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MODELLING AND SIMULATION OF THREE LEVEL NPC INVERTER FOR SOLAR PHOTOVOLTAIC AND BATTERY STORAGE BASED GRID INTEGRATION SYSTEM

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Abstract: In this paper a novel configuration of a three-level neutral-point-clamped (NPC) inverter that be capable of integrate solar photovoltaic (PV) amid battery storage in a grid-connected system is anticipated. The strong point of the anticipated topology lies in a novel, extended unbalance three-level vector modulation modes operation of amid the purpose of can generate the accurate ac voltage under unbalanced dc voltage conditions. This dissertation presents the propose philosophy of the anticipated configuration and the notional construction of the anticipated modulation modes operation. A new control algorithm for the anticipated system is also obtainable in order to control the power delivery between the solar PV, battery, and grid, which concurrently provides maximum power point tracking (MPPT) function for the solar PV. This paper is concerned with the design and study of a grid-connected three-phase solar PV system 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.

I. INTRODUCTION

In the past, centralized power generation was promoted. The power generation units were generally built away from the populated areas but close to the sites where the fuel (i.e., fossil fuel) was available. This kept the transportation cost (of the fuel) to a minimum and eliminated the possibility of pollution in populated areas. Such schemes remained quite popular until recently despite drawbacks such as Ohmic (i2R) losses (due to transmission of electricity through cables over long distances), voltage regulation problems, power quality issues, and expansion limitations. With the power demand increasing consistently, a stage has come when these centralized power generation units can be stressed no further. As a result, the focus has shifted to generation (and consumption) of electric power “locally” leading to “distributed power generation systems” (DGS) [1]. At the same time, increased awareness about the importance of a clean environment and the quickly vanishing fossil fuels have given impetus to the idea of local power generation using nonconventional energy (NCE) sources (e.g., photovoltaic (PV) cells, fuel cells (FC), wind energy, etc.), which may suit a particular region and provide power at various load centers along the main power grid. Most of these sources are pollution-free and abundant. Unfortunately, they are not so reliable. For example, the PV source is not available during the nights or during cloudy conditions. Wind energy may or may not be available. Other sources, such as fuel cells may be more reliable, but have monetary issues associated with them. Because of this, two or more NCE sources are required to ensure a reliable and cost-effective power solution. Such integration of different types of energy sources into a DG system is called a hybrid distributed generation system (HDGS) [4]. Due to the 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]. 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. 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 function of the inverter is to generate three-phase sinusoidal voltages or currents to transfer the power to the grid in a grid-connected solar PV system or to the load in a stand-alone system. In the single-stage connection, only one converter is needed to fulfil the double-stage functions, and hence the system will have a lower cost and higher efficiency, however, a more complex control method will be required. 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 [4]. 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 [2]. 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. This project is concerned with the design and study of a grid-connected three-phase solar PV system 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. Various multilevel topologies are available, including the neutral point clamped (NPC), flying capacitor clamped and cascaded H-bridge circuits. A diode-clamped NPC three-level converter is investigated here. Active NPC (ANPC) multilevel converters, have advantages including the ability to balance losses between power devices. However, they have greater complexity, requiring six switches per phase for a three-level converter and the diode-clamped variant is therefore considered in this project.

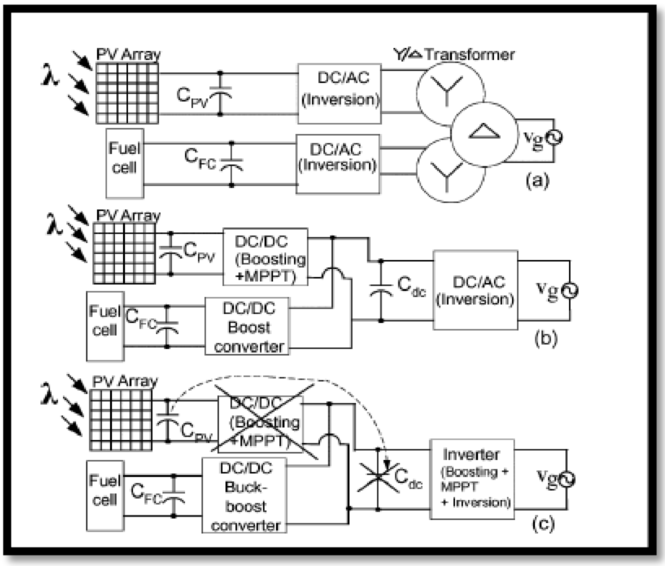


Fig 1.1- hybrid system of pv-fc

In solar PV application, utilization of maximum power from the source is the most important function of the power electronic system. The type of electronic configuration used here are- single stage conversion, consists of DC-DC converter which provides Maximum PowerPoint Tracking (MPPT) of the PV array and to produce DC voltage and double stage conversion which generates three-phase sinusoidal voltage or current to transfer the power to a grid. Unpredictable and fluctuating nature of solar energy system can be overcome by integrating solar PV with the battery storage using three level NPC inverter which is connected to the grid. Usually a converter is used for charging and discharging of the battery. Here, we mainly design and study the grid connected three phase solar PV system integrated with the battery storage using three level NPC inverter having the capability of MPPT, AC side current control and ability to control the charging and discharging of battery.

II. SOLAR PV AND BATTERY OPERATING SYSTEM

A. THE PHOTOVOLTAIC ARRAY

A PV array consists of a number of PV modules, mounted in the same plane and electrically connected to give the required electrical output for the application. The PV array can be of any size from a few hundred watts to hundreds of kilowatts, although the larger systems are often divided into several electrically independent sub arrays each feeding into their own power conditioning system.

B. MOUNTING STRUCTURE

The main purpose of the mounting structure is to hold the modules in the required position without undue stress. The structure may also provide a route for the electrical wiring and may be free standing or part of another structure (e.g. a building). At its simplest, the mounting structure is a metal framework, securely fixed into the ground. It must be capable of withstanding appropriate environmental stresses, such as wind loading, for the location. As well as the mechanical issues, the mounting has an influence on the operating temperature of the system, depending on how easily heat can be dissipated by the module.

C. TILT ANGLE AND ORIENTATION

The orientation of the module with respect to the direction of the Sun determines the intensity of the sunlight falling on the module surface. Two main parameters are defined to describe this. The first is the tilt angle, which is the angle between the plane of the module and the horizontal. The second parameter is the azimuth angle, which is the angle between the plane of the module and due south (or sometimes due north depending on the definition used). Correction of the direct normal irradiance to that on any surface can be determined using the cosine of the angle between the normal to the Sun and the module plane.

The optimum array orientation will depend on the latitude of the site, prevailing weather conditions and the loads to be met. It is generally accepted that, for low latitudes, the maximum annual output is obtained when the array tilt angle is roughly equal to the latitude angle and the array faces due south (in the northern hemisphere) or due north (for the southern hemisphere). For higher latitudes, such as those in northern Europe, the maximum output is usually obtained for tilt angles of approximately the latitude angle minus 10–15 degrees.

D. THE PHOTOVOLTAIC SYSTEM

A PV system consists of a number of interconnected components designed to accomplish a desired task, which may be to feed electricity into the main distribution grid, to pump water from a well, to power a small calculator or one of many more possible uses of solar-generated electricity. The design of the system depends on the task it must perform and the location and other site conditions under which it must operate. This section will consider the components of a PV system, variations in design according to the purpose of the system, system sizing and aspects of system operation and maintenance.

E. System design

There are two main system configurations – stand-alone and grid-connected. As its name implies, the stand-alone PV system operates independently of any other power supply and it usually supplies electricity to a dedicated load or loads. It may include a storage facility (e.g. battery bank) to allow electricity to be provided during the night or at times of poor sunlight levels. Stand-alone systems are also often referred to as autonomous systems since their operation is independent of other power sources. By contrast, the grid-connected PV system operates in parallel with the conventional electricity distribution system. It can be used to feed electricity into the grid distribution system or to power loads which can also be fed from the grid. It is also possible to add one or more alternative power supplies (e.g. diesel generator, wind turbine) to the system to meet some of the load requirements. These systems are then known as ‘hybrid’ systems. Hybrid systems can be used in both stand-alone and grid-connected applications but are more common in the former because, provided the power supplies have been chosen to be complementary, they allow reduction of the storage requirement without increased loss of load probability. Figures below illustrate the schematic diagrams of the three main system types.

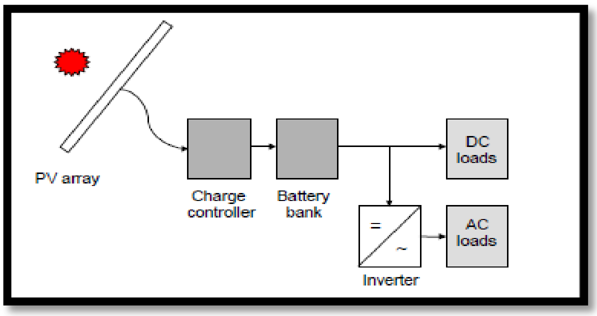


Fig-3.4 Schematic diagram of a stand-alone photovoltaic system

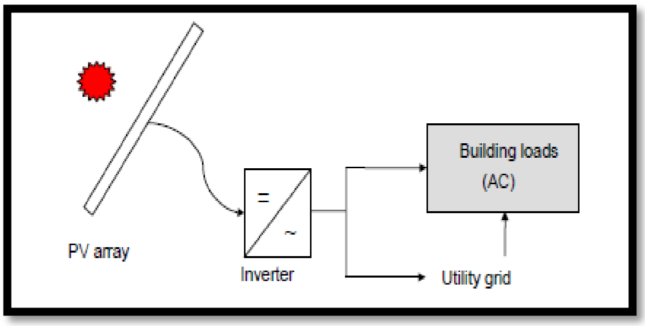


Fig-3.5 Schematic diagram of grid-connected photovoltaic system

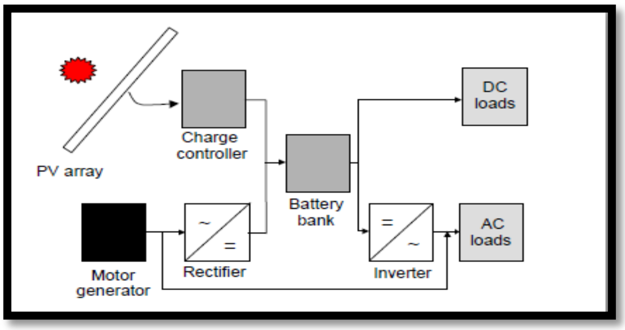


Fig 3.6- Schematic diagram of grid-connected photovoltaic system with motor generator

Fig3.6 shows Schematic diagram of hybrid system incorporating a photovoltaic array and a motor generator (e.g. diesel or wind).

III. STORAGE BATTERIES

A device that stores chemical energy and releases it as electrical energy is called as battery or storage battery. A battery is an electrochemical cell which is often connected in series in electrical devices as a source of direct electric current at a constant voltage. Batteries are classified as follows, I) Primary battery ii) Secondary battery iii) Fuel battery or Flow battery Primary battery is a cell in which the cell reaction is not reversible. Thus, once the chemical reaction takes place to release the electrical energy, the cell gets exhausted. They are use and throw type. Example: Dry cell, Laclanche cell etc. Secondary battery is a cell in which the cell reaction is reversible. They are rechargeable cells. Once the battery gets exhausted, it can be recharged. Example: Nickel-Cadmium cell, Lead-acid cell (storage cell), etc. Flow battery is an electrochemical cell that converts the chemical reaction into electrical energy. When the reactants are exhausted, new chemicals replace them. Example: Hydrogen-oxygen cell, Aluminium-air cell, etc. In Aluminium-air cell, when the cell is exhausted, a new aluminium rod is used and the solution is diluted with more water as the electrochemical reaction involves aluminium and water.

IV. THREE LEVEL NPC INVERTER

A. Introduction to Three Level Inverter (TLI) Technology

This topic describes configuration of three level inverter topology, often referred to as Neutral Point Clamped (NPC) inverter. The three level inverter offers several advantages over the more common two level inverter. As compared to two level inverters, three level inverters have smaller output voltage steps that mitigate motor issues due to long power cables between the inverter and the motor. These issues include surge voltages and rate of voltage rise at the motor terminals and motor shaft bearing currents. In addition, the cleaner output waveform provides an effective switching frequency twice that of the actual switching frequency. Should an output filter be required, the components will be smaller and less costly than for an equivalent rated two level inverter. Most often the NPC inverter is used for higher voltage inverters. Because the IGBTs are only subjected to half of the bus voltage, lower voltage IGBT modules can be used.

B. Basic Circuit Configuration and Its Behaviour

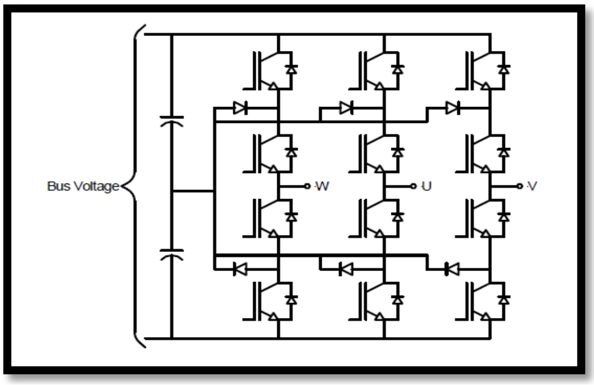


Figure-4.1. NPC Inverter

Figure-4.1 shows the circuit configuration of the NPC inverter. Each leg has four IGBTs connected in series. The applied voltage on the IGBT is one-half that of the conventional two level inverter. The bus voltage is split in two by the connection of equal series connected bus capacitors. Each leg is completed by the addition of two clamp diodes. This topology traditionally has been used for medium voltage drives both in industrial and other applications. In addition to the capability of handling higher voltages, the NPC inverter has several favourable features including lower line-to-line and common-mode voltage steps and lower output current ripple for the same switching frequency as that used in a two level inverter.

4.3 Output Voltage and Switching States

The NPC inverter can produce three voltage levels on the output: the DC bus plus voltage, zero voltage and DC bus negative voltage. The two level inverter can only connect the output to either the plus bus or the negative bus. (Refer to Figure-4.2 for the following example.) For a one phase operation, when IGBTs Q1 and Q2 are turned on, the output is connected to Vp; when Q2 and Q3 are on, the output is connected to V0; and when Q3 and Q4 are on, the output is connected to Vn. Switching states for the four IGBTs are listed in Table 1. Clamp diodes D4 and D5 provide the connection to the neutral point. From the switching states, it can be deduced that IGBTs Q2 and Q3 are on for most of the cycle, resulting in greater conduction loss than Q1 and Q4 but far less switching loss.

In addition, the free wheel diodes for Q2 and Q3 are for most cases, soft switched as the IGBT parallel to the diode is on, thus holding the recovery voltage across the diode to that of the IGBT Vce.

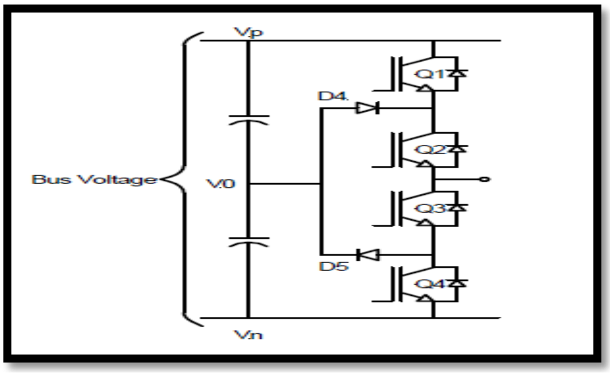
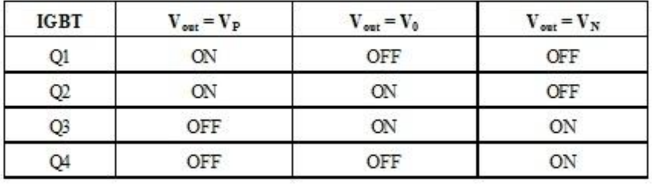


Figure- 4.2 Single Leg



IGBT	$V_{out} = V_P$	$V_{out} = V_0$	$V_{out} = V_N$
Q1	ON	OFF	OFF
Q2	ON	ON	OFF
Q3	OFF	ON	ON
Q4	OFF	OFF	ON

Table-4.1 Switching States

The DC bus capacitors are connected in series and establish V0, the mid-point voltage. Due to available capacitor voltage rating, series connected capacitors are generally required in inverters rated for 480V and 600V service. In NPC inverters, maintaining the voltage balance between the capacitors is important to the proper operation of the NPC topology.

4.4 PROPOSED SYSTEM

The proposed topology is built around a buck-boost inverter topology capable of inversion (dc–ac), boosting and bucking the voltage and MPPT. A combination of PV and FC sources feeds the configuration. While the PV source directly feeds the inverter through a buffer capacitor, CPV, the FC source is interfaced through a buck-boost type dc–dc converter, as shown in the figure. An extra block is added across CPV to divert the excess power generated by the PV source. The proposed system is designed to meet a certain minimum active power demand (Preq) from the grid side. PV is the main source, which is continuously made to track the MPP, while feeding the required amount of power into the grid. The FC source, with buck boost type dc–dc converter, acts as a current source in parallel with the PV source. It is only used to supplement the PV source during low or zero isolation. Thus, FC supplies only the deficit power into the grid. On the other hand, any “excess power” generated by the PV source is conditioned and diverted to an auxiliary application such as electrolysis, to produce hydrogen, which can be stored for later use by the FC source. This results in an optimal utilization of the available sources, rendering a highly economical system [14]. The aforesaid description leads to the following three modes in which the proposed system operates:

1) Mode-I: Only PV mode (only PV provides power).
2) Mode-II: Hybrid mode (both PV and FC provide power).
3) Mode-III: Only FC mode (only FC provides power).

These operating modes are summarized in Table I.

Operating modes of the proposed HDGS system			
Operating Mode	Applicable Condition	Active Source (s)	Active Power Converter (s)
	$P_{ex} = P_{pv}* P_{req} \geq 0$	Only PV	Buck (for $P_{ex} >$ 0)
	$P_{def} = P_{ref} * P_{pv} > 0$	PV and FC	Buck-Boost
	$P_{pv} \approx 0$	Only FC	Buck-Boost

Table 4.2-operating modes of proposed system

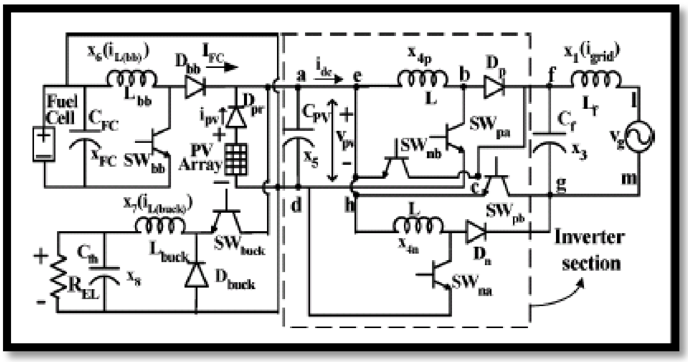


Fig-4.3. Circuit schematic of the proposed integrated configuration for hybrid

Due to its unique hybrid integrated nature, the proposed configuration offers several desirable features as outlined next:

1) It obviates the requirement of a boost converter stage for conditioning the PV power, as shown in fig-4.3.

2) Out of the two capacitors Cdc and CPV, only one is required.

3) Presence of FC in parallel reduces the fluctuations in the PV voltage due to changing environmental conditions. This, in turn, reduces the fluctuations in the power fed into the grid. Consequently, the grid voltage profile improves.

4) Elimination of dips and surges in the PV voltage increases the speed of MPPT.

5) In two-stage systems [4], usually, both PV array and dc capacitor (Cdc) voltages are sensed for MPPT and power control, respectively. In the proposed system, Cdc (or CPV) appears right across the PV terminals due to elimination of the dedicated boost stage on the PV side. Hence, only one sensor is adequate.

6) It eliminates the requirement of extra hardware for communication and coordination between various sources to generate and use the available energy optimally.

7) The special configuration, in which the PV and FC sources are connected, ensures that the FC section works as a current source irrespective of the voltage magnitude at its output.

8) Proposed configuration is a compact, low-cost, and reliable solution for HDG applications.

V. MODELLING AND SIMULATION

NPC control strategy for solar pv-fc hybrid system:-

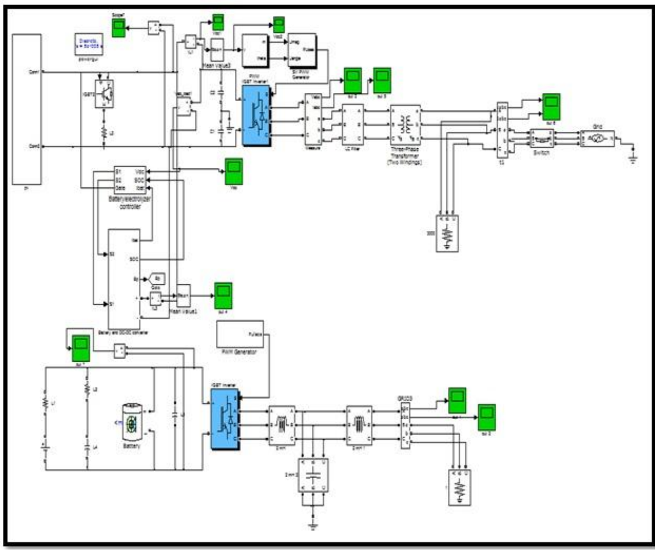


FIG 5.1:-MATLAB model

we have two system photovoltaic and fuel cell in figure in which the three level inverter are connected between the photovoltaic and grid system. Here photovoltaic and fuel cell are connected with hybrid connection. Fuel cell system is one type of battery storage system which will store the excess power genetrated from photovoltaic cell. Here the photovoltaic system are made of many solar cell connected in series or parallel connection. In my matlab model solar radiation was take as input source voltage. Now first photovoltaic generate dc voltage which is measure at the voltage load block.This output dc voltage is given to the dc –dc converter or battery.so the function of dc-dc coverter can convert the constant dc voltage store the voltage.here we use electrolyzer which will compare the sufficient voltage is present or not.Suppose 640 watt power generated then it is compared the dc voltage with subtract battery dc voltage and give us proper voltage for our system.PI controller can compare the value and if power is not sufficient then check for other condition using logical gate.in our system mppt is used for maximum power point track in pv module. Fuel cell also generate dc voltage itself because it is one type of battery.Here electrolyzer take input from battery which are battery current and soc and the dc voltage from the photovoltaic is feed to electrolyzer.so electrolyzer will manipulate the value and give the output which take pulse from IGBT and give output and which is further connected to battery.So it is work as a closed loop and provide 24 hour power to our system. Here generated voltage from fuel cell is fed to IGBT inverter which is in dc form. IGBT can convert the dc voltage to three phase ac voltage. Igbt take a gate signal from pwm generator.After that inductor conncted in series and capacitor are also connected which provide proper operation. Finall we get output ac voltage at scope. In our case one three level inveter are used in which two capacitor are connected in series before IGBT inverter in which neutral point is grounding.so it is called neutral point clamp inverter.This capacitor inject the voltage difference for photovoltaic and fuel cell voltage and give us constant output voltage.Here IGBT inverter take gate pulse from space vector pulse width modulation (svpwm) generator.svpwm take an input from pwm and pwm take voltage as an input and using pwm working give us output as phase angle and magnitude.which are taken as input for svpwm and also take reference frequency as input.svpwm can give a proper gate pulse using selecting proper angle and magnitude and give us constant output and also mitigate harmonics from system.After that we measure the three phase ac voltage at measurement block and using lc filter we remove harmonic and give regulate ac output voltage to grid and r load which are connected at output.here swith are used to turn on and off circuit breaker.

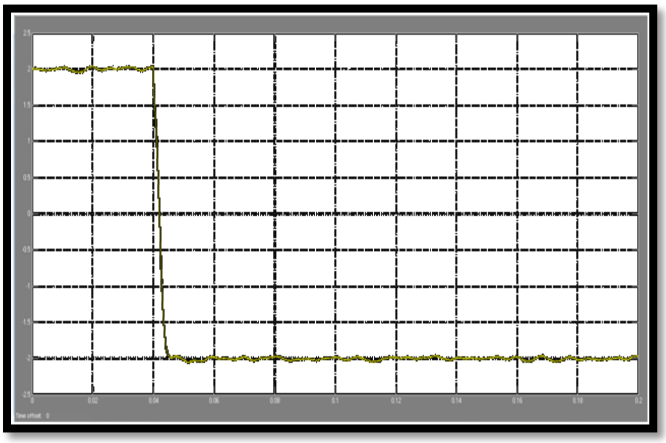


Fig 5.2: current

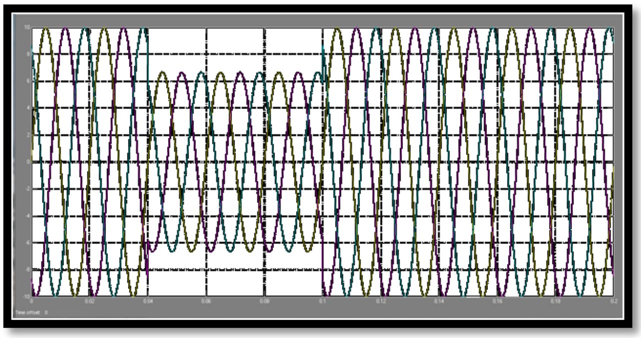


Fig 5.3: grid current

FIG 5.4: dc voltage

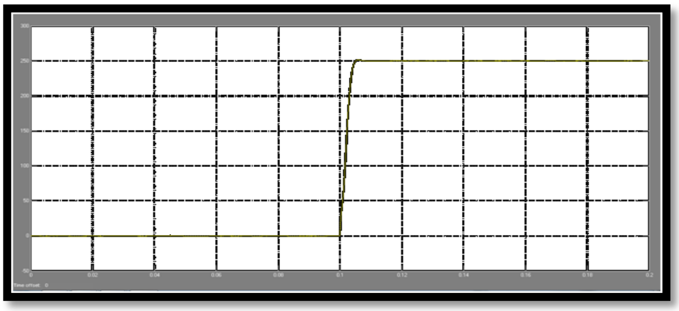


Fig5.5: Reactive Power

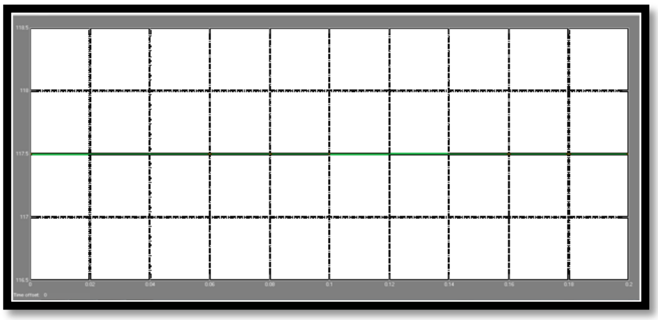


Fig 5.6: voltage

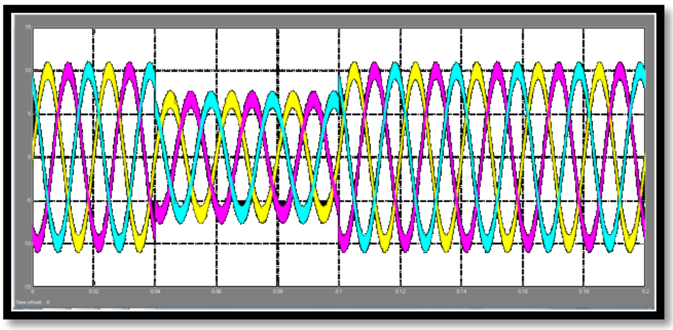


Fig 5.7-grid side Voltage

As shown in the simulation results we can see that using Three level NPC inverter with the solar PV system and fuel cell system with grid integration, the output shows that the three phase output voltage at grid side is constant after the connection of three level NPC inverter with the solar PV and fuel cell based grid integration system. The output current of three phase grid connected system is also becomes stable and pure sinusoidal as shown in the fig above. The power in the grid integration also becomes constant. The value of active and reactive power also comes in constant and stabilize mode after the connection of three level NPC inverter with the Solar PV and battery storage integration system.

VI. 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. The results from experiments using a prototype built in the lab have validated the proposed topology to control both PV and battery storage in supplying power to the ac grid.

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