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Modular Multilevel Converter D-STATCOM for Grid Connected Small Wind Turbines

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Abstract: Multilevel inverters have received more attention in industrial application, such as motor drives, FACTS devices and renewable energy systems, etc. Primarily multilevel inverters are known to have output voltages with more than two levels. A modular multilevel converter (MMC) is one of the next-generation multilevel converters intended for high or medium-voltage power conversion without transformers. Compared with the existing multilevel converters, one of the most desirable advantages offered by MMC may be its ability to process both active power and reactive power with its terminals directly connected to directly high-voltage networks. D-STATCOM (Distribution Static Compensator) is a shunt device which is generally used to solve power quality problems in distribution systems. D-STATCOM is used in correcting power factor, maintaining constant distribution voltage and mitigating harmonics in a distribution network. In this project MMC D-STATCOM inverter controls the DC link voltage as well as the active and reactive power transferred between the renewable energy source, specifically wind turbine, and the grid in order to regulate the power factor (PF) of the grid regardless of the input active power from wind turbine. The proposed topology developed by using Matlab/simulink software. In extension to the base paper we can compare the proposed MMC type of inverter with the 9 level MMC inverter.

Keywords: Multilevel Inverters, D-STATCOM, Modular Multilevel Converter (MMC), PF.

I. INTRODUCTION

Recently renewable energy power supplied into the utility grid has been paid much attention due to increase in fossil fuel prices, environmental pollution and energy demand boom. Among various renewable energy resources such as solar, wind, tidal, geothermal, biomass etc., the solar photovoltaic system being more attractive and promising green resource because of its abundant availability, safe resource, cost free and eco-friendly. The solar photovoltaic (PV) modules directly converts the light energy into the electrical energy, but energy obtained from the PV module acts as low voltage DC source and has relatively low conversion efficiency. In order to improve the efficiency and convert low voltage DC source into usable AC source, the power electronics converters are used to transform DC into AC. Conventional inverter topologies such as voltage source inverter (VSI) and the current source inverter (CSI) are being utilized to convert solar power generated electrical power into the utility grid. Whereas these topologies require additional DC/DC converter stage resulting in a two stage power conversion and also require interfacing transformer to inject power into the grid. These topologies not only increase the circuit complexity but also increase the cost and space requirements. The single stage solar power conversion will satisfy all the control objectives like maximum power point tracking (MPPT), synchronization with grid voltage, and lower harmonic content in the output current. At present scenarios several solutions for a grid connected PV system with conventional two-level and multilevel inverter has been reported in the literature. In case of two-level inverter, it inject maximum PV power into the grid with a unity power factor, however the system fails to be free from higher order harmonics, high voltage stress across the semiconductor power switch and high power losses due to high switching frequency.

In order to overcome the above mentioned problems, multilevel inverter came into picture and attracted more attention because of their significant properties. They offer lower total harmonic distortion (THD), low dv/dt device switch voltage stress, lowering the switch voltage and power rating etc. The multilevel inverter is well suited for high power medium voltage applications and in particular dominated by cascaded multilevel inverter and neutral point clamped multilevel inverter. In these medium voltage applications cascaded multilevel inverter and neutral point clamped multilevel inverter requires transformer to obtain electrical isolation between active DC sources of the H-bridge or NPC converter cells. This condition introduces losses, increases converter footprint, making converter costly, bulky and complex. The main drawback of the cascaded multilevel converter coupled with the transformer makes circulation current between phase during unbalanced network conditions and it may cause asymmetrical phase voltages. The modular multilevel inverter has strong potential to replace cascaded multilevel converter in medium voltage applications. This concept, presents the design of a solar photovoltaic power conversion system with single stage modular multilevel converter.

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Currently intensive research is going on in MMC and it has high potential for medium power applications. Modular multilevel converters have several advantages over conventional multilevel topologies. Among the all power quality concers is controlling the active and reactive power transferring to or from the grid requires attention. Now days, this attention is possible using power electronics. The distributed energy sources such as wind and solar have been attracting increasing interest in recent years. Recently, distributed generation (DG) has been introduced to the modern power systems in order to avoid generating power and transmitting it over a long distance . Relatively small power generations such as small wind or solar system, would be an approach to penetrate renewable to the power systems.

A. Photovoltaic Systems

A photovoltaic system, converts the light received from the sun into electric energy. In this system, semi conductive materials are used in the construction of solar cells, which transform the self contained energy of photons into electricity, when they are exposed to sun light. The cells are placed in an array that is either fixed or moving to keep tracking the sun in order to generate the maximum power. These systems are environmental friendly without any kind of emission, easy to use, with simple designs and it does not require any other fuel than solar light. On the other hand, they need large spaces and the initial cost is high.

B. Fuel Cells

Fuel cells operation is similar to a battery that is continuously charged with a fuel gas with high hydrogen content; this is the charge of the fuel cell together with air, which supplies the required oxygen for the chemical reaction. The fuel cell utilizes the reaction of hydrogen and oxygen with the aid of an ion conducting electrolyte to produce an induced DC voltage. The DC voltage is converted into AC voltage using inverters and then is delivered to the grid. A fuel cell also produces heat and water along with electricity but it has a high running cost, which is its major disadvantage. The main advantage of a fuel cell is that there are no moving parts, which increase the reliability of this technology and no noise is generated. Moreover, they can be operated with a width spectrum of fossil fuels with higher efficiency than any other generation device. On the other hand, it is necessary to assess the impact of the pollution emissions and ageing of the electrolyte characteristics, as well as its effect in the efficiency and life time of the cell.

C. Wind Turbines

Wind turbines transform wind energy into electricity. The wind is a highly variable source, which cannot be stored, thus, it must be handled according to this characteristic. The principle of operation of a wind turbine is characterized by two conversion steps. First the rotor extract the kinetic energy of the wind, changing it into mechanical torque in the shaft; and in the second step the generation system converts this torque into electricity. In the most common system, the generator system gives an AC output voltage that is dependent on the wind speed. As wind speed is variable, the voltage generated has to be transferred to DC and back again to AC with the aid of inverters. However, fixed speed wind turbines are directly connected to grid.

II. CONCEPT OF MMC TOPOLOGY

The modular multilevel converter (MMC) is the most advanced topology for large scale commercial development. MMC is the topology used by SIEMENS for HVDC plus technology. The structure of this topology is based on several modules in which each module consists of a floating capacitor and two switches. This topology is an ideal choice for FACTS applications if the capacitor voltages maintain balanced. MMC is able to transfer active and reactive power regardless of the load characteristics. The main drawback of this topology is that it is requires large capacitors in comparison with similar topologies which may effect the total cost of the inverter. However, this problem can be alleviated by the lack of need for any snubber circuits. The main benefits of the MMC topology are : modular design based on identical converter cells, simple voltage scaling by a series connection of cells, simple realization of redundancy, and possibility of a common DC bus. Although MMC are investigated with many applications, but it has not been reported in the literature with single stage solar PV power conversion system. This concept demonstrates the effective implementation of the photovoltaic supported MMC for grid interface which satisfy all the control objectives like maximum power transferring under varying environmental conditions, synchronizing grid utility voltage with output current for unity power factor operation and low total harmonic distortion.

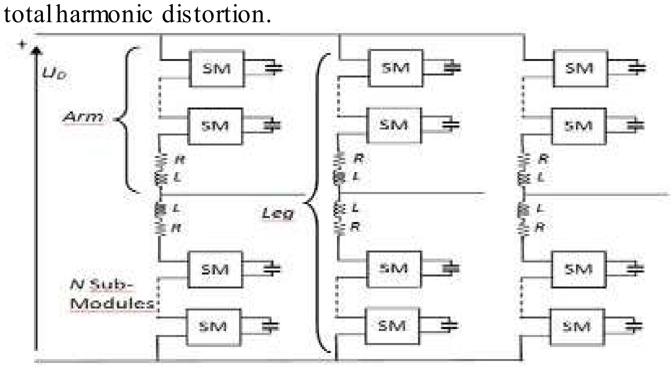

Fig.1. Schematic of a Three-Phase Modular Multi-Level Converter.

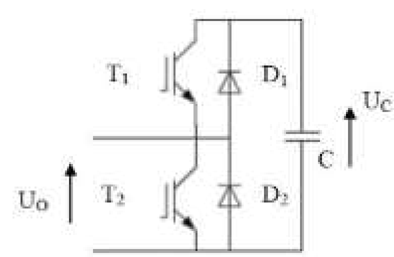

Fig.2. Chopper Cell of a Sub-Module.

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To describe the operation of MMC, each Sm can be considered as a wo-pole switch, it is defined as the status of the sub-module in the upper arm, is equal to the unity, then the output of the Sm is equal to corresponding capacitor voltage; otherwise it is zero. The typical structure of a MMC is shown in Fig1 and the configuration of a Sub-Module (SM) is given. Each SM is a simple chopper cell composed of two IGBT switches (T1 and T2), two anti-parallel diodes (D1 and D2) and a capacitor *C*. Each phase leg of the converter has two arms, each one constituted by a number N of SMs. In each arm there is also a small inductor to compensate for the voltage difference between upper and lower arms produced when a SM is switched in or out. To describe the operation of MMC, each SM can be considered as a two-pole switch. Ifs_{ui}, which is defined as the status of the i_{th}sub-module in the upper arm, is equal to unity, then the output of the i_{th}SM is equal to the corresponding capacitor voltage; otherwise it is zero. Likewise, if S_{li}, which is defined as the status of the i_{th}submodule in the lower arm, is equal to unity, then the output of the i_{th}lower SM is equal to the corresponding capacitor voltage; otherwise it is zero. Generally, when S_{ui} or $S_{li}$is equal to unity, the i_{th}upper or lower SM is ON; otherwise it is OFF. Therefore, the upper and lower arm voltages of the MMC are as follows:

$$v_{upperArm} = \sum_{i=1}^{n-1}(S_{ui}v_{ci}) + v_{l1} \quad (1)$$

$$v_{lowerArm} = \sum_{i=1}^{n-1}(S_{li}v_{ci}) + v_{l2} \quad (2)$$

Where $V_{upperArm}$, $V_{lowerArm}$ are the voltages of the upper and lower buffer inductors, is the number of voltage levels, and is the voltage of the SM's capacitor in upper arm or lower arm. Therefore, the output DC and AC voltages of the 5-level MMC are described by:

$$v_{dc} = v_{upperArm} + v_{lowerArm} = \sum_{i=1}^{4}(S_{ui}v_{ci}) + \sum_{i=1}^{4}(S_{li}v_{ci}) + (v_{l1+}v_{l2}) \quad (3)$$

$$v_{out} = {}^{v_{dc}}/_{2} - v_{upperArm} = -{}^{v_{dc}}/_{2} + v_{lowerArm} \quad (4)$$

The carrier-based pulse width modulation (CPWM) method is used in this concept to control the SMs' voltages. Fig3 shows the reference and the carrier waveforms for a 5-level CPWM.

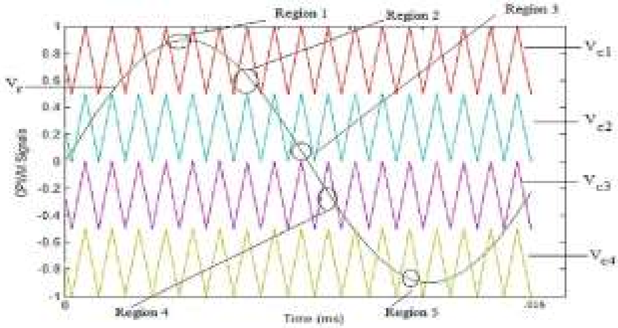

Fig.3. CPWM Waveforms for a 5-Level MMC.

Fig3 shows that there are five operating regions for a 5-level MMC defined in Table1.

TABLE I. Operating Regions for a 5-Level MMC

Region	Status	$n_{UpperArm}$	$n_{lowerArm}$	V_{out}
1	$v_r \geq v_{c1}, v_{c2}, v_{c3}, v_{c4}$	0	4	${}^{v_{dc}}/_{2}$
2	$v_r < v_{c1}$ $v_r \geq v_{c2}, v_{c3}, v_{c4}$	1	3	${}^{v_{dc}}/_{4}$
3	$v_r < v_{c1}, v_{c2}$ $v_r \geq v_{c3}, v_{c4}$	2	2	0
4	$v_r < v_{c1}, v_{c2}, v_{c3}$ $v_r \geq v_{c4}$	3	1	$-{}^{v_{dc}}/_{4}$
5	$v_r < v_{c1}, v_{c2}, v_{c3}, v_{c4}$	4	0	$-{}^{v_{dc}}/_{2}$

Where $n_{upperArm}$ and $n_{lowerArm}$ are the numbers of SMs which are ON in the upper arm or lower arm, respectively. The total number of SMs with the status of ON is:

$$n_{upperArm} + n_{lowerArm} = 4 \quad (5)$$

The most critical issue to control MMC is to maintain the voltage balance across all the capacitors. Therefore, the SM' voltages are measured and sorted in descending order during each cycle. If the current flowing through the switches is positive, $n_{upperArm}$ and $n_{lowerArm}$of the SMs in upper arm and lower arm with the lowest voltages are selected, respectively. As a result, 4 capacitors with lowest voltages are chosen to be charged. Likewise, if the current flowing through the switches is negative, $n_{upperArm}$ and $n_{lowerArm}$of the SMs in upper arm and lower arm with the highest voltages are selected, respectively. As a result, 4 capacitors with highest voltages are chosen to be discharged. Consequently, the voltages of the SMs' capacitors are maintained balanced.

III. CONTROLLER DESIGN

The aim of the designed D-STATCOM inverter is to provide utilities with distributive control of VAR compensation and power factor (PF) on feeder lines. This inverter is able to control the active and reactive power regardless of the input active power required by the DC link.

A. Simple System Diagram Describing the Power Flow between Two Sources

Control over the reactive power provided by the STATCOM is achieved by selecting both the voltage level of the STATCOM and the angle between the two voltages δ. By using power electronics it is possibleto control the amplitude of the STATCOM voltage by adjusting the modulation index m and the angle δ adding a delay to the firing signals. Adding the modulation index into (6) and (7) gives:

$$P_S = \frac{mE_SE_L}{X}\sin\delta \quad (6)$$

$$Q_S = \frac{mE_SE_L\cos\delta - E_L^2}{X} \quad (7)$$

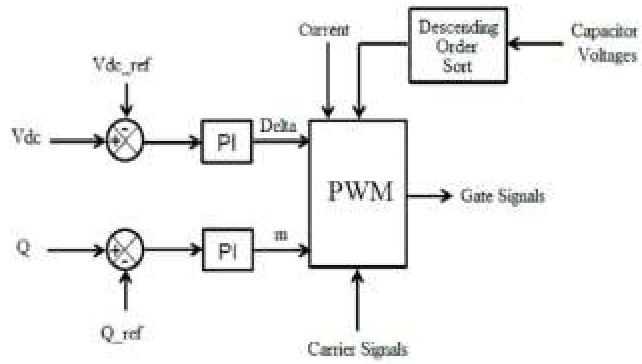

Fig.4. Control System Schematic

IV.SIMULATION RESULTS

A)EXISTING RESULTS

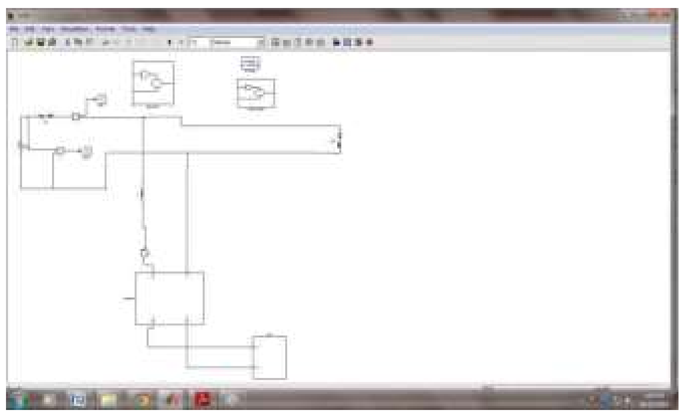

Fig.5. Output Voltage of the D-STATCOM for Five Level Inverter

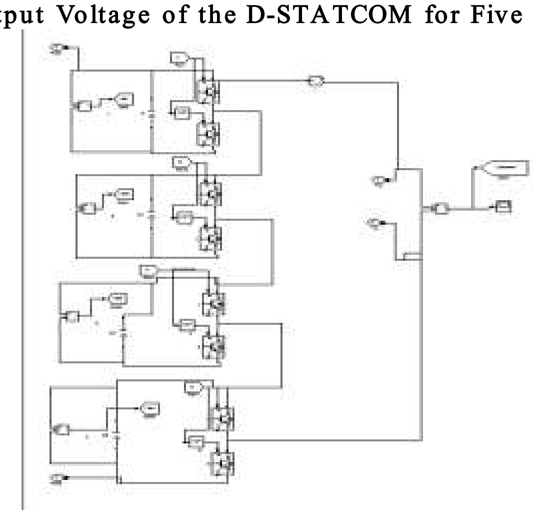

Fig 6 subsystem of DSTATCOM with 5 level converter

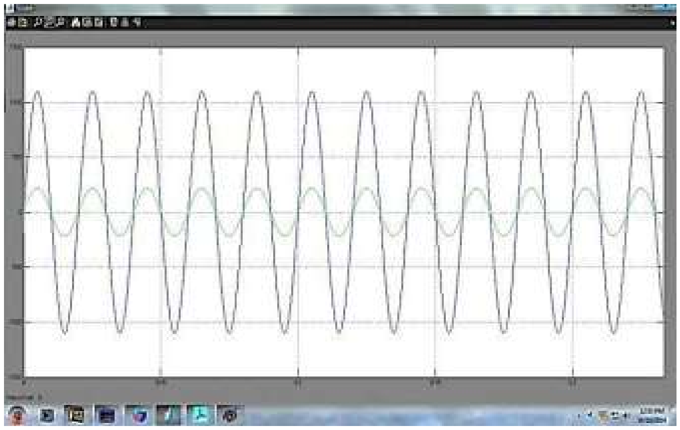

Fig.7. Shows the MATLAB/Simulink Model of Proposed Converter

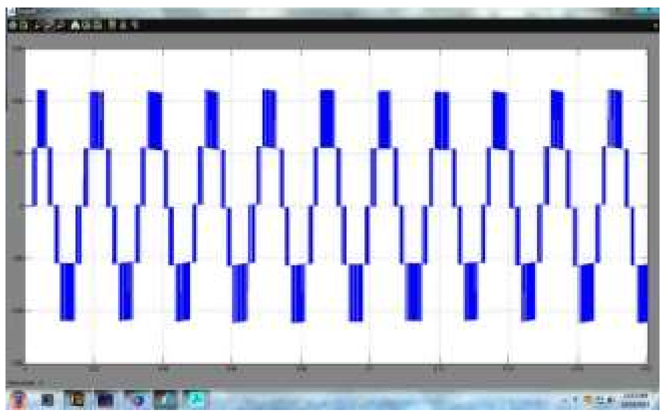

Fig.8. Output voltage of the D-STATCOM for five level inverter

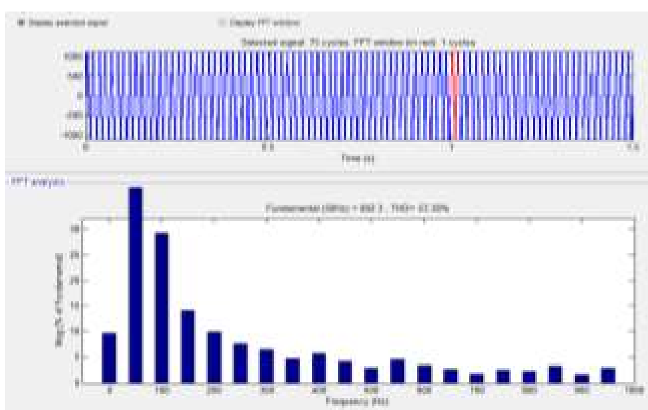

Fig.9 shows the total harmonic distortion of 53.38% without filter

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B) EXTENSION RESULTS

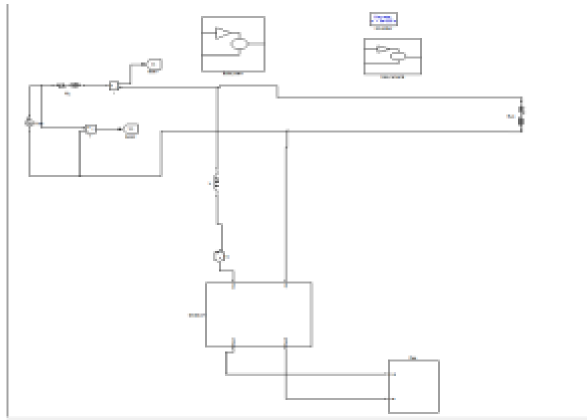

FIG 10 shows the Matlab/simulink model of proposed DSTATCOM

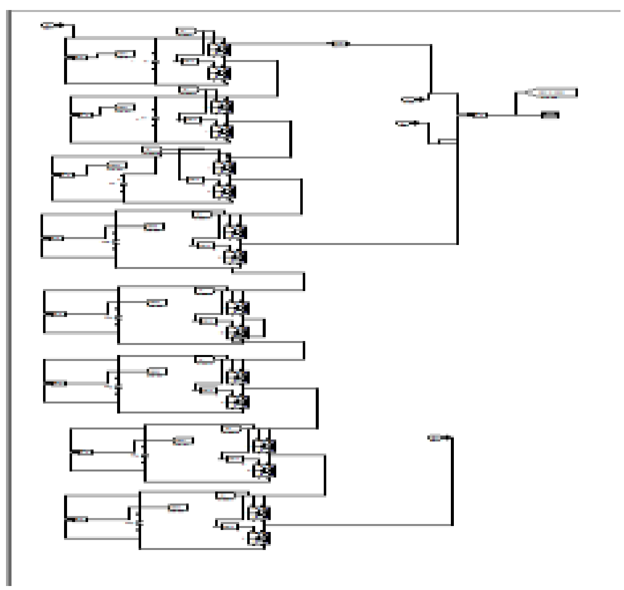

Fig.11 subsystem of nine level DSTATCOM

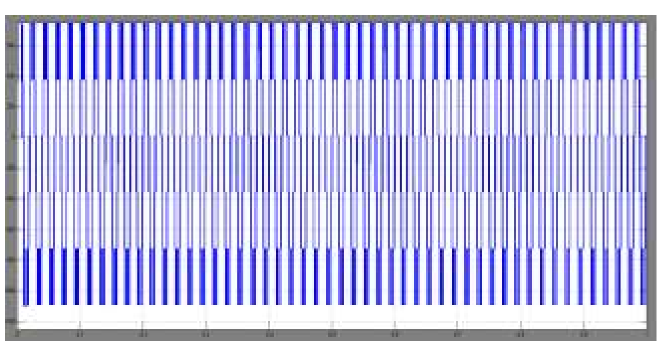

Fig.12 output voltage waveform of the Nine level D-STATCOM

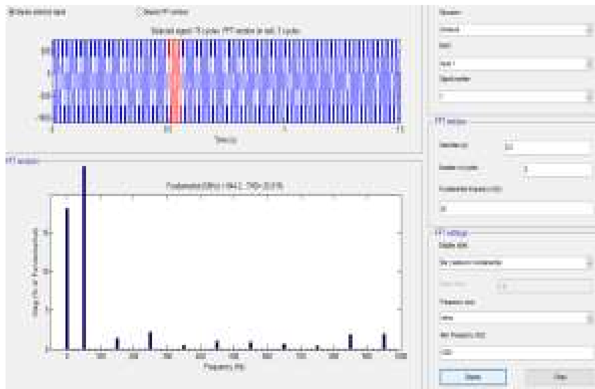

Fig.13 shows the total harmonic distortion of 25.01% without filter

V.CONCLUSION

The proposed D-STATCOM inverter performs in two modes: 1) inverter mode, in which there is a variable active power from the wind turbine, 2) D- STATCOM mode, in which the DC link is open circuit and no active power is gained from the renewable energy source. Finally by increasing the levels, power quality is also improved so in the next generation this concept can be implemented at higher levels to improve the Power Quality.

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