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An Adaptive Frequency Selective Method Based Harmonic Control for Grid Connected Inverters

M.Maheshwari, M.Selvakumar

***Abstract*—** A frequency adaptive selective harmonic control (FA-SHC) scheme method is developed from a hybrid SHC scheme based on the internal model principle, which can be designed for grid-connected inverters to optimally mitigate feed-in current harmonics. The hybrid SHC scheme consists of multiple parallel recursive harmonic control modules with independent control gains, which can be optimally weighted in accordance with the harmonic distribution. The hybrid SHC, thus, offers an optimal tradeoff among cost, complexity, and also performance in terms of high accuracy, fast response, easy implementation, and compatible design. The analysis and synthesis of the hybrid SHC are addressed. The harmonics in the presence of grid frequency variations, the hybrid SHC is transformed into the FA-SHC, being the proposed fractional order controller, when it is implemented with a fixed sampling rate. The FA-SHC is implemented by substituting the fractional order elements with the Lagrange-polynomial-based interpolation filters. The proposed FA-SHC scheme provides fast on-line computation and frequency adaptability to compensate harmonics in grid-connected applications, where the grid frequency is usually varying within a certain range.

***Keywords*—** Selective Harmonic control, Grid Inverter, Matlab

I. INTRODUCTION

Ever Power Quality (PQ) problems have been brought by an increase of renewable energy systems, e.g. Photo-Voltaic (PV) systems and wind turbine systems, as well as the power electronics interfaced loads the energy conversion is typically performed by power electronics converters. optimal harmonic control strategies to compensate these periodic harmonic contents with high control accuracy, while maintaining fast transient response, guaranteeing robustness, and also being feasible for easy implementation Regarding control accuracy, by the Internal Model Principle (IMP) zero error tracking of any periodic signal (e.g. grid current) in steady-state can be achieved, as long as a generator of the reference is included in a stable closed control loop. To secure a clean, sustainable and economical power supply, electricity networks are undergoing a significant evolution from centralized, long transmission lines and traditional systems to 'Smart Grids' with a high penetration of renewable Distributed Generators (DGs) within distribution systems. As the grid penetration and power level of these plants increase steadily, it starts to have significant impacts on the power system. A simple solution to the attenuation of lower order harmonics would be to make the filter inductor bulky. This is not an attractive option as there would be higher fundamental drop, higher losses and higher cost. Thus in this paper, an adaptive technique is used to attenuate the dominant lower order harmonics. As the grid penetration and power level of these plants increase steadily, it starts to have significant impacts on the power system. Therefore, more advanced generators, power electronic systems, and control solutions need to be introduced to make these plants more suitable to be integrated into the power grid.

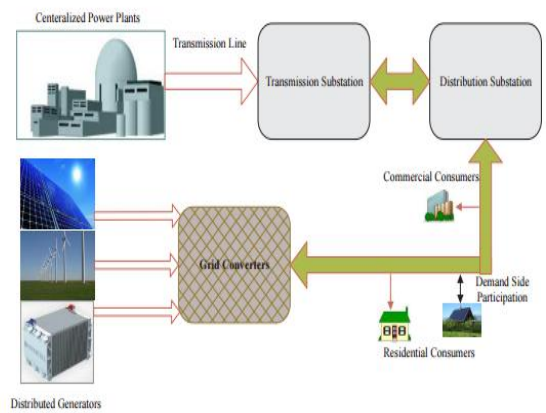

Fig.1 A simple grid connected distributed power generation system.

To suit power system specifications, high performance control strategies are required for the grid converters to regulate voltages, currents and/or frequencies with minimum steady-state error, while maintaining fast transient response, guaranteeing robustness and being feasible in practice. Many IMP-based controllers have been developed for grid-connected inverters, e.g. Repetitive Controller (RC), Resonant Controller (RSC) and hybrid controllers There are also other control strategies which can selectively compensate the harmonic distortion by modifying the modulation schemes, as presented in The above IMP-based controllers offer relative accurate control of periodic signals as internal models of interested harmonics have been included into the control loop. However, optimal mitigation of the harmonics by those controllers is difficult to achieve even considering the fact of unequal harmonic distributions. Taking the harmonic

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distribution into account, multiple parallel resonant controllers and the discrete Fourier transform based RC consisting of the internal models of selected harmonics with independent control gains, can render quite fast transient response at the cost of parallel computation burden and design complexity. The paper utilizes the merits of the hybrid real coded genetic algorithm (HRCGA) in finding the optimal solution to the nonlinear equation system with fast and guaranteed convergence.

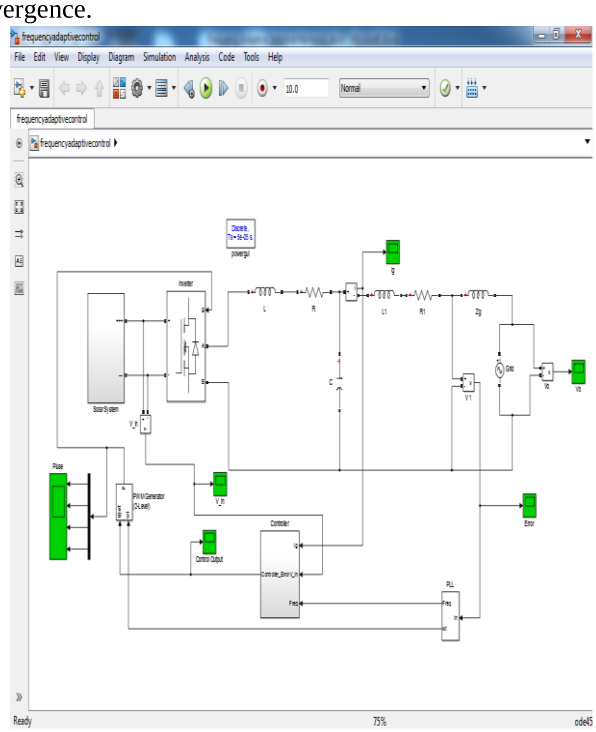


Fig.2 Simulation Block Diagram

II. EXISTING SYSTEM

Regarding control accuracy, by the internal model principle (IMP) zero-error tracking of any periodic signal (e.g., grid current) in steady state can be achieved, as long as a generator of the reference is included in a stable closed control loop. Many IMP-based controllers have been developed for grid-connected inverters, e.g., repetitive controller resonant controller (RSC) and hybrid controllers. In some cases a second phase for implementation is constructed by applying a 90◦ phase shift with respect to the fundamental frequency of single-phase signal [25]. Predictive controllers have a straightforward design procedure for both linear and non-linear models but their performance is dependent on an accurate model and is very sensitive to uncertainties and disturbances [27]. The aforementioned IMP-based controllers offer relative accurate control of periodic signals as internal models of interested harmonics have been included into the control loop.

III. PROPOSED SYSTEM

A high voltage gain interleaved boost converter with dual coupled inductors for high step up and high power applications are proposed the derivation procedure for the proposed topology. This circuit can be divided as two parts. These two segments are named a modified interleaved boost converter and a voltage double module using capacitor-diode and coupled inductor technologies. Regarding control accuracy, by the internal model principle (IMP) zero-error tracking of any periodic signal (e.g., grid current) in steady state can be achieved, as long as a generator of the reference is included in a stable closed control loop. Many IMP-based controllers have been developed for grid-connected inverters, e.g., repetitive controller resonant controller (RSC) and hybrid controllers.

There are also other control strategies, which can selectively compensate the harmonic distortion by modifying the modulation scheme. The aforementioned IMP-based controllers offer relative accurate control of periodic signals as internal models of interested harmonics have been included into the control loop.

A. Simulation Results

1) Input Voltage Waveform

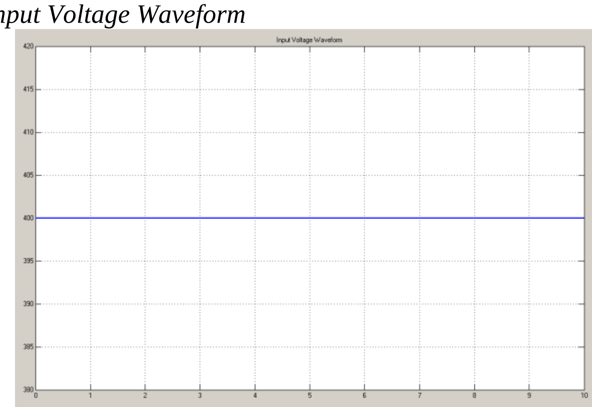


Fig 3.2 Input Voltage Waveform

A power inverter, or inverter, is an electronic device or circuitry that changes direct current (DC) to alternating current (AC). The input voltage, output voltage and frequency, and overall power handling depend on the design of the specific device or circuitry. The inverter does not produce any power; the power is provided by the DC source. A power inverter can be entirely electronic or may be a combination of mechanical effects (such as a rotary apparatus) and electronic circuitry. Static inverters do not use moving parts in the conversion process.

A high voltage gain interleaved boost converter with dual coupled inductors for high step up and high power applications are proposed the derivation procedure for the proposed topology. This circuit can be divided as two parts. These two segments are named a modified interleaved boost converter and a voltage doubler module using capacitor-diode and coupled inductor technologies. The basic boost converter topology is another boost version with the same function in which the output diode is placed on the negative dc-link rail is called a modified interleaved boost converter, which is an input-parallel and output-series configuration derived from two basic boost types.

2) Conventional Control Scheme

A PWM inverter is usually controlled as a current source. In grid connected application, there will be two control loops. One dc bus voltage regulation loop and an inner current control loop. The output of current controller, after adding the feed forward terms generates the voltage reference. This voltage reference is compared with a triangular carrier to obtain PWM pulses which will be input to the gate-driver in the hardware.

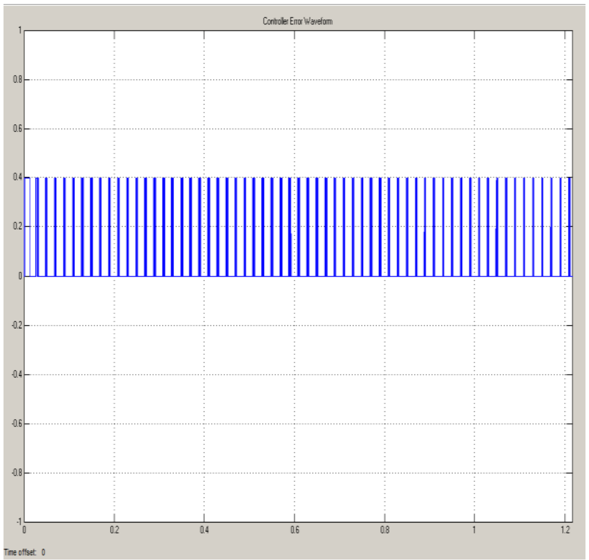


Fig 3.3 Controller Error Waveform

B. Photo Voltaic

Photovoltaic (PV) is the name of a method of converting solar energy into direct current electricity using semiconducting materials that exhibit the photovoltaic effect, a phenomenon commonly studied in physics, photochemistry and electrochemistry. The process is both physical and chemical in nature, as the first step involves the photoelectric effect from which a second electrochemical process take place involving crystallized atoms being ionized in a series, generating an electric current. The direct conversion of sunlight to electricity occurs without any moving parts or environmental emissions during operation. the cost of photovoltaic's has declined steadily since the first solar cells were manufactured and the levelised cost of electricity from PV is competitive with conventional electricity sources in an expanding list of geographic regions.

IV. Frequency Adaptive Selective Harmonic Control

Either the hybrid SHC or the CRC is sensitive to harmonic frequency variations, e.g. grid frequency fluctuation in grid connected inverter systems. Moreover, even in a stable frequency system, the sampling frequency must be selected to ensure an integer period N = fs/f0 for the CRC and an integer period p = N/n for the hybrid SHC control scheme. The harmonic compensation accuracy will be deteriorated if an integer period CRC of a period _N or hybrid SHC of a period _p is adopted to compensate fractional period harmonics. It is therefore necessary to develop frequency adaptive controller for grid-connected inverters to assure high tracking accuracy in the presence of variable grid frequencies.

$$G_{FA-SHC}(s) = \sum_{m \in N_m} \frac{k_m z^c \left[\cos\left(\frac{2\pi m}{n}\right) z^p Q(z) - Q^2(z)\right]}{z^{2p} - 2\cos\left(\frac{2\pi m}{n}\right) z^p Q(z) + Q^2(z)}$$

$$= \sum_{m \in N_m} \frac{k_m z^c \left[\cos\left(\frac{2\pi m}{n}\right) z^{P+F} Q(z) - Q^2(z)\right]}{z^{2(P+F)} - 2\cos\left(\frac{2\pi m}{n}\right) z^{P+F} Q(z) + Q^2(z)}$$

It can be seen from (9) and (14) that, the hybrid SHC scheme is sensitive to frequency variations. If the fractional part F of the period p is omitted in (14), i.e. F = 0 and z−p = z−P , the infinity gains of the integer order GSHC(z) will be shifted away from the selected harmonic frequencies of interest, and may lead to a significant degradation of the control accuracy consequently.

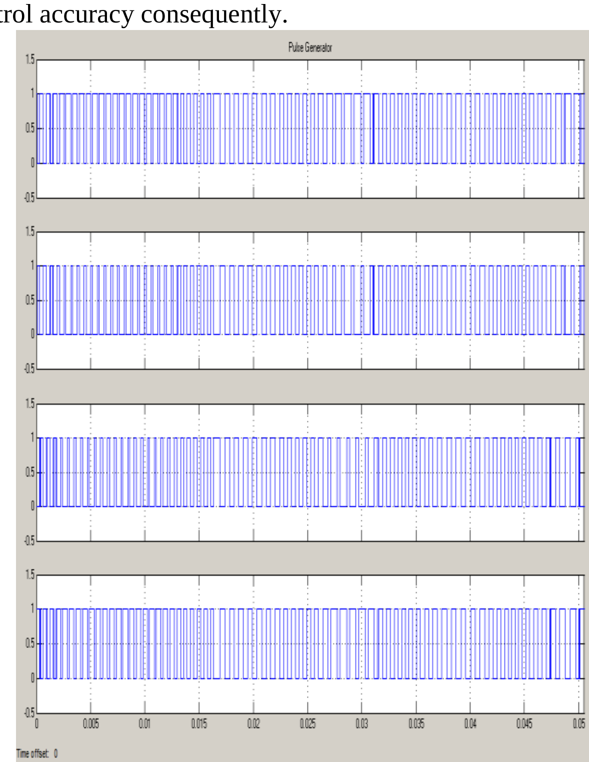


Fig 3.4 Pulse Waveform

V. Experimental Verifications

A. Grid

1) Grid Current Waveform

An electrical grid is an interconnected network for delivering electricity from suppliers to consumers. It consists of generating stations that produce electrical power, high-voltage transmission lines that carry power from distant sources to demand centers, and distribution lines that connect individual customers.

Power stations may be located near a fuel source, at a dam site, or to take advantage of renewable energy sources, and are often located away from heavily populated areas. They are usually quite large to take advantage of the economies of scale. The electric power which is generated is stepped up to a higher voltage at which it connects to the electric power transmission network.

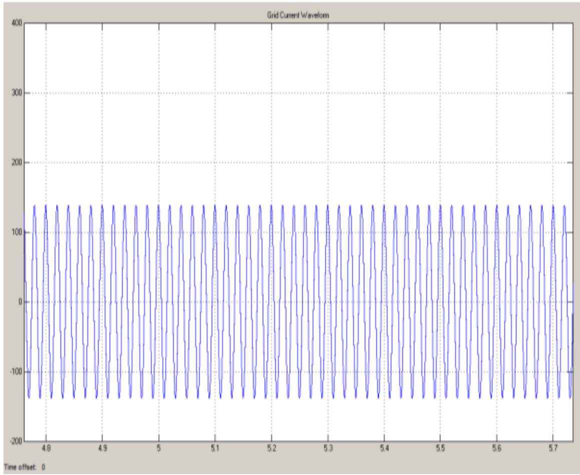


Fig 3.5Grid Current Waveform

B. Pwm Pulse

Pulse-width modulation (PWM), or pulse-duration modulation (PDM), is a modulation technique used to encode a message into a pulsing signal. Although this modulation technique can be used to encode information for transmission, its main use is to allow the control of the power supplied to electrical devices, especially to inertial loads such as motors. In addition, PWM is one of the two principal algorithms used in photovoltaic solar battery chargers,[1] the other being MPPT.

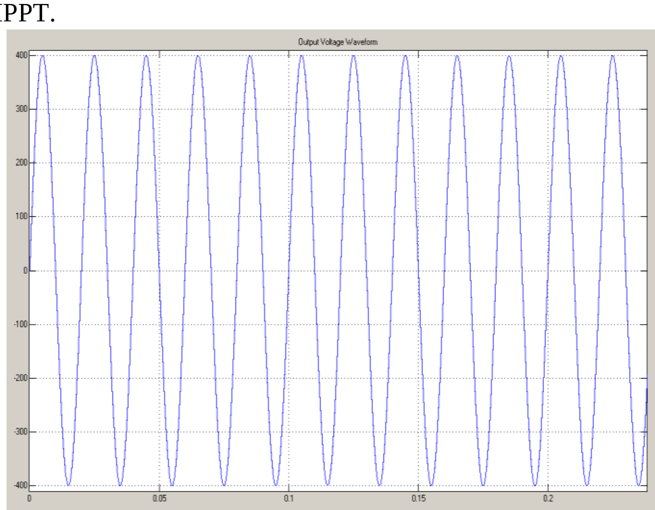


Fig 3.6 Output Voltage Waveform

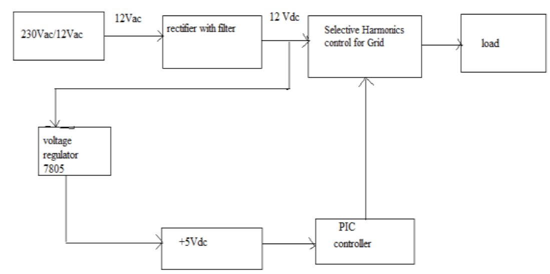
The average value of voltage (and current) fed to the load is controlled by turning the switch between supply and load on and off at a fast rate. The longer the switch is on compared to the off periods, the higher the total power supplied to the load.

The PWM switching frequency has to be much higher than what would affect the load (the device that uses the power), which is to say that the resultant waveform perceived by the load must be as smooth as possible. Typically switching has to be done several times a minute in an electric stove, 120 Hz in a lamp dimmer, from few kilohertz (kHz) to tens of kHz for a motor drive and well into the tens or hundreds of kHz in audio amplifiers and computer power supplies.

VI. Results And Discussions

A. Hardware Descriptions

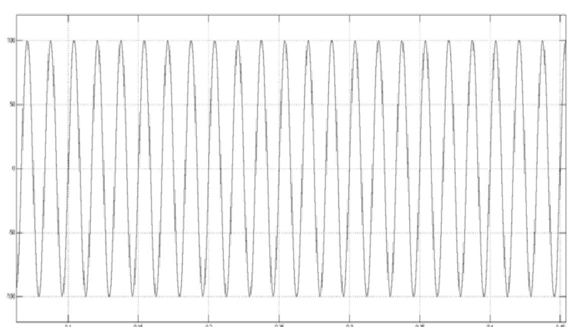
1) Block Diagram



In this section, the performance of this proposed scheme in analyzed in terms of internet bandwidth, complexity of using the scheme, extensibility, availability.

B. Current Control

In electrical signaling an analog current loop is used where a device must be monitored or controlled remotely over a pair of conductors. Only one current level can be present at any time. Given its analog nature, current loops are easier to understand and debug than more complicated digital field buses, requiring only a handheld digital millimeter in most situations. Using field buses and solving related problems usually requires much more education and understanding than required by simple current loop systems.



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The average value of voltage (and current) fed to the load is controlled by turning the switch between supply and load on and off at a fast rate. The longer the switch is on compared to the off periods, the higher the total power supplied to the load.

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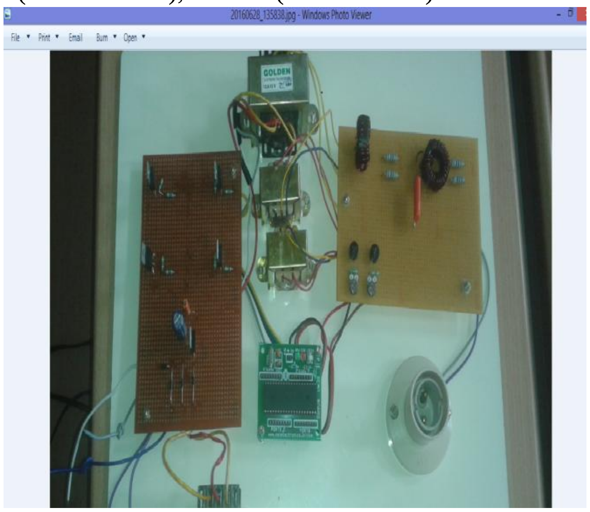
Additional digital communication to the device can be added to current loop using hart Protocol. Digital process buses such as Foundation Field bus and Profile bus may replace analog current loops. For industrial process control instruments, analog 4–20 mA and 10–50 mA current loops are commonly used for analog signaling, with 4 mA representing the lowest end of the range and 20 mA the highest. The key advantages of the current loop are that the accuracy of the signal is not affected by voltage drop in the interconnecting wiring, and that the loop can supply operating power to the device.

E. Phase Locked Loop

A phase-locked loop or phase lock loop (PLL) is a control system that generates an output signal whose phase is related to the phase of an input signal. While there are several differing types, it is easy to initially visualize as an electronic circuit consisting of a variable frequency oscillator and a phase detector. The oscillator generates a periodic signal. Consequently, in addition to synchronizing signals, a phase-locked loop can track an input frequency, or it can generate a frequency that is a multiple of the input frequency. Phase-locked loops are widely employed in radio, telecommunications, computers and other electronic applications.

F. Harmonic Compensator

It is typically applied when considering the frequencies of repeating signals, such as sinusoidal waves, that happen to relate as whole-numbered multiples. In that case, a harmonic is a signal whose frequency is a whole-numbered multiple of the frequency of some other given signal. As multiples of the fundamental frequency, successive harmonics can be found by repeatedly adding the fundamental frequency. For example, if the fundamental frequency (first harmonic) is 25 Hz, the frequencies of the next harmonics are: 50 Hz (2nd harmonic), 75 Hz (3rd harmonic), 100 Hz (4th harmonic) etc.



Hardware

VII. Conclusion And Future Work

An internal-model-principle-based FA-SHC scheme has been proposed in this paper to provide a tailor-made optimal control solution to the tracking or elimination of selective harmonic frequencies for n-pulse grid-connected inverters under normal grid frequency and also grid frequency variations. A hybrid SHC scheme has been developed first, and it takes advantage of the strengths of both conventional RC and multiple parallel resonant controllers in terms of high accuracy due to the removal of most of harmonics, fast transient response due to the parallel combination of optimally parameter-weighted SHC modules, cost-effective and easy real-time implementation, and compatible design.

The analysis and synthesis of the hybrid SHC scheme have been addressed in details. The synthesis of the hybrid SHC also provides a practical framework for housing various RC schemes. The hybrid SHC has been transformed to the fractional-order SHC being of frequency adaptability, which is the proposed FA-SHC scheme. Compared to the hybrid SHC, the proposed FA-SHC requires a little more multiplications and summations to deal with the fractional-order delays. As for grid connected applications, the grid frequency is not maintained always as constant nominal value, e.g., due to the generation-load imbalance and grid faults, and thus, the proposed FA-SHC can be adopted to enhance the performance of grid-connected applications. The effectiveness of the proposed FA-SHC scheme in terms of fast transient response, good tracking accuracy, and immunity to frequency variations.

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