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A Hybrid Solar - Wind Energy System with Battery Storage using a New Configuration of Control Strategy with Three Level NPC Inverter

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Abstract: In this paper a novel configuration of a three level neutral point- clamped (NPC) inverter that can integrate solar photovoltaic (PV),Wind with battery storage in a grid connected system is proposed. The strength of the proposed topology lies in a novel extended unbalance three level vector modulation technique that can generate the correct ac voltage under unbalanced dc voltage conditions. A new control algorithm for the proposed system is also presented in order to control the power delivery between the solar PV, Wind and battery and grid which simultaneously provides maximum power point tracking (MPPT) operation for the solar PV. This configuration allows the two or more sources to supply the load separately or simultaneously depending on the availability of the energy sources An overall power management strategy is designed for the proposed system to manage power flows among the different energy sources and the storage unit in the system. A simulation model for the hybrid energy system has been developed using MATLAB/SIMULINK. The energy system performances under different scenarios, including battery charging and discharging with different levels of solar irradiation has been verified by carrying out simulation studies.

Keywords: MPPT, Solar PV, MPC, Energy Systems.

I. INTRODUCTION

Due to world energy crisis and environmental problems caused by conventional power generation, renewable energy sources such as Photovoltaic (PV) and wind generation systems are becoming more promising alternatives to replace conventional generation units for electricity generation [1-5]. With increasing concern of global warming and the depletion of fossil fuel reserves, many are looking at sustainable energy solutions to preserve the earth for the future generations [5-8]. Other than hydro power, wind and photovoltaic energy holds the most potential to meet our energy demands. Alone, wind energy is capable of supplying large amounts of power but its presence is highly unpredictable as it can be here one moment and gone in another. Similarly, solar energy is present throughout the day but the solar irradiation levels vary due to sun intensity and unpredictable shadows cast by clouds, birds, trees, etc. The common inherent drawback of wind and photovoltaic systems are their intermittent natures that make them unreliable. Advanced power electronic systems are needed to utilize and develop renewable energy sources. In solar PV or wind energy applications, utilizing maximum power from the source is one of the most important functions of the power electronic systems [9,10]. In three-phase applications, two types of power electronic configurations are commonly used to transfer power from the renewable energy resource to the grid: single-stage and double-stage conversion. In the double-stage conversion for a PV system, the first stage is usually a dc/dc converter and the second stage is a dc/ac inverter.

The function of the dc/dc converter is to facilitate the maximum power point tracking (MPPT) of the PV array and to produce the appropriate dc voltage for the dc/ac inverter. The current norm of the industry for high power applications is a three-phase, single stage PV energy systems by using a voltage-source converter (VSC) for power conversion. One of the major concerns of solar and wind energy systems is their unpredictable and fluctuating nature. Grid-connected renewable energy systems accompanied by battery energy storage can overcome this concern. This also can increase the flexibility of power system control and raise the overall availability of the system. Usually, a converter is required to control the charging and discharging of the battery storage system and another converter is required for dc/ac power conversion; thus, a three phase PV system connected to battery storage will require two converters. However, by combining these two intermittent sources and by incorporating maximum power point tracking (MPPT) algorithms, the system's power transfer efficiency and reliability can be improved significantly. The integration of renewable energy sources and energy-storage systems has been one of the new trends in power-electronic technology as shown in Fig.1.

This work is concerned with the design and study of a grid-connected three-phase solar PV system and wind integrated with battery storage using only one three-level converter having the capability of MPPT and ac-side current control, and also the ability of controlling the battery charging and discharging. This will result in lower cost, better efficiency and increased flexibility of power flow control. In this paper, a stand-alone hybrid alternative energy system consisting of wind, PV, and battery is proposed. Wind and PV are the primary power sources of the system to take full advantage of renewable energy, and the battery combination is used as a backup and a long-term storage system. The different energy/storage sources in the proposed system are integrated through an ac link bus. The details of the system configuration, system unit-sizing, and the characteristics of the major system components are also discussed in the paper as shown in Fig.2. An overall power management strategy is designed for the system to coordinate the power flows among the different energy sources. Simulation studies have been carried out to verify the system performance under different scenarios using practical load profile and real weather data.

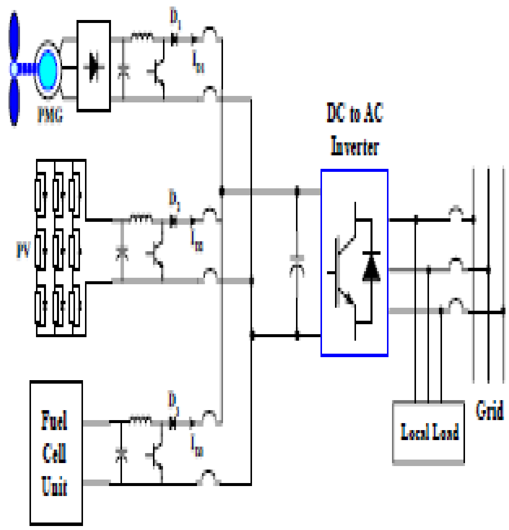


Fig.1. Configuration of Hybrid System.

II. ANALYSIS OF THREE LEVEL NPC INVERETR

The power electronics device which converts D power to AC powerat required output voltage and frequency level is known as an inverter. Two categoriesinto which inverters can be broadly classified are two level invert ers and multilevelinverters. One advantage that multilevel inverters have compared to two level inverters isminimum harmonic distortion. A multilevel inverter can be utiliz ed for multipurpose applications, such as an active power filter, a static VAR compensator and machine drive for sinusoidal and trapezoidal current applications. Some drawbacks to the multilevel inverters are the need for isolated power supplies for each one of the stages, the fact that they are a lot harder to build, they are more expensive and they are more difficult to control in software Full analysis for the three level inverter is given. Desirable voltage and frequency have been achieved however; harmonics distortion should be investigated during three-level inverter operation. Three level inverter NPC inverter is shown in Fig. 3. Each leg contains four active switches S_1 to S_4 with anti paralll diodes D_1 to D_4. The capacitors at the DC side are used to split the DC input into two, to provide a neutralpoint Z. The clamping diodes can be defined as the diodes connected to the neutral point,D_{Z1}, D_{Z2}. When switches S_2 and S_3 are connected, the output terminal A can be taken tothe neutral through one of the clamping diodes. The voltage applied to each of t he DCcapacitors is E, and it equals half of the total DC vol tage V_d.

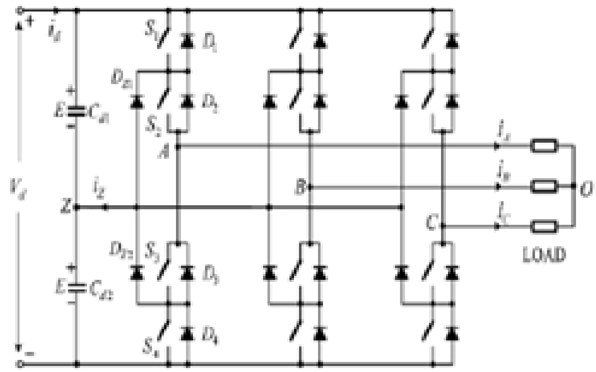


Fig.2. Switching model.

TABLE I: Switching States

Switching State	Device Switching Status (Phase A)				Inverter Terminal Voltage V_{AZ}
	S1	S2	S3	S4	
2	On	On	Off	Off	E
1	Off	On	On	Off	0
0	Off	Off	On	On	-E

III. MAXIMUM POWER POINT ALGORITHM

As was previously explained, MPPT algorithms are necessary in PV applications because the MPP of a solar panel varies with the irradiation and temperature, so the use of MPPT algorithms is required in order to obtain the maximum power from a solar array. Over the past decades many methods to find the MPP have been developed and published. These techniques differ in many aspects such as required sensors, complexity, cost, range of effectiveness, convergence speed, correct tracking when irradiation and/or temperature change, hardware needed for the implementation or popularity, among others. A complete review of 19 different MPPT algorithms can be found in [8]. Among these techniques, the P&O and the In Cond algorithms are the most common. These techniques have the advantage of an easy implementation but they also have drawbacks, as will be shown later. Other techniques based on different principles are fuzzy logic control, neural network, fractional open circuit voltage or short circuit current, current sweep, etc. Most of these methods yield a local maximum and some, like the fractional open circuit voltage or short circuit current, give an approximated MPP, not the exact one. In normal conditions the V-P curve has only one maximum, so it is not a problem. However, if the PV array is partially shaded, there are multiple maxima in these curves. In order to relieve this problem, some algorithms have been implemented as in [14]. In the next section the most popular MPPT techniques are discussed.

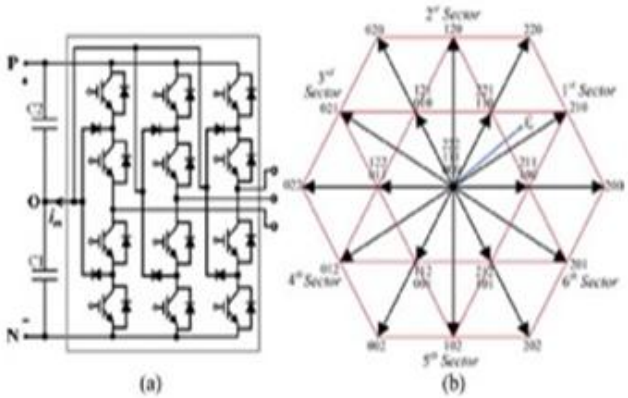
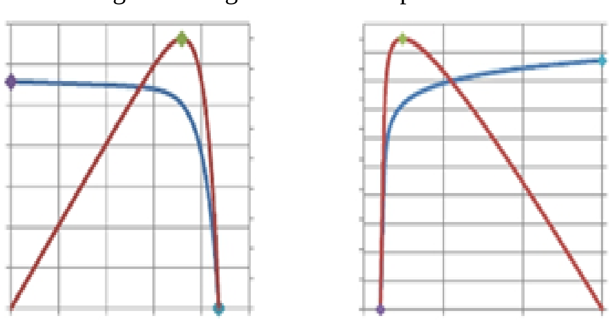


Fig.3. Three level inverter circuit and its SPVWM diagram.

III. PERTURB AND OBSORB METHOD

The P&O algorithms are exercised by imposing periodic, incremental or decremental, perturbations on the PV generator terminal voltage and then comparing the resulting power output with its value in the last perturbation cycle. If the changes in the power and voltage are of the same polarity, that is, if , dPv/dVp > 0 then the MPPT schemes continues to change the voltage in the same direction as that in the last cycle; otherwise, for the next cycle, the voltage is changed in the opposite direction. Fig. 5 illustrates a flowchart of the basic P&O algorithm.δV denotes the voltage increment step which determines the algorithm tracking speed and accuracy A common problem associated with the P&O algorithms is that the exact MPP can never be reached and settled at. Thus, the power exhibits periodic oscillations around its maximum value. Although mainly the case under constant or slowly-varying atmospheric conditions this phenomenon happens also under rapidly changing atmospheric conditions [4]. Many different P&O algorithms are introduced in the literature. They all require measurement of both V_{pv} and I_{pv}. In this method, the sign of the last perturbation and the sign of the last increment in the power are used to decide what the next perturbation should be. As can be seen in Fig.4, on the left of the MPP incrementing the voltage increases the power whereas on the right decrementing the voltage increases the power.



[a] voltage [b] current

Fig.4. Voltage and Current plots.

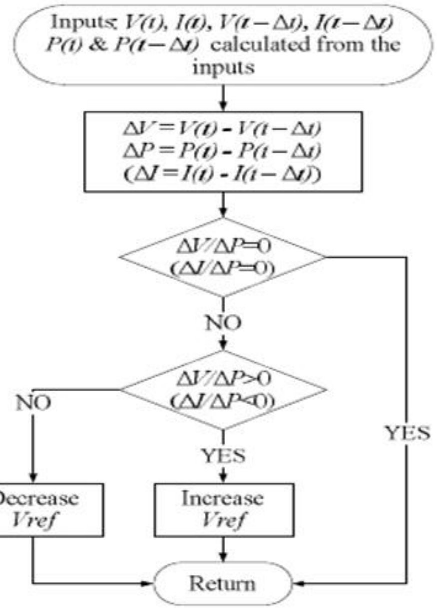


Fig.5. Flow chart for the P&O method.

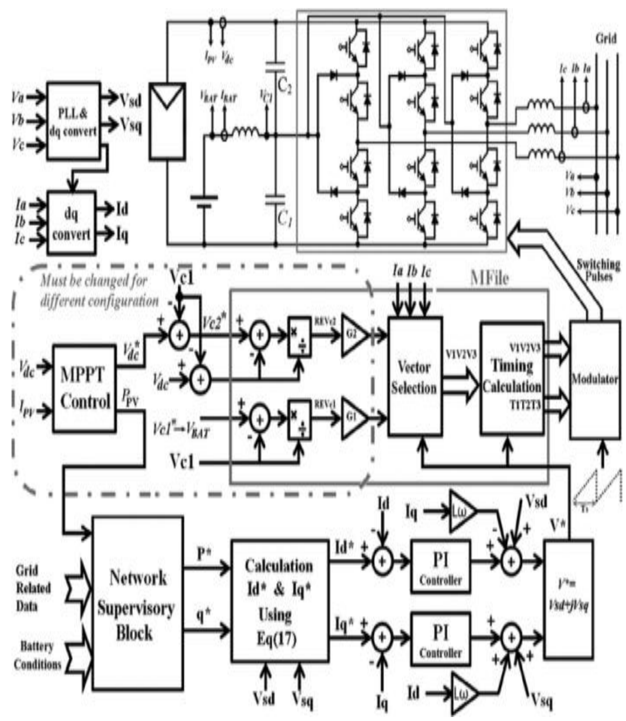


Fig.6. Simulation circuits for controlling the proposed mode.

IV. PROPOSED MODEL

Based on the discussions in SectionsII and III, new configurations of a three- level inverter to integrate battery storage a solar pv and wind are proposed. Where no extra converter is required to connect the battery storage to the grid connected PV and Wind systems as shown in Fig.6. These can reduce the cost and improve the overall efficiency of the whole system particularly for medium and high power applications. Fig8 for representing the six sectors in the hexagon.

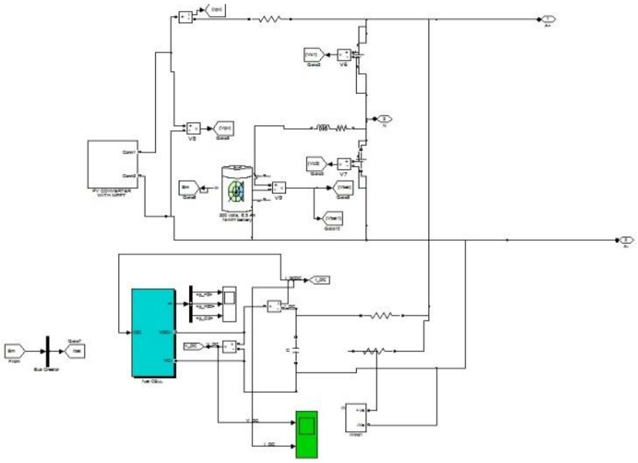


Fig.7. Control system diagram to integrate solar, wind and Battery systems.

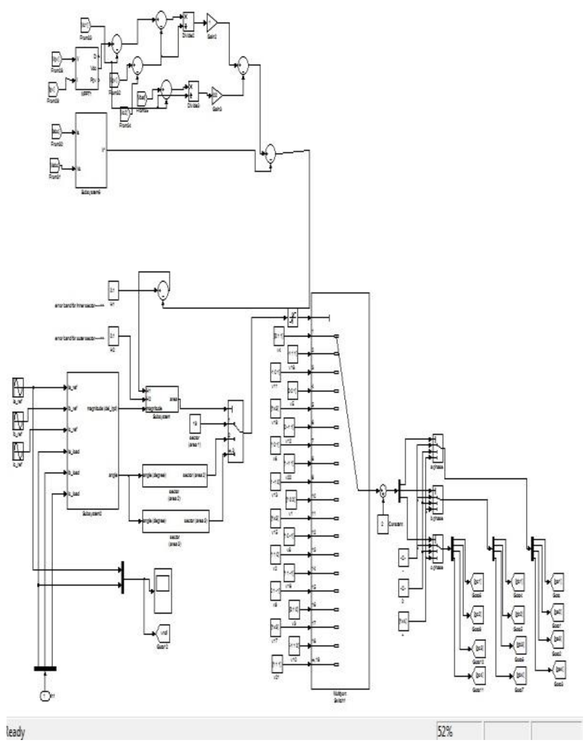


Fig.8. Simulation circuit for controlling of proposed system.

V. CONTROL TOPOLOGY SPACE VECTOR MODULATION TECHNIQUE

SVPWM generates the appropriate gate drive waveform for each PWM cycle. The inverter is treated as one single unit and can combine different switching states (number of switching states depends on levels). The SVPWM provides unique switching time calculations for each of these states [6]. This technique can easily be changed to higher levels and works with all kinds of multilevel inverters (cascaded, capacitor clamped, diode clamped). The three vectors that form one triangle will provide duty cycle time for each, giving the desired voltage vector (Vref). This can be described with the formula: V = $T_1 V_1 T_2 V_2 T_3 V_3 /T_c$ calculations for each of these states [6]. This technique can easily be changed to higher levels and works with all kinds of multilevel inverters (cascaded, capacitor clamped, diode clamped). The three vectors that form one triangle will provide duty cycle time for each, giving the desired voltage vector (Vref). This can be described with the formula: V = $T_1 V_1 T_2 V_2 T_3 V_3 /T_c$. SVPWM also have good utilization of the DC link voltage, low current ripple and relative easy hardware implementation. Compared to the SPWM, the SVPWM has a 15% higher utilization ratio of the voltage. This features makes it suitable for high voltage high power applications, such as renewable power generation. As the number of level increase the redundant switching states increases and also the complexity of selection of the switching states. So, deciding which level is right for a certain application it is important to find a balance between losses and specification of the positioning of the reference vector. The space vector diagram for a three-level SVM. There are:

- six long vectors (200, 220, 020, 022, 002, and 202);
- six medium vectors (210, 120, 021, 012, 102, and 201);
- twelve short vectors (100-211, 110-221, 010-121, 011-122,001-112, and 101-212); and
- three zero vectors (222, 111, 000).

Long vectors and zero vectors do not affect voltage balance because no NP current flows. Medium vectors are uncontrolled vectors that cause voltage imbalance and the redundant short vectors are utilized to balance the capacitor voltages. However, when there is no external dc-link supply, capacitor voltage ripple is unavoidable.

Volt sec along α axis

$$V_1 T_1 + V_2 \cos 60^0 T_2 = V_S T_S \cos\alpha \tag{1}$$

Finding out average value in SECTOR 1:

$$V_{AO\ avg} = \frac{\frac{Vdc}{2}}{Ts}(T_1 + T_2) = V_S/\sqrt{3}\ [\sin(60+\alpha)] \tag{2}$$

$$V_{BO\ avg} = \frac{\frac{Vdc}{2}}{Ts}(-T_1 + T_2) = V_S/\sqrt{3}\ [\sin(\alpha - 30^0)] \tag{3}$$

$$\text{Vref} = V\alpha + V\beta = 2/3\ (Va + aVb + a2\ V_c) \tag{4}$$

$$V\alpha = 3/2\ VA \tag{5}$$

$$V\beta = \frac{\sqrt{3}}{2}(VB - VC) \tag{6}$$

A. Controlling Method

The requested active and reactive power generation by the inverter to be transferred to the grid will be determined by the network supervisory block. This will be achieved based on the available PV generation, the grid data, and the current battery variables. The MPPT block determines the requested dc voltage across the PV to achieve the MPPT condition. This voltage can be determined by using another control loop, with slower dynamics, using the measurement of the available PV power. The details of the MPPT algorithm to determine the desired voltage ($V_d{*}_c$) can be found in [3] and [4]. Based on the requested active (p^{**}) and reactive power (q^{**}), and the grid voltage in the dq-axis, $v_{s\,d}$ and $v_{s\,q}$, the requested inverter current in the dq-axis, i_d and i_q can be obtained using (17):

$$p = v_{s\,d}\, i_d + v_{s\,q}\, i_q \tag{7}$$

$$q = v_{s\,q}\, i_d + v_{s\,d}\, i_q \tag{8}$$

By using a proportional and integral (PI) controller and de-coupling control structure, the inverter requested voltage vector can be calculated. The proposed control system is shown in Fig. 7. In the proposed system, to transfer a specified amount of power to the grid, the battery will be charged using surplus energy from the PV or will be discharged to support the PV when the available energy cannot support the requested power. After evaluating the requested reference voltage vector, the appropriate sector in the vector diagram can be determined. To determine which short vectors are to be selected, the relative errors of capacitor voltages are used. Based on the control system diagram given in Fig. 7, on the ac side, the requested active power, p^*, and reactive power, q*, will be generated by the inverter by implementing the re-quested voltage vector and applying the proper timing of the applied vectors. Further, on the dc side, MPPT control can be achieved by strict control of $V_{C\,2}$ (G_2 _ G_1) with reference value of ($V_d{*}_c - V_{C\,1}$) and more flexible control of $V_{C\,1}$ with reference value of the battery voltage, $V_{B\,AT}$. By using the decision function (F) with the given reference values, the proper short vectors to be applied to implement the requested vector can be determined. With MPPT control, the PV arrays can transfer the maximum available power ($P_{P\,V}$), and with generating the requested vector in the ac side, the requested power P* is transferred to the grid. Then, the control system will automatically control $V_{C\,1}$ to transfer excess power ($P_{P\,V} - P^*$) to the battery storage or absorb the power deficit ($P^* - P_{P\,V}$) from the battery stora.

VI. SIMULATION RESULTS

Simulation results pertaining to the proposed model are presented in this section as shown in Fig.9 through Fig.14.

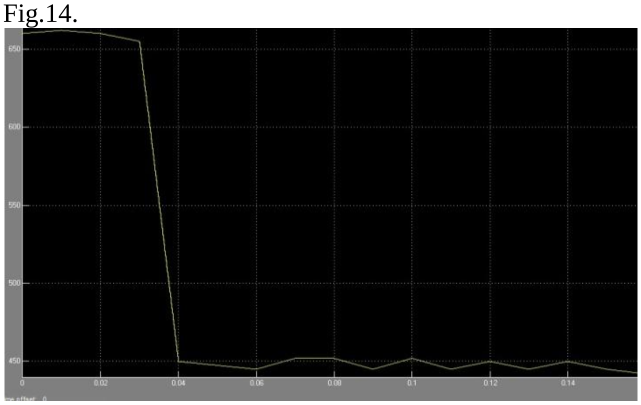


Fig.9. Active power injected to the grid.

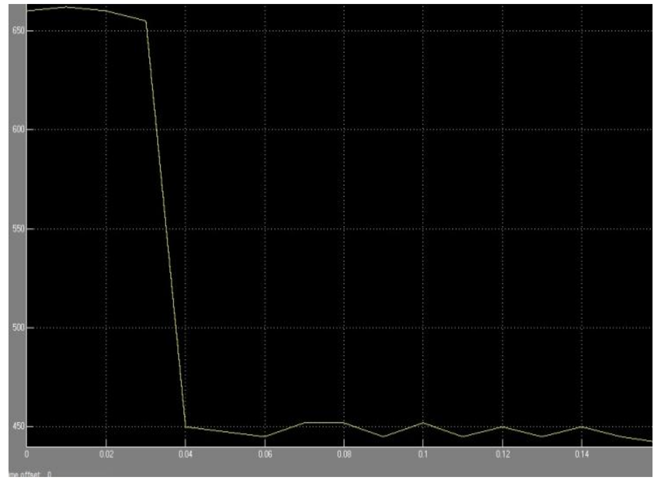


Fig.10. Reactive power injected to the grid.

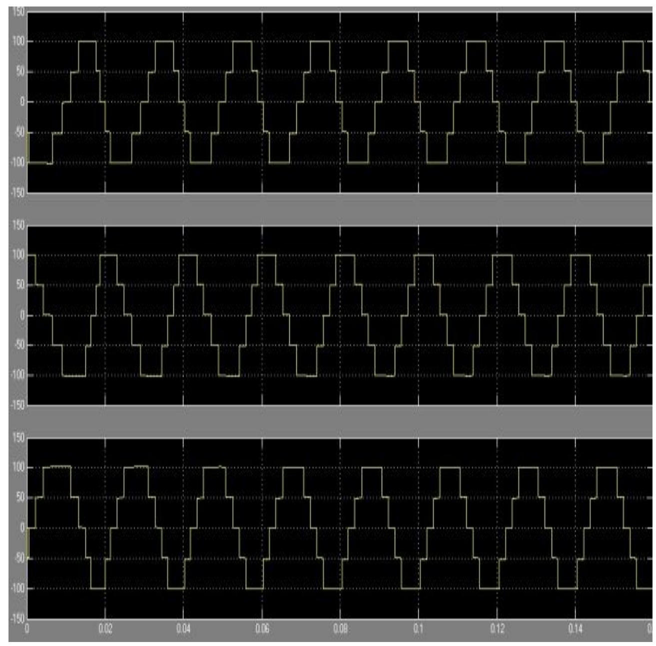


Fig.11. Phase to Phase Inverter voltages.

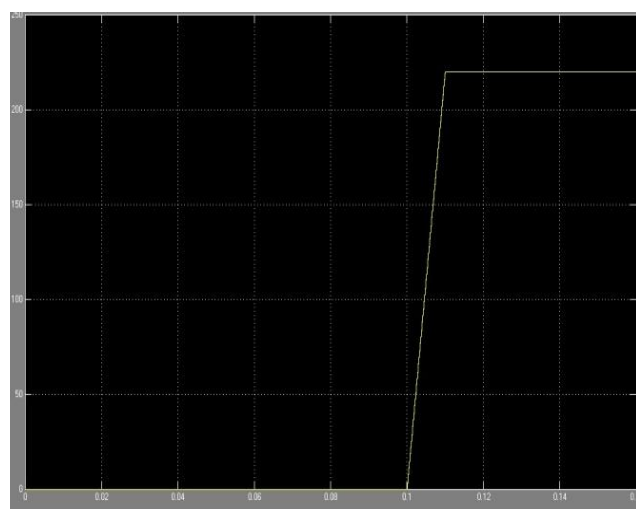


Fig.12. PV module DC voltage.

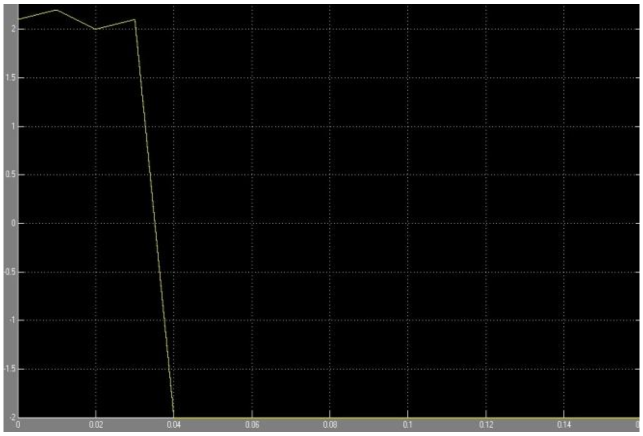


Fig.13. Battery current.

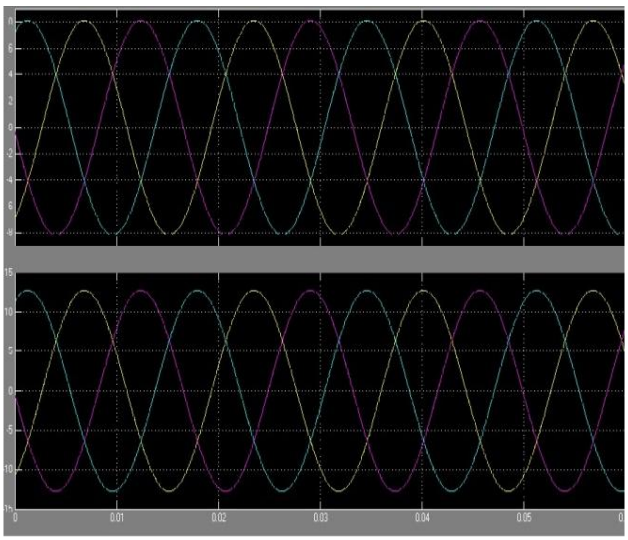


Fig.14. Grid current and voltages.

VII. CONCLUSION

A novel topology for a three-level NPC voltage source inverter that can integrate both renewable energy and battery storage on the dc side of the inverter has been presented. A theoretical framework of a novel extended unbalance three-level vector modulation technique that can generate the correct ac voltage under unbalanced dc voltage conditions has been proposed. A new control algorithm for the proposed system has also been presented in order to control power flow between solar PV, battery, and grid system, while MPPT operation for the solar PV is achieved simultaneously. The effectiveness of the proposed topology and control algorithm was tested using simulations and results are presented. The results demonstrate that the proposed system is able to control ac-side current, and battery charging and discharging currents at different levels of solar irradiation.

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