GRID CONNECTED PV SYSTEM USING 9-LEVEL FLYING CAPACITOR MULTILEVEL INVERTER

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ABSTRACT

Renewable energy sources (RES) gain an importance in recent decades because they are pollution free, easily eretable, and limitless. Among RES, Photovoltaic systems are mostly used as they are light, clean and easily installable. Normally PV cells converts sunlight into electricity in the form of dc. A suitable converter is usually needed to convert the dc power into ac power, which is then injecting into the power grid. The Multilevel Inverters [MLI] can be used to convert the dc into ac for integration of renewable energy sources into the conventional grids. Low level inverters have high THD due to high dV/dt rating. Cost is reduced by using minimum number of sources for FCMI. The proposed Inverter can be used to integrate the Photovoltaic system into Grid, with satisfying the grid requirements such as phase angle, frequency and amplitude of the Grid voltage. A 9-level Flying capacitor multilevel inverter, which dramatically reduces the low-order harmonics and THD is simulated using Matlab/Simulink environment and the corresponding results are presented in this paper.

Keywords: Flying Capacitor Multilevel Inverter, Total Harmonic Distortion, Photovoltaic system, Simscape, Simulink

1. INTRODUCTION

Renewable energy sources are alternatives to our conventional energy sources such as fossil fuels e.g. oil, coal, gas that is not renewable. The conventional energy sources are limited and can be exhausted. Many renewable energy sources are existing such as solar, wind, biomass, hydro, geothermal and ocean power. Among PV has the advantage of clean and no pollution, and etc. So, PV systems are attracting attention in the world. The basic element of a PV system is the solar cell. A solar cell directly converts the energy of sunlight directly into electricity in the form of dc. Grid interconnection of PV system requires an efficient converter to convert the low voltage dc into ac. The conventional H-bridge inverter produces a square output, which contains infinite number of odd harmonics and dv/dt stress is also high. Normal PWM inverter can reduces the THD, but switching losses are high and also this inverter is restricted to low power applications. The importance of multilevel inverters [MI] has been increased since last few decades. These new types of inverters are suitable for high voltage and high power application due to their ability to synthesize waveforms with better harmonic spectrum and with less THD.

Multilevel inverters have many advantages such as capacity to handle high voltage, low switching losses, low electromagnetic concerns, and their improved output waveform with low distortion. Compared to two-level inverter topologies at the same power ratings, Multi level Inverters (MIs) also have the advantages that the harmonic components of line-to-line voltages fed to load are reduced owing to its switching frequencies. It also provides an alternative for
medium voltage ratings systems, while at the same time enabling the interface of renewable energy sources to high power applications.

Generally MIs are classified into three types: they are I. Diode Clamped MIs 2.Flying capacitor MIs 3.Cascaded H-bridge MIs. Diode clamped MIs require large number of clamping diodes as the level increases . In FCMIs, Switching utilization and efficiency are poor and also it requires large number of capacitors as the level increases and cost is also high [1]. Cascaded H-bridge MIs are mostly preferred for high power applications as the regulation of the DC bus is simple. But it requires separate dc sources and also the complexity of the structure increases as the level predominantly increase. In order to address the above concerns, this paper proposes a new type of multilevel inverter which requires less number of DC sources and switches compared to Cascaded H-bridge MIs. THD of the output voltage is also less when compared to the conventional MIs. By using this inverter we can efficiently integrate the PV into the existing conventional power grid.

Most common problem associated with the FCMI is the capacitor balancing [2],[3]. The proper balancing is essential for the FCMI since the voltage on the capacitors will set the voltage steps on the output waveform. If the capacitors get too unbalanced, the output will have a higher THD and the motor distortions will be high which cause reduced life of the motor [4]. There are different techniques to balance the capacitors such as the use of redundant switching states, the use of an RL-C filter in parallel with the load (most expensive), and the simplest technique which is the self-balancing of the capacitors. Here MOSFETs are selected as switches in FCMI and are driven [5].

2. GRID CONNECTED PV SYSTEM

The block diagram given below shows the entire system. It consists of a PV system, a DC/DC boost converter and a 9-level flying capacitor multilevel inverter, which is connected to interface with the grid [6].

![Figure 1. Grid tied photovoltaic system (PV)](image)

From Fig. 1, the PV cell directly converts the solar energy into electricity in the form of dc [8]. The voltage obtained from the PV is fed into a DC/DC boost converter and the boosted DC is fed into a 9-level flying capacitor multilevel inverter. Finally the FCMI output is connected to the power grid with satisfying the grid requirements such as phase angle, frequency and amplitude of the grid voltage.

3. SIMSCAPE MODEL OF PHOTOVOLTAIC CELL

3.1 Simscape model of solar cell module having 72 individual cells

![Figure 2. SimElectronics Simulation Model for a single Cell](image)
This Model was developed using blocks of SimElectronics and Simulink. Solar cell was connected with blocks such as current sensor and voltage sensor to measure the current and voltage across solar cell. Blocks for varying Irradiance level and Temperature, were also connected in the above model. Rest of the blocks were the interface between major blocks. The advantage of using of this high level of implementation is to create a simple equivalent circuit, which have much more complex parameters, including the effect of temperature in the device which is very important for behavior of this type of system.

![SimElectronics Simulation Model for a single Cell](image1)

3.2 Simscape model of solar cell module having 72 individual cells- 4 representations of individual blocks

![Simscape model of solar cell module](image2)
4. DC\DC BOOST CONVERTER

In many industrial applications, it is required to convert a fixed-voltage dc source into a variable voltage dc source. A dc-dc converter converts directly from dc to dc and simply known as a dc converter. A dc converter can be considered as dc equivalent of an AC transformer with a continuously variable turn ratio. Like a transformer, it can be used to step down or step up a dc voltage source.
A converter can be used to step up a dc voltage and an arrangement for step-up operation is shown in Fig.8. When switch is closed for time $t_1$, the inductor current rises and energy is stored in inductor $L$. If the switch is open for time $t_2$, the energy stored in the inductor is translated through diode $D$ and inductor current falls.

6. SYSTEM OVERVIEW

The basic schematic diagram of a grid connected PV system with flying capacitor multilevel inverter is shown below.

Hardware model of the system consists of,
- Transformer
- AC-DC converter
- DC link capacitors
- Flying capacitors
- Power electronic switches
- Microcontroller units for PWM generation
- MOSFET gate drives.

The main part of the system is the inverter that consists of semiconductor switches. The inverter has a driver section that provides the switching pulses to the power switches. A controller section (typically an electronic circuit) is used to generate the right commands/pulses to control the inverter in an appropriate way. Here, a microcontroller is used to control the FCMI system as well as perform the other task of driving the variable frequency drive [7].

The rectifier converts incoming ac to dc which is given by the step-down transformer. This signal is then given to flying capacitor multilevel inverter across the dc link capacitors. As the input is fed to the two half-legs of the FCMI,
power electronic switches will be switched ON and OFF according to each required output levels as programmed in the MGDs. The flying capacitors will charge and discharge accordingly for maintaining the different levels.

The nine level output produced is fed into a variable frequency drive in which direct torque control is possible. It is achieved by varying the frequency of the drive. As the output fed into the drive is from this nine level inverter, the input to the drive is very much smooth and somewhat like a sinusoidal signal. Thus the harmonics produced in the motor is very much reduced. Here the motor input is given through a step-up transformer. So the signal will be smoothened much more and thus Total Harmonic Distortion (THD) will be very less.

The main part of the hardware is the power supply. For getting the required DC input voltages for various IC’s and for the power supply of the microcontroller we use voltage regulator circuits. We use fixed voltage regulator LM7809 and LM7805 for getting 9V and 5V voltages.

Power supply unit consists of,
- Transformer
- Bridge circuit
- Filter circuit
- Voltage regulator

The maximum voltage that can be applied to the microcontroller chip available in the market is +5V. Also this voltage must be a regulated one to avoid data violations occurred by the supply voltage fluctuations. This in turn fixes our first voltage requirement as regulated +5V. The D/A converter requires a –15V supply and a +10V reference voltage. The output current to voltage amplifier requires a ±12V.

Hence our power supply requirements are +10V, +12V, -12V, -15V and +5V. Here the current consumption of the +10V and –15V will be too low since they are the reference voltages. The ±12V is applied to the op-amp only and this requires only in terms of few mille amps. However the case of the +5V supply is too different since it is the main supply to the system. The consumption of this level will be few hundred mille amperes above 0.5A. Thus the total current requires can be settled as below 1A.

When AC voltage is applied to the primary of the transformer, it can be stepped up or down depending upon the value of dc voltage which is needed. In our circuit the transformer of 230V/12-0-12V is used to perform the step down operating where a 230V AC appears as 12V AC across the secondary winding of the transformer.

A commonly used circuit for supplying DC from AC source is bridge rectifier. A bridge rectifier of four diodes (IN4007) is used to achieve full wave rectification. Two diodes will conduct during the positive half cycle and other two will conduct during negative half cycle. The DC voltage at the output terminals of bridge rectifier is less than 90% of RMS value.

In filter circuits, usually capacitor is acting as a surge arrester always follows the rectifier unit. This capacitor is also called as a bypassing capacitor; it is not only used to short the ripple with frequency of 120HZ to ground but also to leave the frequency of the DC to appear at the ground.

The voltage regulator plays an important role in any power supply unit. The primary purpose of a regulator is to aid the rectifier and filter circuit in providing the constant DC output voltage. Power supplies without regulators having an inherent problem of changing DC voltage values due to variation in the load or any fluctuation in the AC liner voltage. With a regulator connected to the DC output, the voltage can be maintained at constant value. IC7805 is to produce a 5V and IC7812 is used to produce a voltage of 12V.
DC output from rectifier is fed to the input side of flying capacitor multilevel inverter circuit. Switching signals for inverter switches are generated by using PWM generator unit. Gate drive circuit provides electrical isolation between power and control sections. Different components of hardware is shown in Fig. 11.

![Image of hardware components](image)

**Figure 11. Different components of hardware**

### 7. EXPERIMENTAL RESULT

Output voltage waveform of FCMI fed Induction motor circuit is shown in Fig. 12.

![Image of output voltage waveform](image)

**Figure 12. Output voltage waveform**
8. CONCLUSION

A Grid connected PV system with FCMI is proposed in this paper. The FCMI topology requires only single source and the Total Harmonic Distortion for this topology is minimum. To obtain a higher efficiency in the FCMI, the MOSFETs need to be replaced by Power MOSFETs with much lower resistance and the capacitance need to be increased in each capacitor to achieve a FCMI with higher current rating. The criteria used incorporate the lowest number of switching transitions, equal device usage and capacitor voltage balance. The proposed strategy has the potential to be used in a diverse range of applications that include stand alone renewable energy systems in remote rural areas, electric motor drives, and industrial applications. Further work in this area has the potential to greatly empower impoverished communities.

REFERENCES