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SIMULATION OF THREE LEVEL NPC INVERTER FOR SOLAR PHOTOVOLTAIC AND BATTERY STORAGE 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

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 fulfill 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]. 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 paper.

II. SOLAR PV AND BATTERY OPERATING SYSTEM

Solar cell

There are several types of solar cells. However, more than 90 % of the solar cells currently made worldwide consist of wafer-based silicon cells. They are either cut from a single crystal rod or from a block composed of many crystals and are correspondingly called mono-crystalline or multi-crystalline silicon solar cells. However, they indicate lower efficiencies than wafer-based silicon solar cells, which mean that more exposure surface and material for the installation is required for a similar performance. A number of solar cells electrically connected to each other and mounted in a single support structure or frame is called a 'photovoltaic module'. Modules are designed to supply electricity at a certain voltage, such as a common 12 volt system. The current produced is directly dependent on the intensity of light reaching the module. Several modules can be wired together to form an array. Photovoltaic modules and arrays produce direct-current electricity. They can be connected in both series and parallel electrical arrangements to produce any required voltage and current combination.

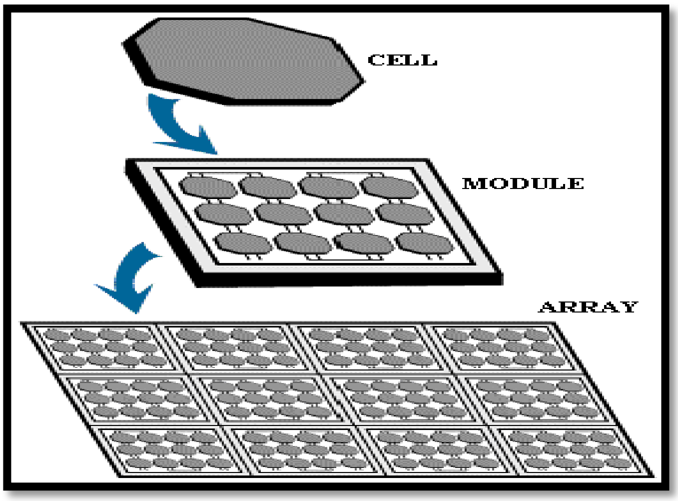

Fig-2.1 ELECTRICAL CONNECTION OF THE CELLS

There are two basic connection methods: series connection, in which the top contact of each cell is connected to the back contact of the next cell in the sequence, and parallel connection, in which all the top contacts are connected together, as are all the bottom contacts. In both cases, this results in just two electrical connection points for the group of cells.

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.

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.

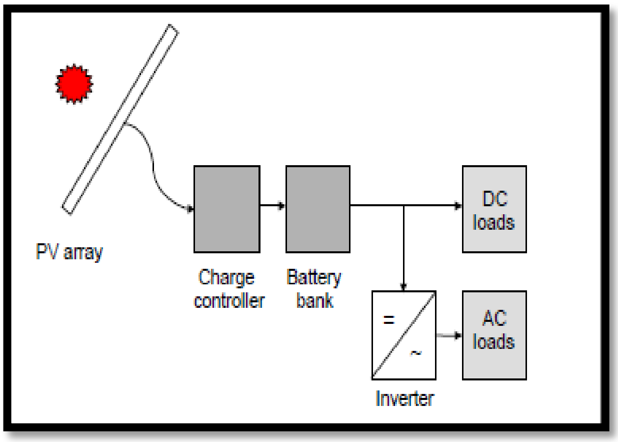

Fig-2.2 Schematic diagram of a stand-alone photovoltaic system

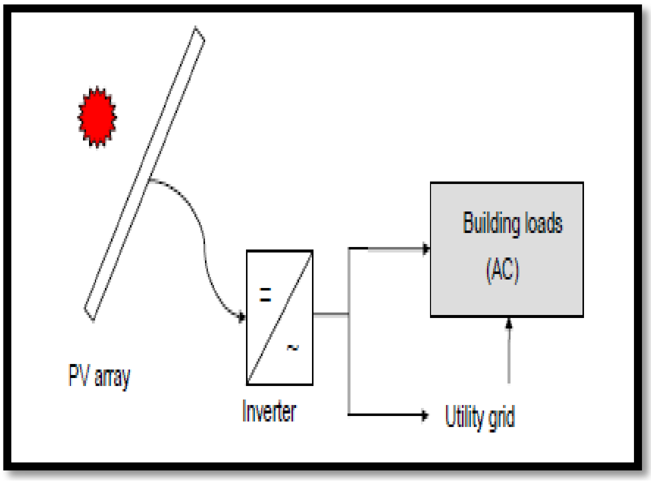

Fig-2.3 Schematic diagram of grid-connected photovoltaic system

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.

SOLID OXIDE FUEL CELLS

Solid oxide fuel cells (SOFCs) offer a clean, low-pollution technology to electrochemically generate electricity at high efficiencies; since their efficiencies are not limited the way conventional heat engine's is. These fuel cells provide many advantages over traditional energy conversion systems including high efficiency, reliability, modularity, fuel adaptability, and very low levels of polluting emissions. Quiet, vibration-free operation of SOFCs also eliminates noise usually associated with conventional power generation systems.

Up until about six years ago, SOFCs were being developed for operation primarily in the temperature range of 900 to 1000oC (1692 to 1832oF); in addition to the capability of internally reforming hydrocarbon fuels (for example, natural gas), such high temperature SOFCs provide high quality exhaust heat for cogeneration, and when pressurized, can be integrated with a gas turbine to further increase the overall efficiency of the power system.

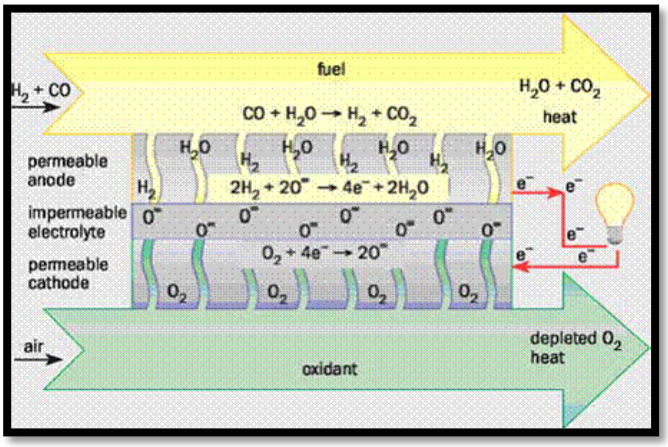

Fig 2.4- Operating principle of a solid oxide fuel cell

An SOFC essentially consists of two porous electrodes separated by a dense, oxide ion conducting electrolyte. The operating principle of such a cell is illustrated in Figure 1. Oxygen supplied at the cathode (air electrode) reacts with incoming electrons from the external circuit to form oxide ions, which migrate to the anode (fuel electrode) through the oxide ion conducting electrolyte. At the anode, oxide ions combine with hydrogen (and/or carbon monoxide) in the fuel to form water (and/or carbon dioxide), liberating electrons. Electrons (electricity) flow from the anode through the external circuit to the cathode. The materials for the cell components are selected based on suitable electrical conducting properties required of these components to perform their intended cell functions; adequate chemical and structural stability at high temperatures encountered during cell operation as well as during cell fabrication; minimal reactivity and inter diffusion among different components; and matching thermal expansion among different components.

Interconnect

Since a single cell only produces voltage less than 1 V and power around 1 W/cm2, many cells are electrically connected together in a cell stack to obtain higher voltage and power. To connect multiple cells together, an interconnection is used in SOFC stacks. The requirements of the interconnection are the most severe of all cell components and include: nearly 100 percent electronic conductivity; stability in both oxidizing and reducing atmospheres at the cell operating temperature since it is exposed to air (or oxygen) on the cathode side and fuel on the anode side; low permeability for oxygen and hydrogen to minimize direct combination of oxidant and fuel during cell operation; a thermal expansion coefficient close to that of the cathode and the electrolyte; and non-reactivity with other cell materials. To satisfy these requirements, doped lanthanum chromite is used as the interconnection for cells intended for operation at about 1000oC (1832oF). In cells intended for operation at lower temperatures (<800oC; <1412oF), it is possible to use oxidation-resistant metallic materials for the interconnection. Compared to lanthanum chromite ceramic interconnects, metallic alloys offer advantages such as improved manufacturability, significantly lower raw material and fabrication costs, and higher electrical and thermal conductivity. But to be useful for the interconnect application, the metallic alloys must satisfy additional requirements, including resistance to surface oxidation and corrosion in a dual atmosphere (simultaneous exposure to oxidizing and reducing atmospheres), thermal expansion matching to other stack components (particularly for stacks using a rigid seal design), chemical compatibility with other materials in contact with the interconnect, such as seals and cell materials, high electrical conductivity not only through the bulk material but also in in-situ-formed oxide scales, mechanical reliability and durability at the cell operating temperature, and strong adhesion between the as-formed oxide scale and the underlying alloy substrate.

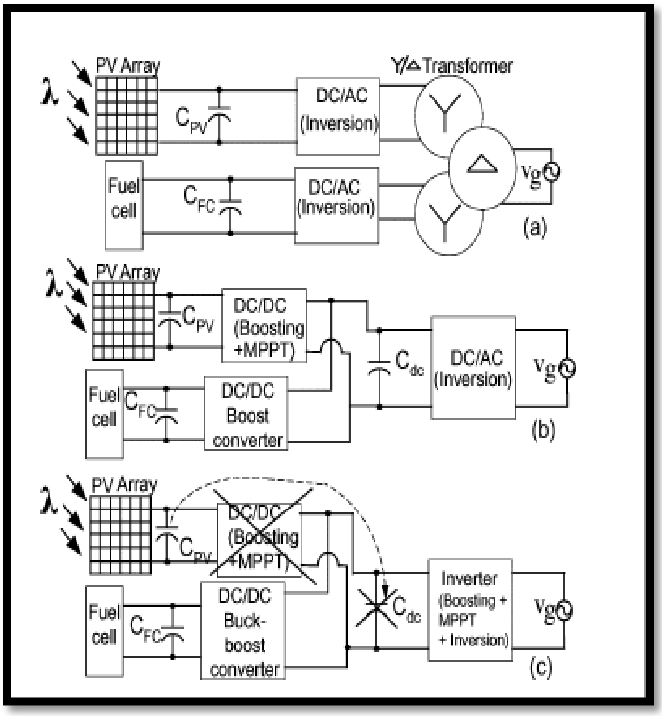

Fig 2.5- hybrid system of PV-FC

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.

Thus, at small power levels, generation by the PV source remains unutilized. This may be acceptable for high power applications, but could be a matter of concern for residential or medium-power installations [22]. If the function of the PV side dc–dc converter is merged with the inversion stage, as shown in Fig. 1(c), even a small fraction of power generated during low isolation can be utilized. Most HDGS configurations discussed earlier use an H-bridge inverter topology for interfacing with the grid, which either needs a line frequency bulky transformer at the output or high dc link voltage at the inverter input. This paper proposes an integrated solution for PV/FC-based HDGS using a new configuration depicted in Fig. 1(c). The proposed system uses an inverter with boosting capability, which eliminates the requirement of high dc voltage at the inverter input, thereby saving the cost of high-voltage buffer capacitor. Various other features, working principle, control strategy and simulation, and experimental results for the proposed configuration are described in the subsequent sections of this project.

III. 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

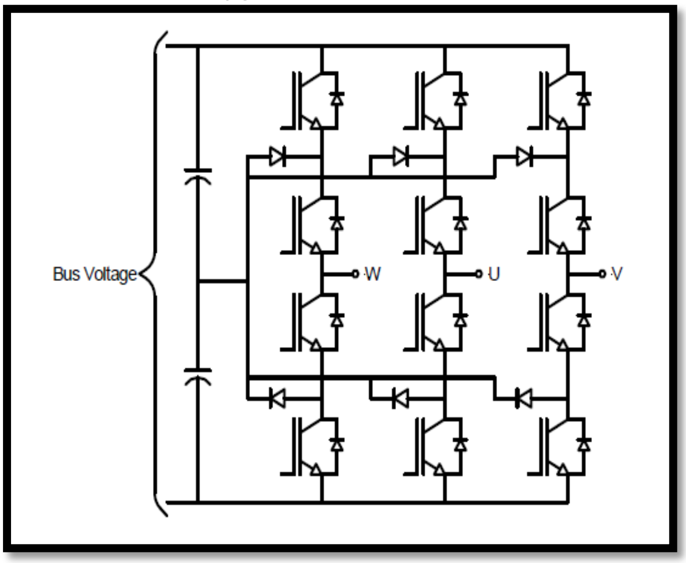

Figure-3.1. NPC Inverter

Figure-3.1 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 favorable 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.

C. 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-3.2 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. 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.

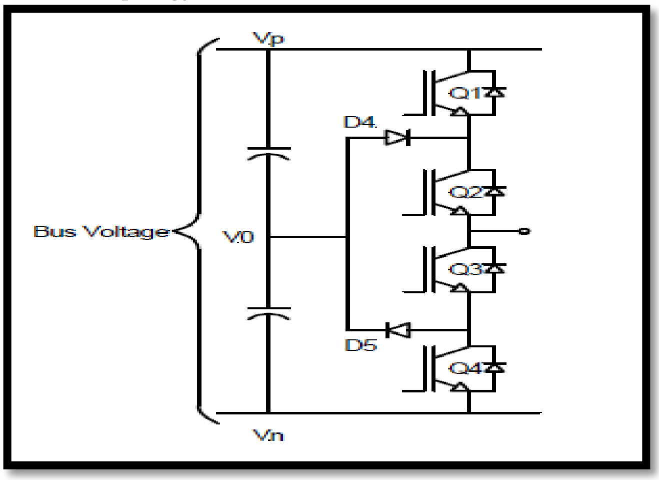

Figure- 3.2 Single Leg

IGBT	Vout = Vp	Vout = V0	Vout = Vn
Q1	On	Off	Off
Q2	On	On	Off
Q3	Off	On	On
Q4	Off	Off	On

Table-1 Switching States

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D. 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)
I	$P_{ex}=P_{PV}-P_{req}\geq 0$	Only PV	Buck* (for $P_{ex}>0$)
II	$P_{def}=P_{req}-P_{PV}>0$	PV and FC	Buck-boost
III	$P_{PV}\approx 0$	Only FC	Buck-boost

*Buck converter is optional. It depends upon the excess power application.

Table-2-operating modes of proposed system

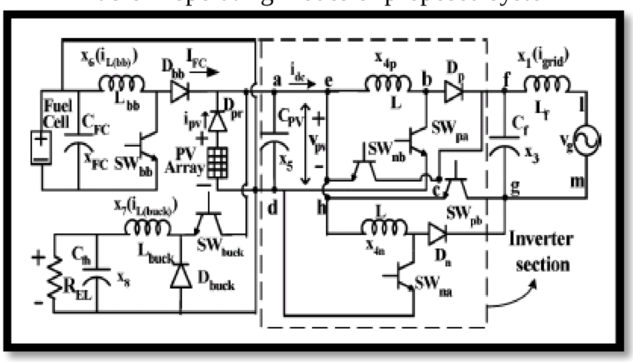

Fig-2.3. Circuit schematic of the proposed integrated configuration for hybrid

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-2.3.
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.

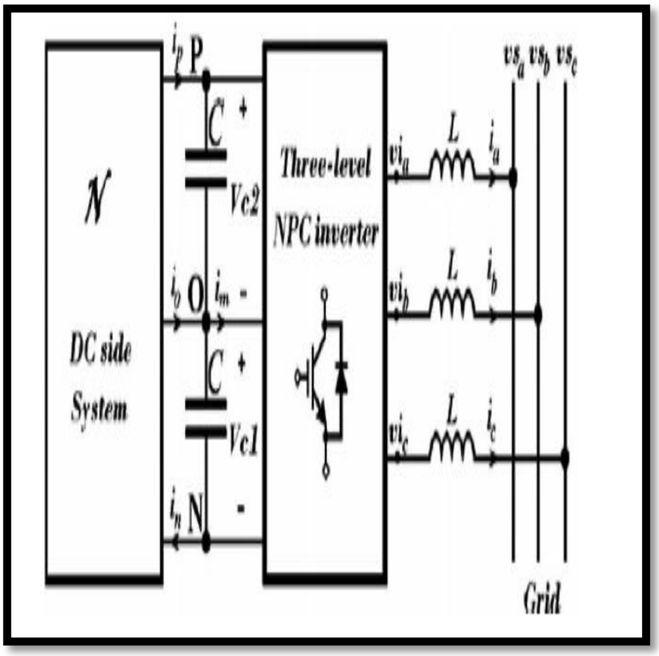

Fig-2.4 General diagram of a grid connected three-wire three-level inverter

Fig-2.4 shows a general structure of a grid-connected three-level inverter showing the DC and AC sides of the inverter. The DC side system, shown as N can be made up of many circuit configurations, depending on the application of the inverter. For instance, the DC side system can be a solar PV, a wind generator with a rectifying circuit, a battery storage system or a combination of these systems where the DC voltage across each capacitor can be different or equal.

IV. MODELLING AND SIMULATION

MATLAB model of grid connected Photovoltaic and Battery storage hybrid system is shown in fig below:-

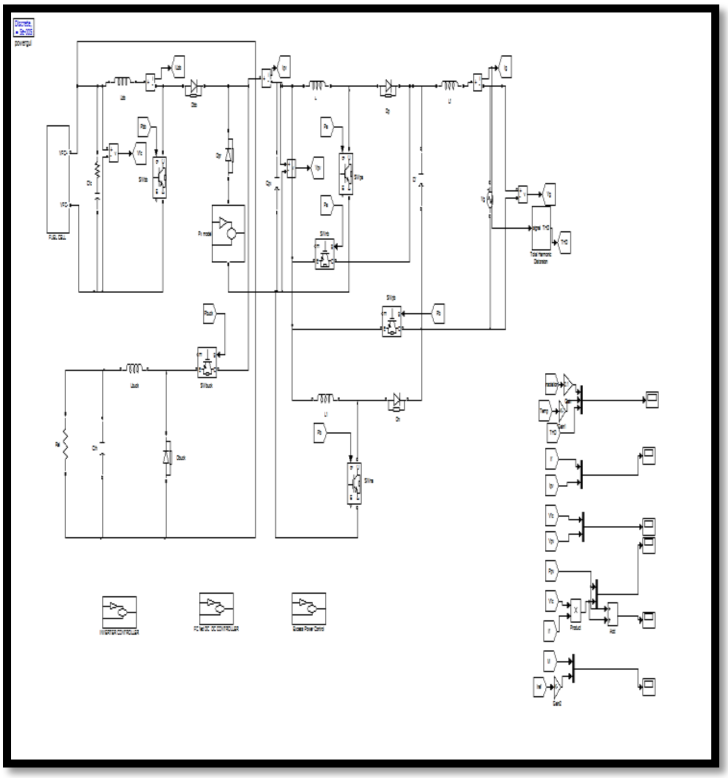

Fig 4.1-MATLAB model of PV-FC base grid connected system

The simulation results of the grid connected hybrid system without NPC inverter is shown in fig below. The simulation results of PV and FC voltage, current, power shown in fig below:-

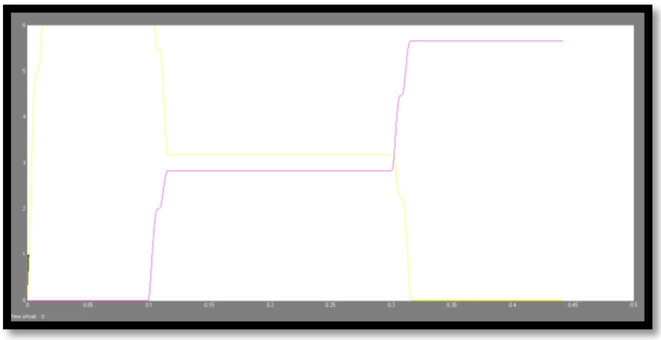

Fig 4.2-Ipv and Ifc current waveform

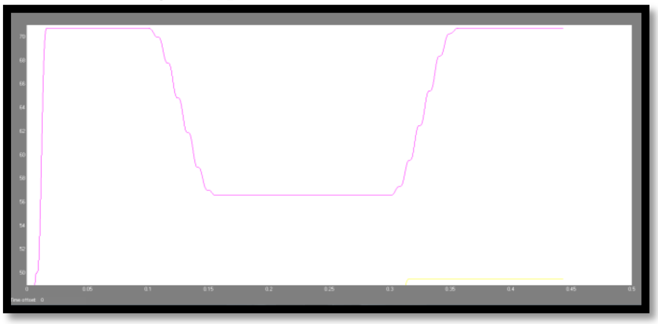

Fig 4.3-Vpv and Vfc voltage waveform

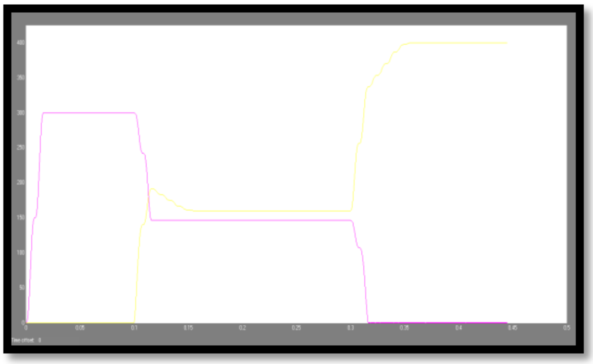

Fig 4.4-Ppv and Pfc generated power waveform

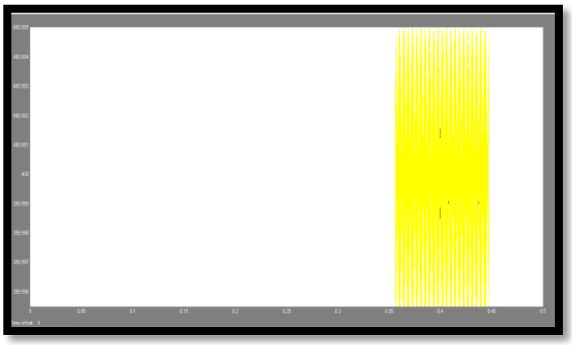

Fig 4.5-Total power of the system (Ppv+Pfc)

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 levels NPC inverter with the Solar PV and battery storage integration system.

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

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.

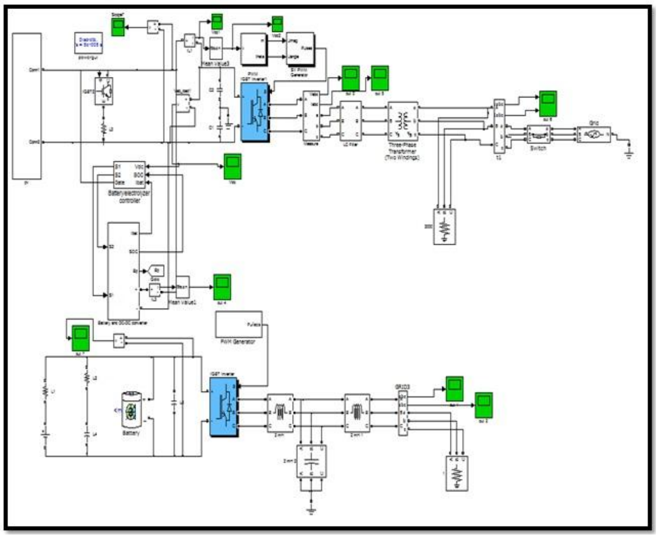

Fig 4.6-MATLAB model of proposed system

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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.

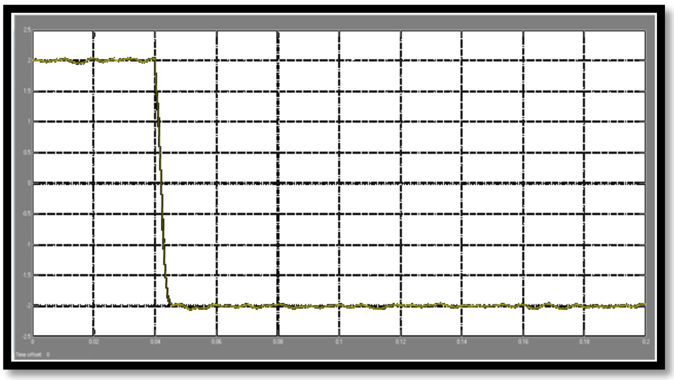

Fig 4.7- current

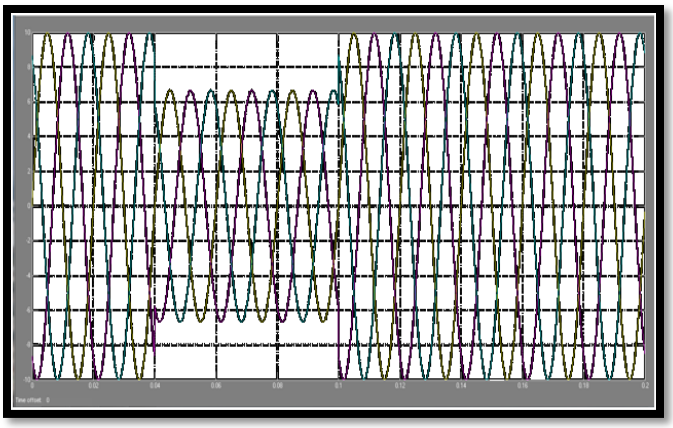

Fig 4.8-grid current

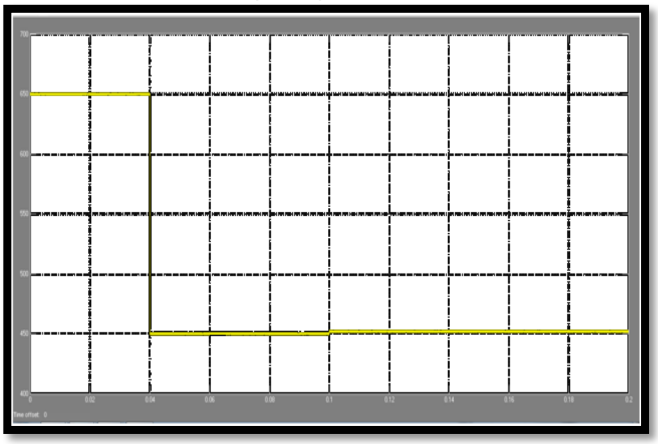

Fig 4.9 dc voltage

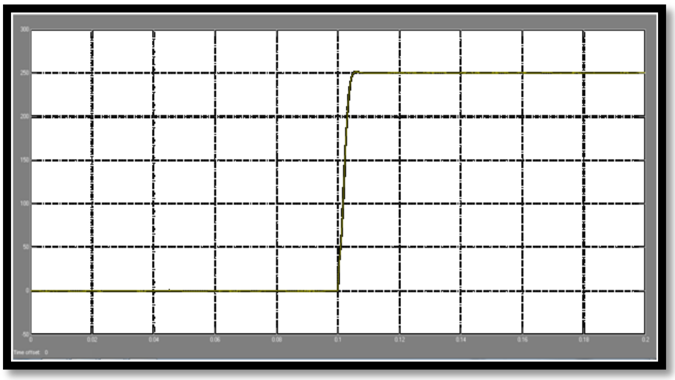

Fig 4.10 var

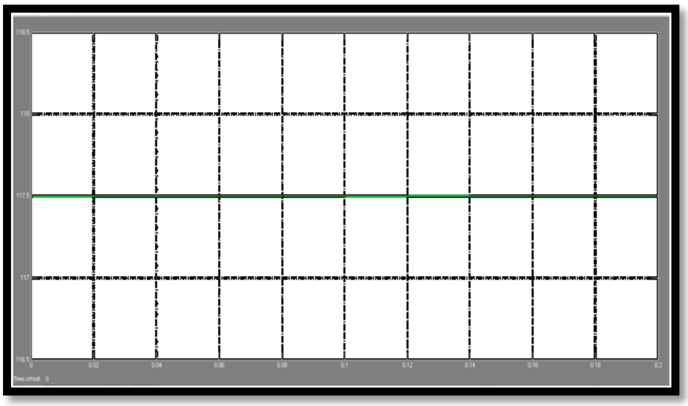

Fig 4.11-voltage

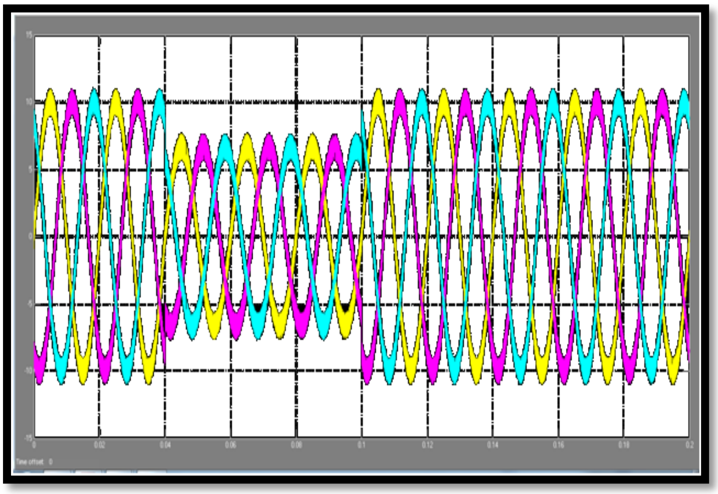

Fig 4.12- three phase grid side voltage

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.

V. 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. The simulation results shows that 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.

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