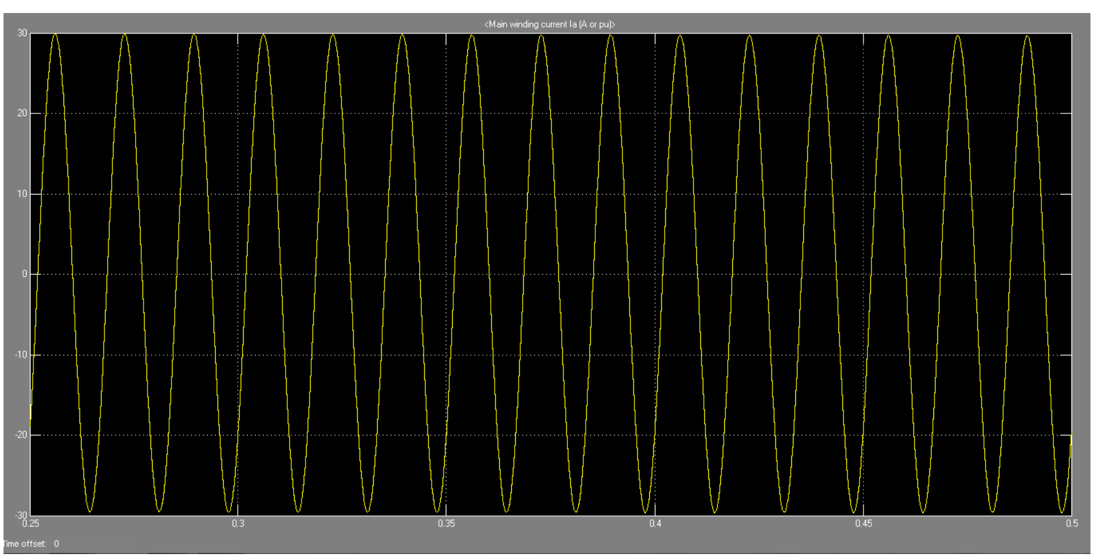

Fig.11 armature current of the machine

V.CONCLUSION

Modification to the inverter current control for a grid connected single-phase photovoltaic inverter has been proposed in this paper, for ensuring high quality of the current injected into the grid. For the power circuit topology considered, the dominant causes for lower order harmonic injection are identified as the distorted transformer magnetizing current and the dead time of the inverter. It is also shown that the presence of dc offset in control loop results in even harmonics in the injected current for this topology due to the dc biasing of the transformer. A novel solution is proposed to attenuate all the dominant lower order harmonics in the system. The proposed method uses an LMS adaptive filter to estimate a particular harmonic in the grid current that needs to be attenuated. The estimated current is converted into an equivalent voltage reference using a proportional controller and added to the inverter voltage reference. The design of the gain of a proportional controller to have an adequate harmonic compensation has been explained. To avoid dc biasing of the transformer, a novel PRI controller has been proposed and its design has been presented. The interaction between the PRI controller and the adaptive compensation scheme has been studied. It is shown that there is minimal interaction between the fundamental current controller and the methods responsible for dc offset compensation and adaptive harmonic compensation. The PRI controller and the adaptive compensation scheme together improve the quality of the current injected into the grid. The complete current control scheme consisting of the adaptive harmonic compensation and the PRI controller has been verified and the results show good improvement in the grid current THD once the proposed current control is applied. The transient response of the whole system is studied by considering the startup transient and the overall performance is found to agree with the theoretical analysis. It may be noted here that these methods can be used for other applications that use a line interconnection transformer wherein the lower order harmonics have considerable magnitude and need to be attenuated. The system is applied to split phase motor and observed the performance characteristics.

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