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Hybrid solar-wind-hydro renewable energy system

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Abstract. This paper presents power generation systems suitable for remote places. Rural areas need generation in the form of hybrid power system. This system consists of three renewable energy sources, namely solar, wind and hydro turbine and also consists of battery. The model has designed to provide power quality for Hybrid Renewable Energy Systems. Various renewable/alternative energy sources, energy storage and their applicability in terms of performance and total harmonic distortion for different inverters are discussed. The MATLAB/SIMULINK software is used to study and design the proposed hybrid renewable energy system model. The harmonic analysis was carried out using and demonstrated. Based on simulation results, it has been found that renewable/alternative energy sources will replace the conventional energy sources and would be a feasible solution for distribution of electric power for standalone applications at remote and distant locations.

Keywords: simulink modeling, hybrid renewable energy systems (HRES), total harmonic distortion (THD)

1 Introduction

With increase in demand for electrical energy, there is a need to search for an alternative source of power generation as the conventional sources of energy are started to deplete. The solution for this problem is the concept of renewable energy source that includes Solar, Wind, and Hydro etc.

The increasing use of the Renewable Energy Sources (RES) and the intermittency of the power generated by them create stability, reliability and power quality problems in the main electrical grid[3]. A change will take place from a relatively few large, conventional generation centres and transmission of electricity to more diverse and dispersed generation and transmission.

The term hybrid energy system refers to those applications in which multiple energy conversion devices are used together to supply an energy requirement. These systems are often used in isolated applications[5, 7] and normally include at least one renewable energy source in the configuration. Hybrid energy systems are used an alternative to more conventional systems, which typically are based on a single fossil fuel source. Hybrid energy systems may also be used as part of distributed generation application in conventional electricity grid.

"Hybrid energy systems are combinations of two or more energy conversion devices (e.g., electricity generators or storage devices), or two or more fuels for the same device, that when integrated, overcome limitations that may be inherent in either." This definition is useful because it includes a wide range of possibilities and the essential feature of the multiplicity of energy conversion. A considerable interest has emerged in combined or 'hybrid' energy systems. In the context used here, that refers to an application in which multiple energy conversion devices are used together to supply an energy requirement[4]. The intermittent nature of many Renewable Energy resources (e.g., wind, solar, ocean wave), hybrid combinations of two or more of

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their relevant power generation technologies, along with storage and/or Alternate Energy power generation, can improve system performance[6].

Due to advancement in semiconductor technology, semiconductor switches such as Metal oxide semiconductor field effect transistor (MOSFET), insulated gate bipolar transistor (IGBT) with high switching frequency and high power handling capacities are used in low and medium distribution energy systems.

In photovoltaic power conversion system, the DC output power of the photovoltaic array should be converted into the AC power of the utility power system. Under this condition, an inverter is required to convert DC power into AC power. There are various types of inverters.

Inverter technology is the key technology to have reliable and safety grid interconnection operation of photovoltaic (PV) system[1]. It is also required to generate high quality power to AC utility system with reasonable cost. To meet with these requirements, up to date technologies of power electronics inverters are applied across PV panels. By means of high frequency switching of semiconductor devices with (PWM) Pulse Width Modulation technologies, high efficiency conversion with improved power factor and low harmonic distortion power can be generated[2].

Multilevel converter topologies are classified into following three categories:

(1) Multilevel configuration with diode clamps;

(2) Multilevel configuration with flying capacitors;

(3) Multilevel configuration with cascaded single-phase H-bridge inverters.

Several modulation and control techniques exist for multilevel inverters. The purpose of modulation techniques is to reduce harmonic content. Modulation techniques are classified as sinusoidal PWM, space vector PWM, selective harmonics elimination PWM and random PWM techniques.

In this paper a hybrid renewable energy system model is proposed and simulated using MATLAB/Simulink. The performance is analyzed subsequently and the results are shown to demonstrate the effectiveness of the Simulink model proposed. Based on simulation results, it has been found that renewable/alternative energy sources will replace the conventional energy sources and would be a feasible solution for distribution of electric power for standalone applications at remote and distant locations.

2 DC-AC converter

The advent of high power electronic modules has encouraged the use of more DC transmission and made the prospects of interfacing dc power sources such as photovoltaic and fuel cells. Multilevel inverter structures have been developed to overcome shortcomings in solid-state switching device ratings so that they can be applied to high-voltage electrical systems. The general function of multilevel inverter is to synthesize a desired AC voltage from several levels of DC voltages. For this reason multilevel inverters are ideal for connecting either in series or in parallel to the AC grid with renewable energy sources like photovoltaic or with energy storage devices such as capacitors and batteries.

Multi carrier sinusoidal pulse width modulation methods, used in multilevel inverters can be broadly classified as:

- Level shifted PWM
- Phase shifted PWM

2.1 Level shifted PWM

Level shifted PWM shown in Fig. 1 (LS-PWM) is used for controlling voltage of a diode clamped multilevel inverter. The control principle of the level shifted SPWM is to use several triangular carrier signals keeping only one modulating sinusoidal signal. For a three level inverter two carriers and for a five level inverter, four triangular carriers are needed. In general if an m-level inverter is employed, $(m-1)$ carriers are needed.

The carriers have the same frequency f_c and the same peak-to-peak amplitude A_c. The zero reference is placed in the middle of the carrier set. The modulating signal is a sinusoid of frequency f_m and amplitude A_m. At every instant, each carrier is compared with the modulating signal. Each comparison switches the switch "on" if the modulating signal is greater than the triangular carrier assigned to that switch. Obviously, the actual driving signals for the power devices can be derived from the results of the modulating-carrier comparison by means of a logic circuit.

The main parameters of the modulation process are:

1. The frequency ratio $k = f_c/f_m$, where f_c is the frequency of the carriers, and f_m is the frequency of the modulating signal.

2. The modulation index $M = A_m/(m' * A_c)$, where A_m is the amplitude of the modulating signal, A_c is the peak-to-peak amplitude of the carriers, and $m' = (m-1)/2$, where m is the number of level (which is odd).

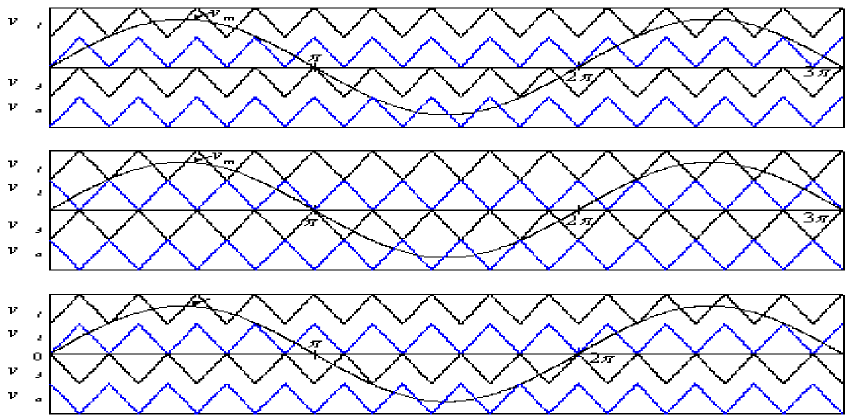

Fig. 1. Level shifted PWM waveform

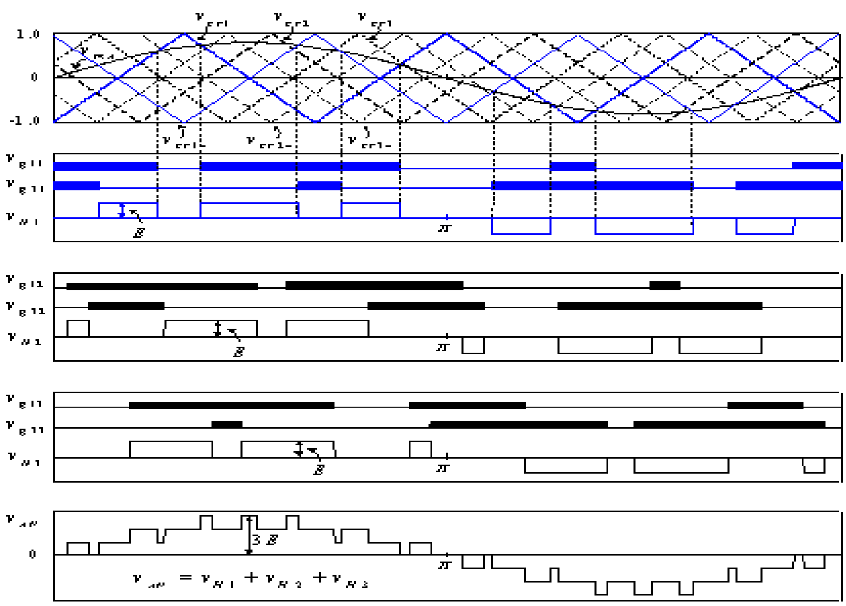

Fig. 2. Phase shifted PWM waveform

2.2 Phase shifted PWM

Phase shifted PWM as shown in Fig. 2 (PS-PWM) is used with cascaded H-bridge (CHB) and flying capacitor (FC) inverters, since each cell is modulated independently using sinusoidal unipolar PWM and bipolar PWM, respectively, providing an even power distribution among the cells. A carrier phase shift of

1800/m for the CHB and of 3600/m for the FC is introduced across the cells to generate the stepped multilevel output waveform with lower distortion (where m is the number of cells). The difference between the phase shifts and the type of PWM (unipolar or bipolar) is because one CHB cell generates 3-level outputs, while one FC cell generates two level outputs.

2.2.1 Advantages of unipolar PWM switching over bipolar PWM switching

Bipolar PWM output contains either $+V$ or $-V$ always. Hence, each state change involves a transition by $2V$. Hence switching harmonic content in this scheme is more. In addition, the switching harmonic content is the highest when the PWM is trying to generate zero volt output after the averaging filter. Unipolar PWM uses $+V$ and zero to make positive outputs and $-V$ and 0 to make negative outputs. Switching harmonic content in this case will be small and will be zero at zero crossings.

The switching patterns given in Tab. 1 are used for cascaded multilevel inverter shown in Fig. 3.

Table 1. Switching logic for a 5-level cascaded multilevel inverter

Output Voltage	S1	S2	S3	S4	S5	S6	S7	S8
V_{dc}	1	0	0	1	1	0	0	1
$V_{dc}/2$	1	0	1	0	0	1	0	1
0	1	1	1	1	0	0	0	0
$-V_{dc}/2$	0	1	0	1	1	0	1	0
$-V_{dc}$	0	1	1	0	0	1	1	0

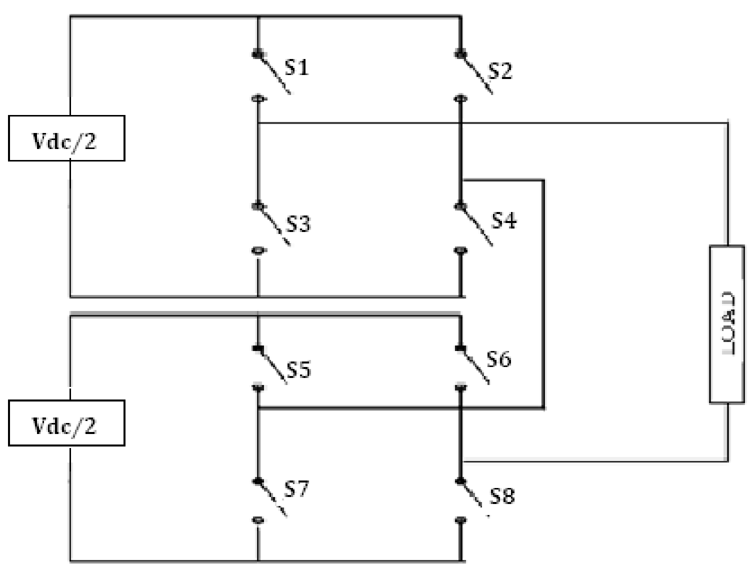

Fig. 3. 5-level cascaded multilevel inverter

3 Modeling of hybrid renewable energy systems

Hybrid energy systems are combinations of two or more energy conversion devices (e.g., electricity generators or storage devices), or two or more fuels for the same device, that when integrated, overcome limitations that may be inherent in either. The following section describes the HRES modeled by conventional inverter with PWM.

3.1 Model for HRES using conventional inverter

The complete simulation model of the HRES is developed using the MATLAB/Simulink environment as depicted in Fig. 4. It consists of three phase conventional inverter (IGBT based Inverter) along with repeating sequence, filter, PV model, Wind, Hydro model and Battery models. The output voltage waveforms of the Conventional Inverter without and with Filter are shown in Fig. 5 and Fig. 6 respectively. The Peak value is 250V. The Fig. 7 shows the FFT analysis for the Conventional Inverter with filter.

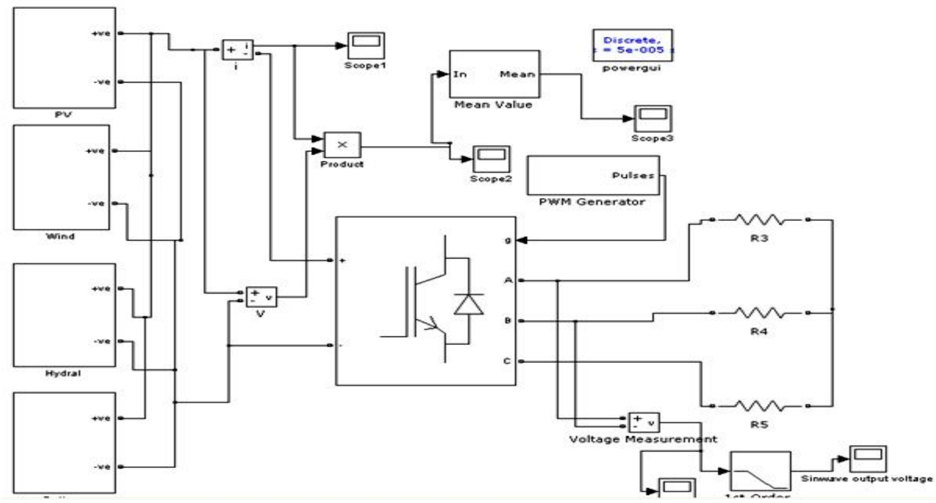

Fig. 4. Matlab/Simulink model of HRES with conventional inverter

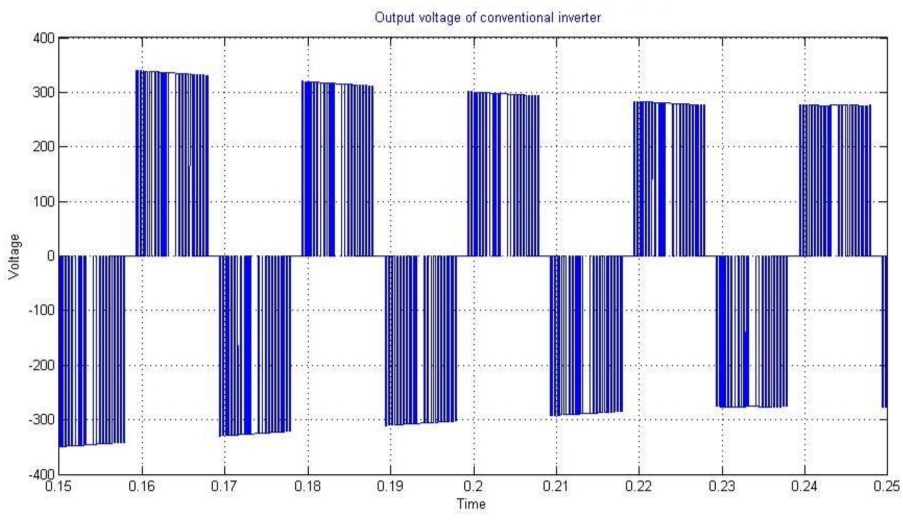

Fig. 5. Output voltage of conventional inverter without filter

3.2 Model for HRES using multilevel inverter

The simulation model allows studies such as:

- Renewable energy sources electrical parameters (powers, voltages, currents, etc.); renewable energy sources constructive parameters (blades length and number of wind turbine, PV panels number and dimensions, number of hydroelectric turbines, batteries number, etc.);
- Voltage and frequency control (control algorithms);

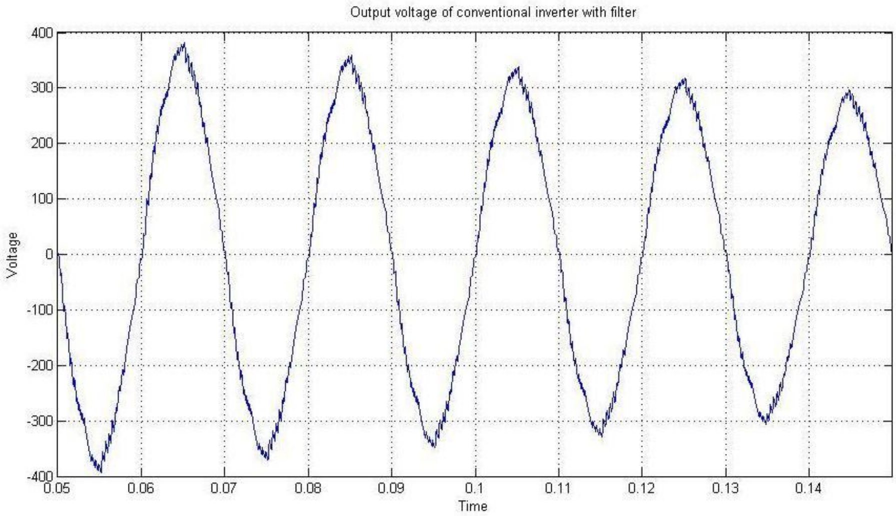

Fig. 6. PWM output of conventional inverter with filter

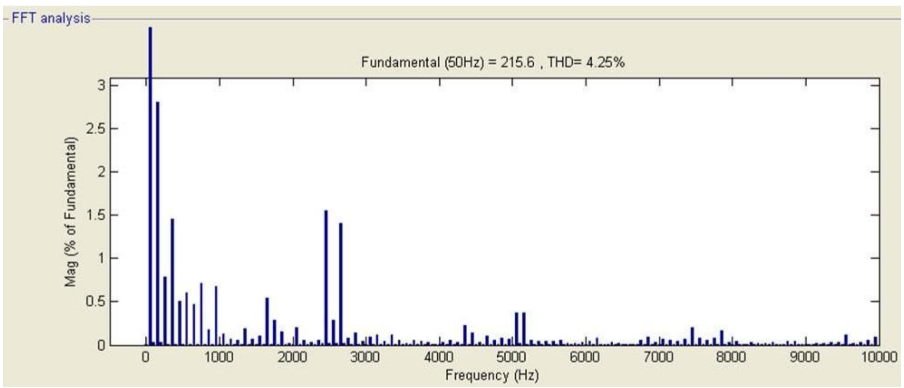

Fig. 7. FFT analysis of conventional inverter output with filter

- Electrical energy conversion (type of DC/AC conversion methods);
- Consumer modeling and control;
- Power quality distortion phenomena and analysis renewable energy availability.

Fig. 8 shows the Simulink model of HRES using multilevel inverter. The subsystem for one phase is shown in Fig. 9. The simulation results are provided by a hybrid system with installed PV power of 1kW, wind power of 1kW and a hydroelectric turbine of 1kW. It has to be mentioned that the output voltage of hybrid power system generators is 12V and the consumer uses 60% of the available power. The rest is being used for battery charging. It can be also notified the presence of harmonics caused by consumer but also by the power electronics from electric energy conversion modules. If necessary, on AC side, the power quality can be raised up by using power active filtering devices. The output phase voltage waveforms of the Multilevel Inverter without and with filter are shown in Fig. 10 & Fig. 11 respectively. The Peak value is around 240V. The Fig. 12 shows THD and the FFT analysis. Its peak magnitude is 251.1 with 50Hz.THD value is 0.38% and dominant harmonic is 13th harmonic. The output line voltages of the Multilevel Inverter without and with filter are shown in Fig. 13 and Fig. 14 respectively. The Peak value is around 415V. Tab. 2 gives the comparison of HRES system comprising the conventional inverter and multilevel inverter.

Table 2. Comparisons of result

Converter	Fundamental with 50Hz	THD (%)	Dominant Harmonic
HRES with conventional inverter	215.6	4.25	3^{rd}
HRES with multilevel inverter	251.1	0.38	13^{th}

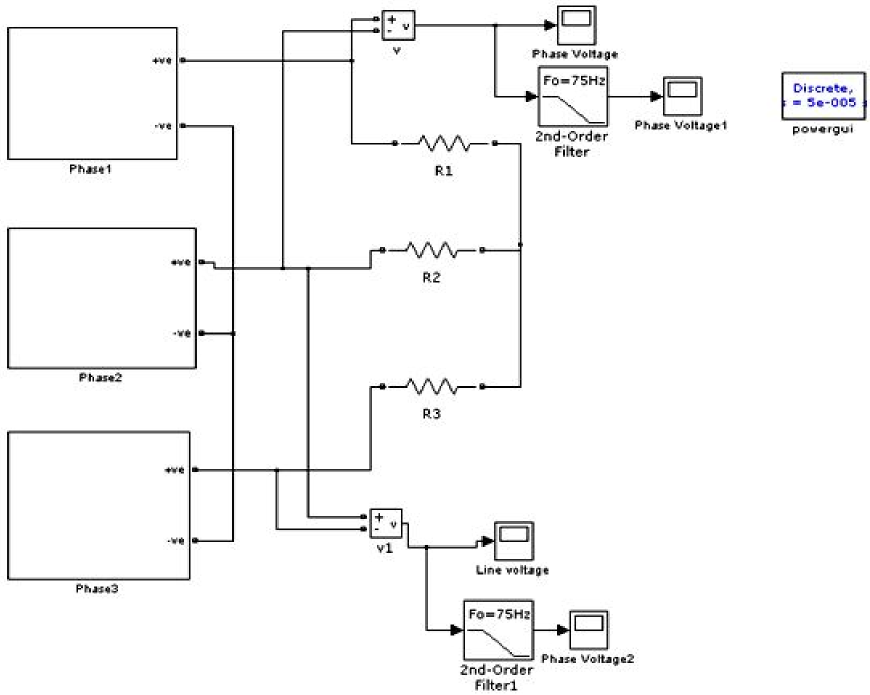

Fig. 8. Matlab/Simulink model for HRES using multilevel inverter

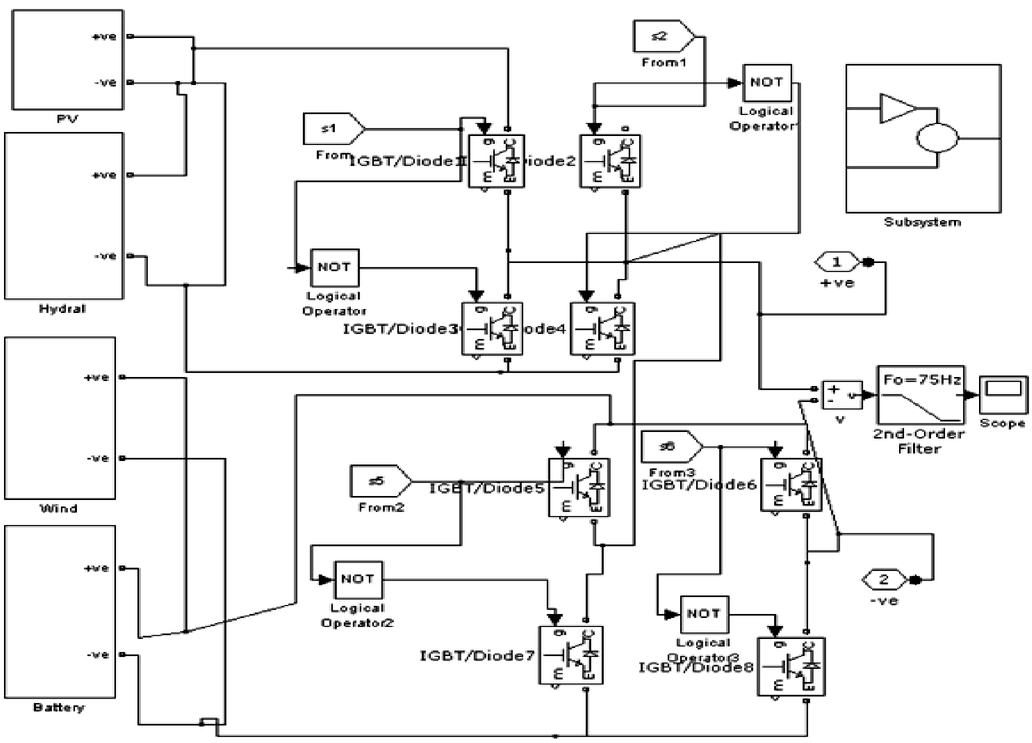

Fig. 9. Simulink model for phase 1 HRES

4 Conclusions

Multi level cascaded H bridge inverter with phase shifted PWM have been simulated using Matlab/Simulink. CHB multilevel inverter can be easily interfaced with renewable energy sources (PV, Wind, hydal). Phase shifted PWM CHB multilevel inverter to produce higher voltage level. As number of level increases, the THD content approaches to small value as expected. Thus it eliminates the need for filter. Though, THD decreases with increase in number of levels, some lower or higher harmonic contents remain dominant

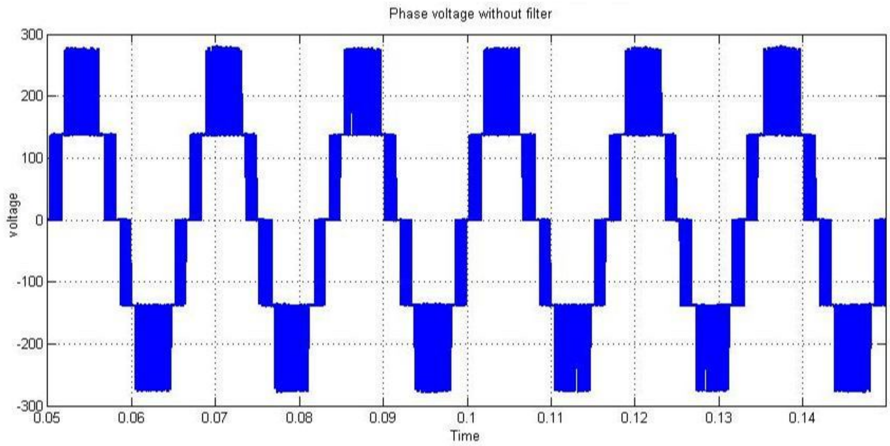

Fig. 10. Output phase voltage of multilevel inverter without filter

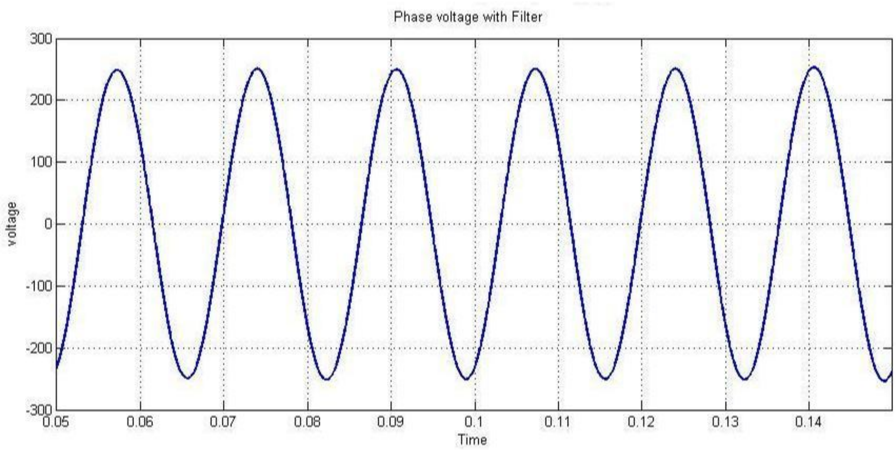

Fig. 11. Output phase voltage of multilevel inverter with filter

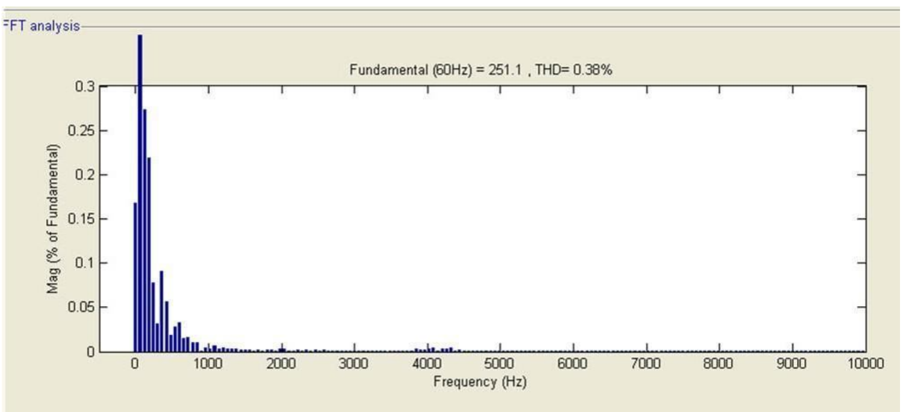

Fig. 12. FFT analyses of multilevel PWM output with filter

in each level. With the conventional inverter for the same filter THD is 4.25 % with multilevel inverter the THD value is reduced to 0.38% for the same filter used in conventional Inverter. Small variation in THD and percentage of harmonics experienced during the change in PWM techniques.

References

[1] J. Chavarria, D. Biel, et al. Energy-balance control of pv cascaded multilevel grid-connected inverters under level-shifted and phase-shifted pwms. *Industrial Electronics IEEE Transactions*, 2012, **60**: 98–111.

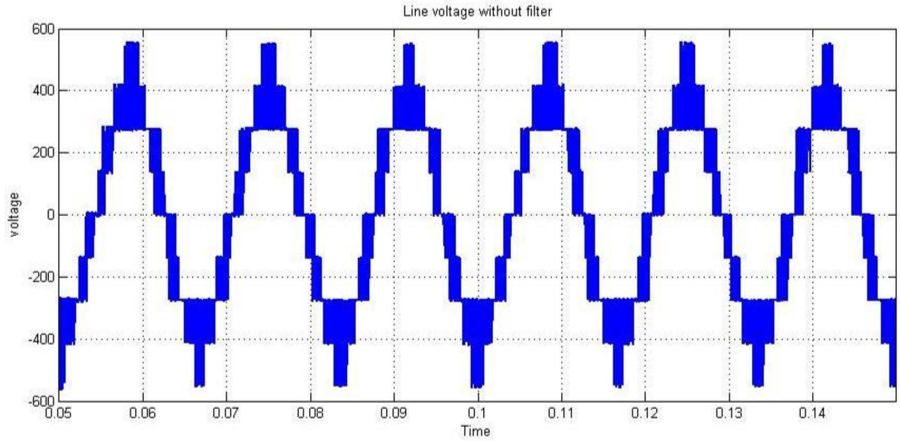

Fig. 13. Output line voltage of multilevel inverter without filter

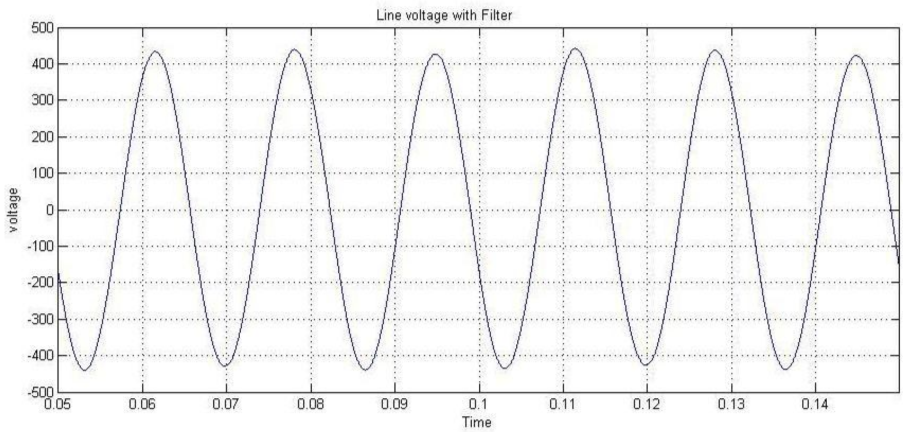

Fig. 14. Output line voltage of multilevel inverter with filter

[2] M. Chithra, S. Dasan. Analysis of cascaded h bridge multilevel inverters with photovoltaic array. **in:** *Emerging Trends in Electrical and Computer Technology (ICETECT)*, 2011, 442–447.
[3] A. Etxeberria, I. Vechiu, et al. Hybrid energy storage systems for renewable energy sources integration in microgrids. **in:** *IPEC 2010 conference*, 2010, 532–537.
[4] F. Gurin, D. Lefebvre, et al. Hybrid modeling for performance evaluation of multisource renewable energy systems. *IEEE Transactions on Automation Science and Engineering*, 2011, **8**(3).
[5] D. Lal, B. Dash, et al. Optimization of pv/wind/micro-hydro/diesel hybrid power system in homer for the study area. *International Journal on Electrical Engineering and Informatics*, 2011, **3**(3).
[6] M. Nehrir, C. Wang, et al. A review of hybrid renewable/alternative energy systems for electric power generation: Configurations, control, and applications. *IEEE Transactions on Sustainable Energy*, 2011, **2**(4).
[7] J. Razak, K. Sopian, et al. Optimization of pv-wind-hydro-diesel hybrid system by minimizing excess capacity. *European Journal of Scientific Research*, 2009, **25**(4): 663–671.
[8] N. Sujitha, K. Ramani. A new hybrid cascaded H-Bridge multilevel inverter Performance analysis. **in:** *Advances in Engineering, Science and Management (ICAESM)*, 2012, 46–50.
[9] U. Sureshkumar, P. Manoharan, et al. International conference on Advances in Engineering, science and Management (ICAESM). **in:** *Economic cost analysis of hybrid renewable energy system using HOMER*, 2012, 94–99.
[10] D. Fares, S. Karaki, et al. Design and simulation of a hybrid renewable energy system. **in:** *Power and Energy Conference at Illinois (PECI)*, 2011, 1–7.