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Active and Reactive Power Control for Grid-Connected PV Systems Using Cascaded Multilevel Converters

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Abstract: *Photovoltaic (PV) panels generator module is the widely used system solar generated powers are cascaded and connected to the grid with a constant AC supply .pv cell which gets subjected to various intensities of sun light cannot supply a constant DC voltage. A traditional method to avoid this problem is to control either of active or reactive power to control this voltage. This paper concentrates on the control of both active and reactive powers using DC-DC Converters with MPPT technique to keep the output DC voltage without fluctuations. PI controller is used to apply this MPPT technique. A comparative study of the traditional method with the proposed system has been made with the help of MATLAB Simulation*

Keywords: *Active and Reactive power control,DC-DC converter,PV Panel MPPT, voltage distribution.*

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I. Introduction

Due to over population and industrialization the demand for electrical power is increasing more and more. Fossil sources also depleting day by day. In order to achieve the power demand renewable energy sources are the best alternative. Among all renewable sources Solar energy is most popular and having more abundance all over the globe and as well as pollution concern also PV system is the best alternative in renewable sources. After development of new power electronic devices it is becoming easy to establish large scale PV generating systems. There are mainly two types of generating systems in PV. One is small scale PV system and another one is large scale PV system. Small scale PV systems are mainly used in Distributed Generating systems (DG).The problem with PV DG system is for designing this system high voltage gain need to be required [1-4]. In order to achieve this high gain we are choosing Grid connected PV system that is Large scale Grid connected PV system

In Grid connected PV system Power Electronic devices such as converters and inverters are main parts along with PV panels. Converters are used for stepping up the voltage which is produced by PV panels. Voltage source inverters are needed for conversion of DC-AC supply and for getting MPPT or stabilizing the DC voltage. Cascaded Modular Multilevel Inverters having so many advantages like improved Waveform quality and less THD etc. For interfacing Large scale PV system with Grid the main medium we requires is this Cascaded Modular Multilevel Inverters [5]. Thus Large scale PV systems with Cascaded Modular Multilevel Inverters are facing some severe problems like mismatch of MPPT power values of each Module, Thermal gradient, dirt etc. In this entire system the input forgrid is given by Cascaded Multilevel inverter which converts DC output from DC-DC converter to AC supply for each phase of grid. If the output of Inverter is mismatch to the grid requirements then active power flow will get disturbs [6-7]. For example if a converter module having high active power generation then automatically that module will supply more AC supply to the grid this may cause degrade of power quality due to over modulation. In Order to overcome this problems proper control strategies are developing for this large scale cascaded PV systems. There are different control techniques for cascaded PV system. For DC-DC converter we will use MPPT control technique for stabilizingDC [8] voltage and for Multilevel inverter we will use any of the PWM control techniques along with PI controller etc. By using this methods we can't achieve Reactive power compensation and design of PV system wise also some problems are there like leakage current etc [9-12].

II. Circuit Topology And Design Parameters

Block Diagram for large scale Cascaded PV system is shown in Fig (1). Only single phase circuit is shown in the figure.

Phase a

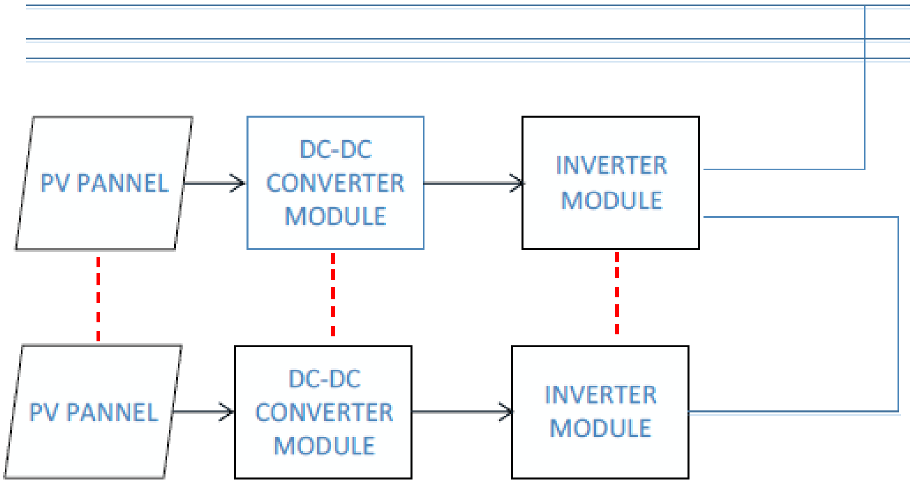

Fig (1). Block Diagram of Cascaded PV system for one phase

And the proposed large scale cascaded PV system is showed in Fig (2), which gives the three phase large scale Cascaded PV system in which two stages of power conversion takes place. In 1st stage power harvested from solar panel is given to DC-DC converter for Boost or Buck action i.e for voltage stabilization we are using Current Fed Dual Active Bridge DC-DC converters. The end of this CF-DAB DC-DC converters are connected with cascaded Modular Multilevel Inverters with High Voltage Insulation. In this configuration no need of line frequency transformers, Inverter module is directly connected to grid without any line Frequency Transformers. This is the one of the main advantage of this model compared to conventional methods. In DC-DC converter module each of the individual section is connected to one PV panel this is nothing but we are achieving MPPT for each section independently so we can harvest more solar energy. This paper is focused on applying of Fuzzy Logic Control to Modular Multilevel Inverter with active and reactive power control of Grid connected Cascaded PVsystem.

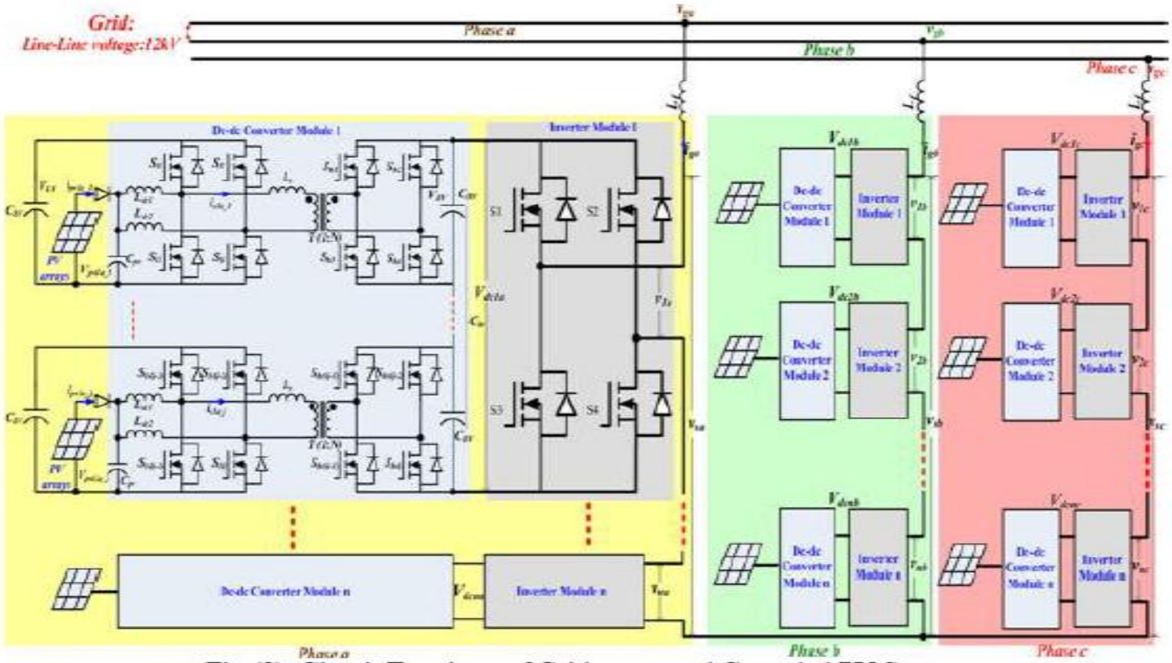

Fig (2). Circuit Topology of Grid connected Cascaded PV System

III. Multi-Level Inverter

Numerous industrial applications have begun to require higher power apparatus in recent years. Some medium voltage motor drives and utility applications require medium voltage and megawatt power level. For a medium voltage grid, it is troublesome to connect only one power semiconductor switch directly. As a result, a multilevel power converter structure has been introduced as an alternative in high power and medium voltage situations. A multilevel converter not only achieves high power ratings, but also enables the use of renewable energy sources. Renewable energy sources such as photovoltaic, wind, and fuel cells can be easily interfaced to a multilevel converter system for a high power application. The concept of multilevel converters has been introduced since 1975. The term multilevel began with the three-level converter. Subsequently, several multilevel converter topologies have been developed. However, the elementary concept of a multilevel converter to achieve higher power is to use a series of power semiconductor switches with several lower voltage dc sources to perform the power conversion by synthesizing a staircase voltage waveform. Capacitors, batteries, and renewable energy voltage sources can be used as the multiple dc voltage sources. The commutation of the power switches aggregate these multiple dc sources in order to achieve high voltage at the output; however, the rated voltage of the power semiconductor switches depends only upon the rating of the dc voltage sources to which they are connected.

Advantages & Disadvantages: A multilevel converter has several advantages over a conventional two-level converter that uses high switching frequency pulse width modulation (PWM). The attractive features of a multilevel converter can be briefly summarized as follows. Staircase waveform quality: Multilevel converters not• only can generate the output voltages with very low distortion, but also can reduce the dv/dt stresses; therefore electromagnetic compatibility (EMC) problems can be reduced. Common-mode (CM) voltage: Multilevel converters• produce smaller CM voltage; therefore, the stress in the bearings of a motor connected to a multilevel motor drive can be reduced. Furthermore, CM voltage can be eliminated by using advanced modulation strategies Input current: Multilevel converters can draw input current with low distortion.

A. Diode-Clamped (DC) Topology

The diode-clamped (DC), also called neutral-point clamped (NPC), topology is based on the utilization of a number of diodes in order to block small DC sources. The configuration of a single-phase 3-level and 5-level diodeclamped inverter is shown in Fig.3

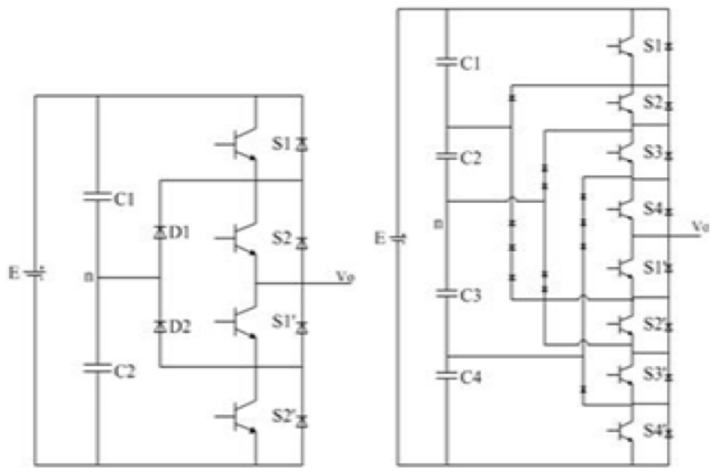

Fig.3 Single-phase 3-level and 5-level DC topology.

The DC topology can easily be extended to a generic n-level configuration. In a 3-level diode-clamped inverter, the DC bus voltage is divided by capacitor banks into two equal steps. Operation of the inverter is simple. The name of the DC topology originates from the fact that the voltage between two switches is clamped through the clamping diodes. When switches are(s1,s2) on and are(s1′s2′) off, output voltage of the inverter is equal to the voltage of , which is equal to ⁄. Likewise, when switches (s1,s2) are off and(s1′s2′) are on, output voltage of the inverter is equal to the voltage of , which is equal to-E/2. When are on and are off, output voltage of the inverter is equal to 0. In a 5-level diode-clamped inverter, the DC bus voltage is split into four equal voltage steps. In this case, the number of diodes required to clamp the voltage changes point by point. Each diode is sized to provide voltage blocking for the voltage across one capacitor. For instance,D1 is represented only by one diode, while D1'is represented by three diodes equal toD1 , which are in series because it must block voltage across capacitors c2, c3, and c4, meaning that it is allowed to use one diode with higher blocking capability or three diodes in series with equal blocking capability toD1 . Considering the diode reverse voltage for an n-level inverter, calculated by vr=E/n-1 , the diode reverse voltage for a 5-level inverter is equal toE /4, thus demonstrating that increasing the number of levels results in decreased voltage stress on the components.

B. Flying Capacitor (FC) Topology

This topology is similar to diode-clamped topology in which diodes are replaced by capacitors in order to maintain voltage levels across DC link capacitors. Fig 4 shows the structure of a single-phase 3-level and 5-level flying-capacitor inverter. The topology has a ladder structure of DC dice capacitors, in which, the voltage on each capacitor differs from voltage of the next capacitor. FC topology can easily be extended to higher levels. Voltage across each capacitor is given by: vc=E/n. This voltage is the reverse voltage drop each switch can withstand when all capacitors are fully charged. These capacitors are known as clamping capacitors because their function of them is similar to the clamping diodes in diode-clamped topology because they maintain the voltage drop between the buses to which they are connected

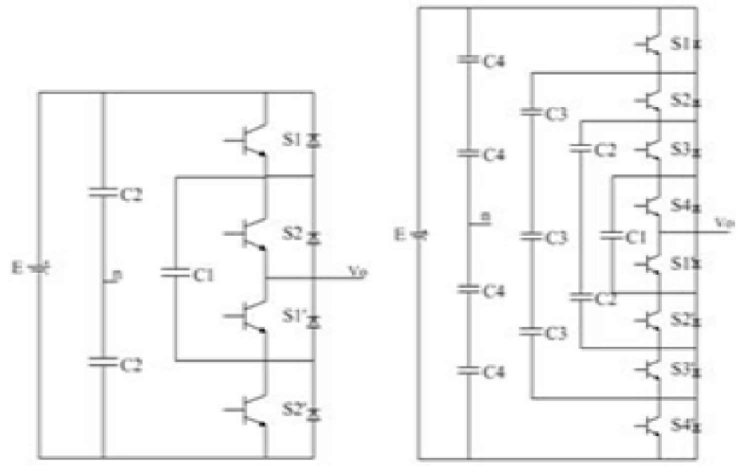

Fig.4 Single-phase 3-level and 5-level FCtopology

The operation of a 3-level flying-capacitor is similar to the 3-level diode-clamped inverter. When switches(s1,s2) are on and(s1′ s2′)are off, output voltage of the inverter is equal to+E ⁄2, and when switches (s1,s2) are off and (s1′ s2′)are on, output voltage of the inverter is equal to-E ⁄2. When(s1,s1′) are on and(s2 s2′) are off, voltage of the capacitor c1is increased and when(s2 s2′) are on and s1,s1′) are off, the capacitor c1 is in discharging mode. In the latter two cases, output voltage of the inverter is equal to 0. By switching between these two states, charge on the capacitor c1 maintains balanced. These two switching states are called intra-phase redundant states. In the 3-level inverter, various switch configurations cannot occur. Si andsi′ , where the number of switches is, should be switched in a complimentary way. Possible configurations for a singlephase n-level flying-capacitor inverter are as: N= 2 n−1For this topology the number of possible configurations is greater than the number of possible output voltage levels. The total number of possible switching states for a 5-level flying capacitor inverter is 16 whereas the possible number of output voltage levels is 5, while creating 11 redundancies. Therefore, maintaining voltage balancing for this inverter is complicated

IV. Designing And Conrol Technique

DC-DC converters control has two degrees of freedom: the duty cycle and the phase shift angle, by which the solar generated voltage and LVS dc-link voltage V_{LV} are controlled, respectively. Solar generated voltage is directly controlled by the duty cycle so that it can be well kept at the reference voltage which is generated from MPPT algorithm. Usually the bandwidth of the duty cycle loop is about several kHz, which is much higher than 120 Hz; thus, the double-frequency component in the LVS or HVS is blocked and high utilization factor of MPPT is reached in the solar generation side. For simplicity, a simple PI controller is applied. The solar generated voltage and current are both sensed for the calculation of active power and change in current/change in voltage which are used in MPPT algorithm. The MPPT algorithm generates a reference voltage for the solar generated voltage regulation. Power transferred from LVS to HVS is determined by the phase shift angle. By regulating LVS voltage through phase angle, the power generated from the wind turbine and the power delivered to HVS are matched. To minimize the peak transformer, the LVS dc-link voltage V_{LV} is controlled to follow the reference V_{HV}/N that is HVS voltage divided by turn ratio N, so that they are balanced. Proportional resonant controller is employed to obtain enough gain at double frequency to ensure the LVS voltage to dynamically follow the reference voltage.

Fig (5) shows the CF-DAB DC-DC CONVERTERS control for individual Unit of DC-DC Converter module [18]. The same technique can be used for all the modules. As the name itself tells Dual Active Bridge, This control has two degrees of Control Freedom, The main parameters used in this control technique are Duty cycle (D) and Phase shift angle (ϕ), by which PV panel voltage and Low voltage Side voltage is controlled

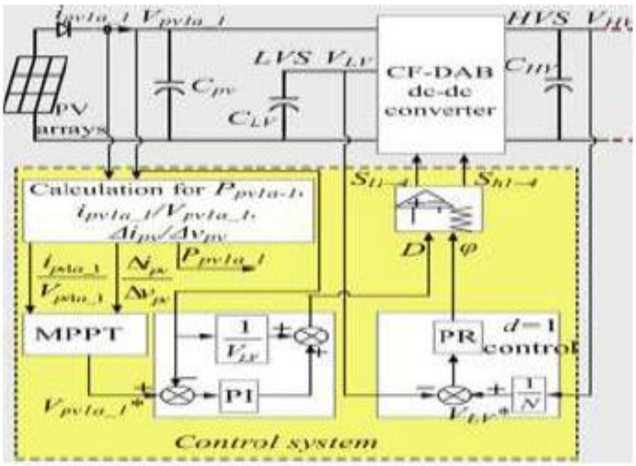

Fig (5).CF-DAB DC-DC Converter Control

The Duty cycle bandwidth is taken as 10 kHz. Which is must higher than 100HZ, Thus MPPT is achieved in PV panel. In this paper a simple high bandwidth PI controller is applied. Power transferred from LVS to HVS is given by the phase shift angle ϕ.VLV is controlled by VHV/N i.e high voltage divided by number of turns.

A. MPPT CONTROL

MPPT algorithm has been proposed in the literature for maintaining constant voltage.

The algorithm used to achieve maximum power point tracking is the INC methods. The INC method offers good performance under rapidly changing atmospheric conditions. However, four sensors are required to perform the computations. If the sensors require more conversion time, then the MPPT process will take longer to track the maximum power point. During tracking time, the solar power output is less than its maximum power. In order to implement the MPPT algorithm, a buck-boost dc/dc converter is used. The parameters L and C in the buck-boost converter must satisfy the following conditions

The buck-boost converter consists of one switching device (GTO) that enables it to turn on and off depending on the applied gate signal. The gate signal for the GTO can be obtained by comparing the saw tooth waveform with the control voltage. The basic inverter control schemes can be broadly divided into two categories: current control and voltage control. In grid-connected PV system, the inverter operates in current control mode where the grid regulates the voltage and frequency by setting current reference for the inverter to allow exchange of real and reactive powers. The objective is to control the real and reactive power to some reference values .The power references and the voltage references are then used to set the references for the current controllers. The inverter is supplied from a DC link capacitor interconnected to the PV power system via a DC-DC converter combined with a Maximum Power Point Tracking (MPPT) controller to extract the maximum power from the PV system. In the mathematical model of the Pulse Width Modulation (PWM) inverter expressed in the d-q rotating frame there is an inherent coupling between the real and reactive components of the current which makes it difficult to regulate the power injected into the grid from the PV generation system. An effective decoupling strategy based on proportional-integral (PI) controllers is designed to eliminate the interaction between the two current components

$$L > \frac{(1-D)^2 R}{2f} ; C > \frac{D}{Rf(\frac{\Delta V}{V_{out}})}$$

The large scale grid connected PV system with the proposed control strategy is implemented in MATLAB. The parameters in simulation are listed in Table I.

SYSTEM CIRCUIT PARAMETERS IN SIMULATION

Parameters		Values
PV inverter modules in each phase	Number	4
	DC capacitor voltage	3000V
	DC capacitor size	400μF
	Filter inductor	0.8mH

	Switching Frequency	5kHz
DC-DC converter module	PV array output voltage	100V-200V
	capacitor voltage	300V-600V
	Switching Frequency	50kHz
Grid (three phase)	Rated real power	3 MW
	Rated reactive power	15 MVar
	Rated RMS line-line voltage	12 kV

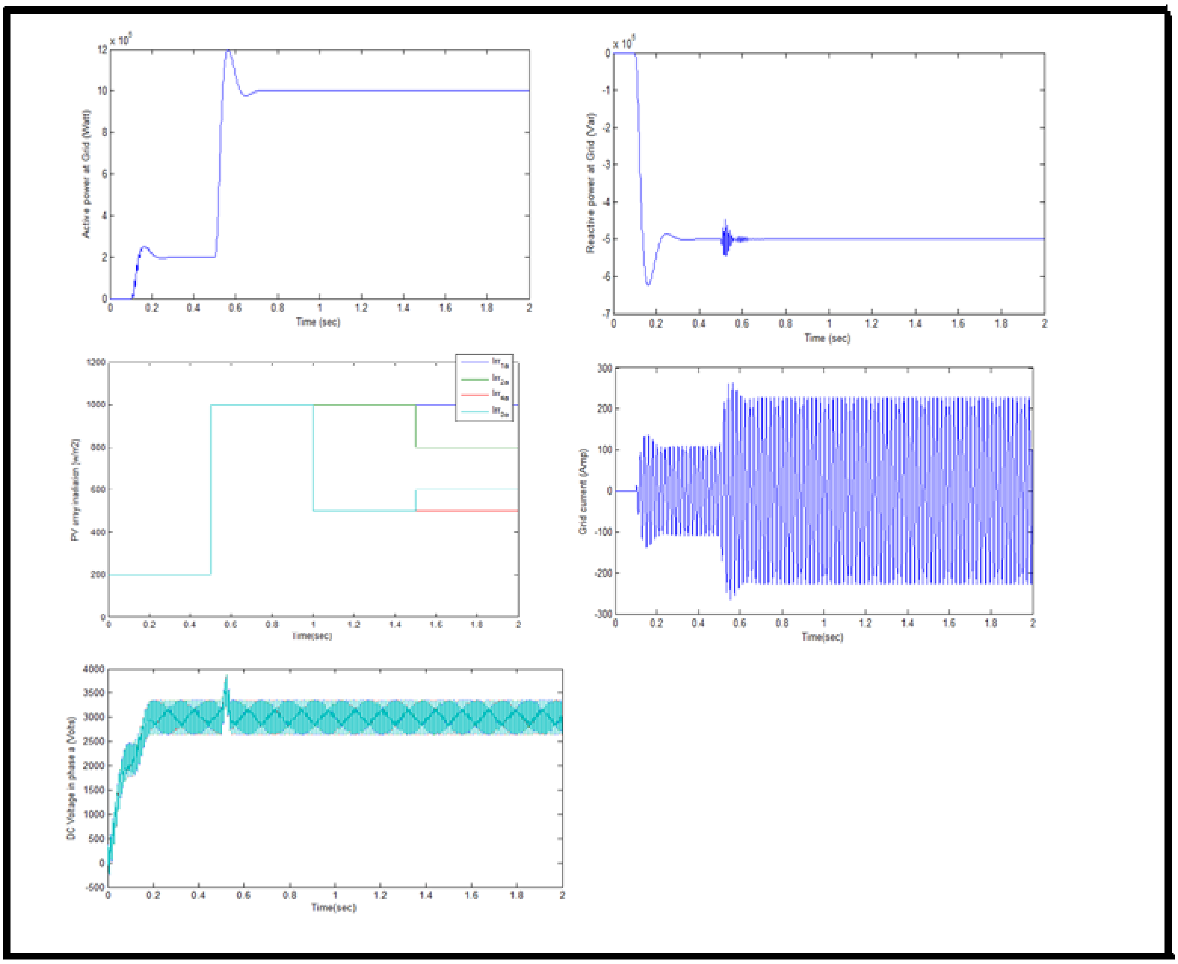

Fig 6: Simulation results of PV system with active and reactive power control in phase a.

In the traditional method, if the solar irradiation changes occur on the third and fourth PV inverter modules decrease, the unsymmetrical active power generation may result in the output voltage over modulation of the first and second inverter modules because they will be charged with the more voltage output to meet the system stability. On the other hand, the reactive power from the first and second PV inverter module increases. The increasing burden of reactive power generation makes the output voltage over modulation from the first and second inverter modules resulting in serious grid current distortion**.**

The proposed control strategy improves the system operation performance by controlling the active and reactive power independently. Although the solar irradiation on first and second inverter modules is different from one on third and fourth inverter modules after 1 s, the reactive power from them is controlled to be symmetrical. By this proper reactive power distribution, the over modulation caused by the active power mismatch is eliminated. Even when different active power is generated from the four inverter modules after 1.5 s, the effective reactive power compensation can ensure the system with good power quality and stability.

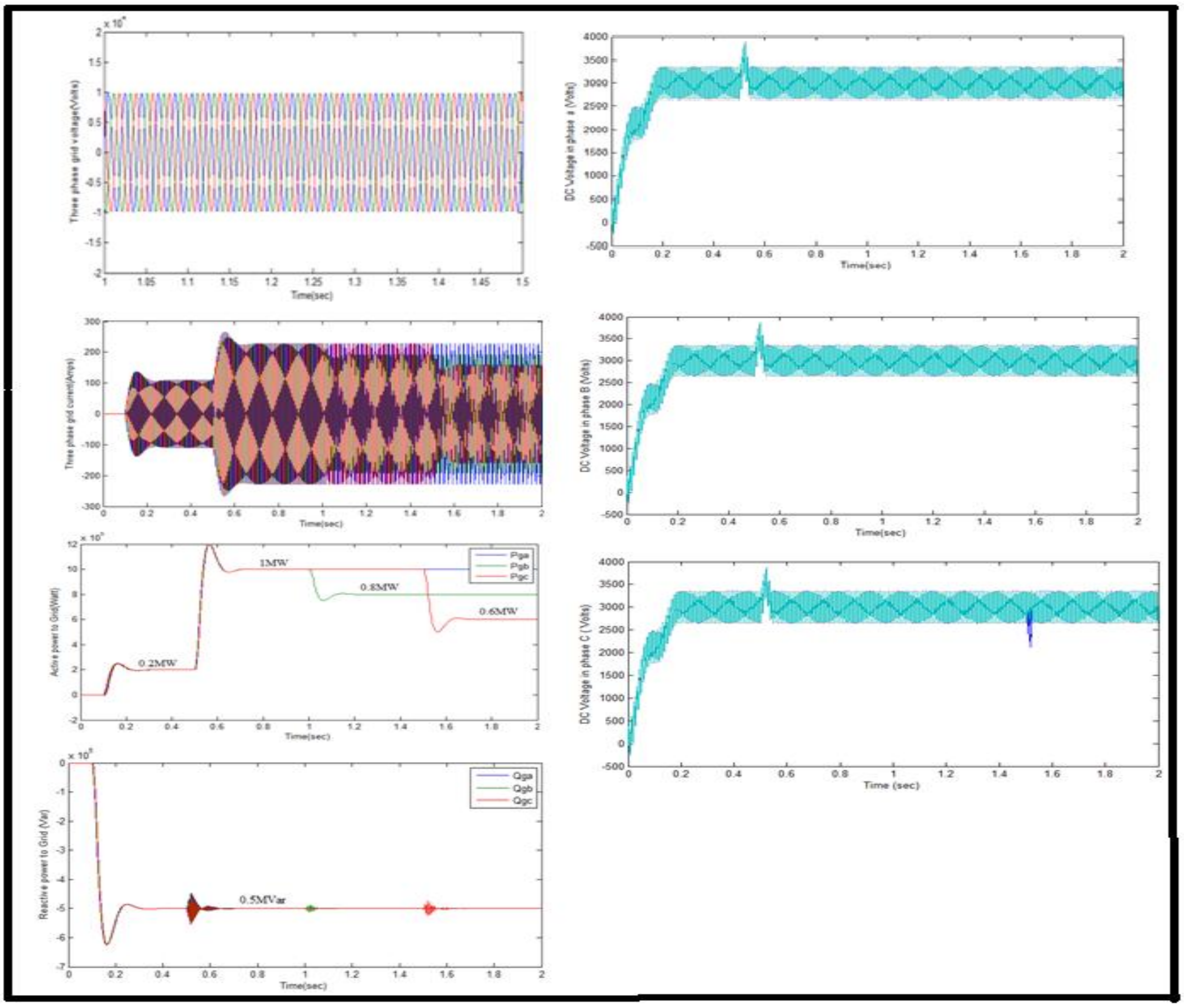

Fig 7: Simulation results of PV system with the proposed control in three phases

Fig. 3 shows the simulation results of three-phase cascaded PV system with the proposed control strategy. The solar irradiation for PV inverter modules changes from 200 to 1000 W/m2 at 0.5 s. The active power to grid, increases from 0.6 to 3 MW and the reactive power to grid, is controlled to be −1.5 MVAR. At 1 s, solar irradiation appears on these PV inverter modules in phase b is different from other two phases. Therefore, different active power is generated from three phase. At 1.5 s, different solar irradiations in the three phase result in different active powers with 1, 0.8, and 0.6 MW, respectively. With the effective control strategy, the reactive power in the three phases is controlled to 0.5 MVAR. In this case, although the grid currents are unbalanced, this system still has good power quality .The dc voltages on these modules, have good dynamic performance and are controlled to vary with 20% rated voltage.

V. Conclusion

The main priorities of any system are its reliability and cost effectiveness. These can be fulfilled in the proposed system. Also the discussed techniques can be easily implemented with some considerable changes in the traditional method which can be done with led efforts, time and money. This technique can also be planned to be implemented at consumer level.This paper tended to the dynamic and responsive power conveyance among fell PV inverter modules and their effects on power quality and framework dependability for the huge scale lattice associated fell PV framework. The yield voltage for each\ module was isolated in view of lattice current synchronization to accomplish free dynamic and responsive power conveyance. A decoupled dynamic and responsive power control technique was produced to improve framework operation execution. The proposed control system empowered the fell PV inverter modules to sufficiently typify their particular responsive power remuneration ability paying little heed to their dynamic power era. In addition, it was exhibited that the danger of over tweak of the yield voltage from the fell PV inverter modules can be viably decreased, which enhances framework control quality and steadiness. Correspondingly, the recreation and exploratory results affirmed the legitimacy of the proposed control system

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