

# A New and Strange 15 Level Inverter Topology for Harmonic Reduction Using Hybrid Renewable Energy System

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**ABSTRACT:** The electrical power quality issue has been the main concern of the power companies. A power quality difficult can be defined as any problem is established on voltage, current, or frequency variation that results in power failure. This paper presents a new single-phase 15-level (3 H-bridges) Cascade Multilevel DC-AC inverter. The proposed system is to design a new type of inverter with Flexible AC Transmission System (FACTS) capabilities. The inverter is connected between the hybrid sources which consists of wind and solar and the distributed loads in order to regulate the active and reactive power. Cascaded Multilevel Converters used as the topology to meet all the requirements of a single-phase system such as Total Harmonic Distortion (THD), efficiency, and total cost of the system. This inverter is capable of controlling active and reactive power by controlling its phase angle and modulation index. The function of the proposed inverter is to transfer active power to the grid as well as keeping the PF of the local power lines constant at a target Power Factor (PF). The results are obtained by simulation.

**KEYWORDS:** Multi Level Inverter (MLI), Cascaded H-Bridge Inverter (CHB), Solar Energy Inverter, D-STATCOM.

## I. INTRODUCTION

Because of energy resources and their utilization will be a prominent concern of this era, the problems of natural resource reduction, environmental waves, and the rising demand for new energy resources have been discussed commonly in recent years. Some forms of renewable zero-pollution energy resources, including wind, solar, bio, geothermal and hence into view, have gained more importance and are being researched by many scientists and engineers [1-2]. Solar cell installations occupy the use of multiple solar panels or parts, which can be coupled in series or in parallel to afford the preferred voltage level to the inverter. Thus, the Cascaded H-bridge multilevel inverter topology requires a separate DC source for each H-bridge so that high power and/or high voltage that can outcome from the combination of the multiple modules in a multilevel inverter would favour this topology [3-6]. To maximize the energy produced from each network, a maximum power point tracking (MPPT) approach is required. The task of finding the optimum operation point may enhance the complexity and component count as the number of isolated DC sources increase. The approach selected to deal with the number of input sources was to supervise AC output power parameters instead of DC input measurement [7].

A high PF is normally popular in a power system to decrease power losses and enhance voltage regulation at the load. It is often desired to regulate the PF of a system to nearby 1.0. When reactive elements supply or absorb reactive power nearby the load, the apparent power is reduced. In other words, the current drawn by the load is decreased, which reduces the power losses. Therefore, the voltage regulation is produced if the reactive power compensation is performed near large loads. Traditionally, utilities have to use capacitor banks to compensate the PF issues, which will increase the total cost of the system. The current way of controlling the PF of these power lines is to use small distribution static synchronous compensators (D-STATCOMs). The D-STATCOMs are usually placed in parallel with the distributed generation systems as well as the power systems to function as a source or sink of reactive power to increase the power quality issues of the power lines.

The STATCOM used in distribution systems is called D-STATCOM (Distribution-STATCOM) and its configuration is the same, but with small alterations. It can swap both active and reactive power with the distribution system by changing the amplitude and phase angle of the converter voltage with respect to the line terminal voltage. A multilevel inverter can decrease the device voltage and the output harmonics by increasing the number of output voltage levels. There are different types of multilevel inverters: cascaded H-bridge (CHB), neutral point clamped, flying capacitor [8-11]. In particular, among these topologies, CHB inverters are being generally used for the reason that of their modularity and simplicity. Different modulation methods can be applied to CHB inverters. CHB inverters can also increase the number of output voltage levels easily by raising the number of H-bridges.

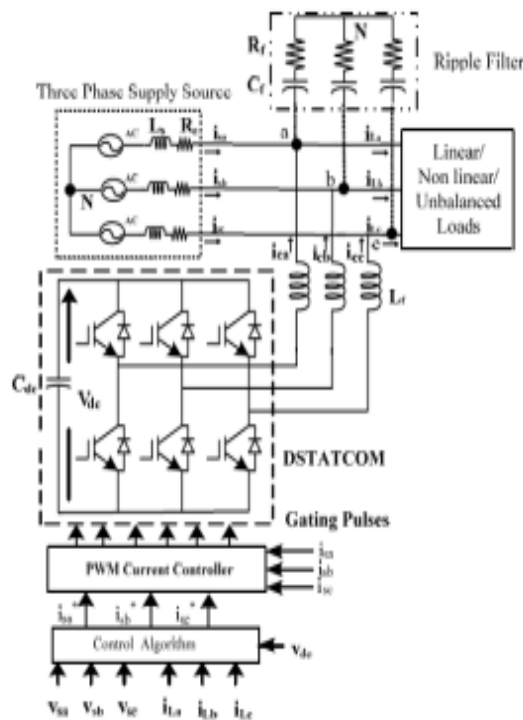


Fig.1 Schematic diagram of D-STATCOM

Fig. 1 shows the schematic diagram of a DSTATCOM coupled to a three phase AC mains feeding three phase loads. Three phase loads may be a lagging power factor load or an unbalanced load or non-linear loads or mixed of these loads. For dropping ripple in compensating currents, interfacing inductors ( $L_f$ ) are used at AC side of the voltage source converter (VSC). A small series connected capacitor ( $C_f$ ) and resistor ( $R_f$ ) indicates the ripple filter placed at PCC in parallel with the loads and the compensator to filter the high frequency switching noise of the voltage at PCC.

In an existing system, the modular multilevel inverter is implemented, so the power injected is done without harmonics, the reactive power injected is done with reduced harmonics. Due to the development of harmonics the regulation of the system is low. So the overall efficiency of the circuit is less compared to the proposed system. For increasing voltage levels the number of switches also will increase in number. Hence the voltage stresses and switching losses will increase and the circuit will become difficult. By using the proposed topology number of switches will reduce significantly and hence the efficiency will improve.

In the proposed system, 11-level Cascaded h-bridge inverter with Multi-Carrier PWM is used. Because the Multiple Carrier PWM to remove the each h-bridge modules with single source. Here, Cascaded H-bridge inverter with PI Controller technique. This control technique to increase the modulation level of Cascaded H-bridge inverter by using

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error tolerance value. The error will be compared with voltage reference using single control technique with minimum harmonics calculation.

The main advantages of proposed system are easy to control the real and reactive power compensation, to control the voltage stability. So the harmonics of the circuit is very low. The target power factor and efficiency is also being improved.

This paper deals simulation design of single phase cascaded 11- level inverter with separate four dc sources and one renewable energy sources using and multicarrier pulse width modulation technique and the output results of both methods are compared is illustrated in Fig.2.

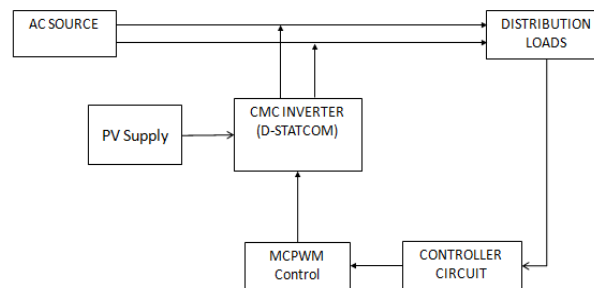


Fig. 2 Block diagram of proposed system

## II. SOLAR ENERGY SYSTEM

A solar panel is a set of photovoltaic modules electrically connected and mounted on a sustaining structure. A photovoltaic module is a packaged, connected assembly of solar cells. The solar module can be used as a component of a larger photovoltaic system to produce and supply electricity in commercial and residential applications. Each module is rated by its DC output power below standard test conditions (STC), and typically ranges from 100 to 320 watts. The efficiency of a module determines the area of a module specified the same rated output - an 8% efficient 230 watt module will have twice the area of a 16% efficient 230 watt module. A single solar module can generate only a limited amount of power; most installations contain multiple modules. A photovoltaic system typically includes a panel or an array of solar modules, an inverter, and at times a battery and or solar tracker and interconnection wiring.

A photovoltaic cell is the basic device that converts solar radiation into electricity which is made of semiconductor materials, such as silicon. For solar cells, a thin semiconductor wafer is specially treated to form an electric field, positive on one side and negative on the other. When light energy strikes the solar cell, electrons are knocked movable from the atoms in the semiconductor material. If electrical conductors are attached to the positive and negative sides, forming an electrical circuit, the electrons can be captured in the form of an electric current that is, electricity. This electricity can then be used to power a load. A PV cell can either be circular or square in construction.

Cells are set in a frame to form a module. The several PV cells are connected in series (for high voltage) and in parallel (for high current) to form a PV module for preferred output. Separate diodes may be wanted to avoid reverse currents, in case of partial or total shading, and at night. The p-n junctions of mono-crystalline silicon cells may have adequate reverse current characteristics and these are not essential. Reverse currents waste power and can also direct to overheating of shaded cells. Solar cells become less efficient at higher temperatures and installers try to provide good ventilation behind solar panels. Each PV cell is rated for 0.5 –0.7 volt and a current of 30mA. Based on the manufacturing process they are classified as: Poly crystalline: efficiency of 12%. Amorphous: efficiency of 6-8% Life of crystalline cells is in the range of 25 years where as for amorphous cells it is in the range of 5years.

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The power that one module can produce is not sufficient to meet the requirements of home or business. Most PV arrays use an inverter to convert the DC power into alternating current that can power the motors, loads, lights etc. The modules in a PV array are usually first coupled in series to obtain the desired voltages, the individual modules are then connected in parallel to allow the system to generate more current.

The materials used in PV cells are as follows:

- (i) Single-crystal silicon
- (ii) Polycrystalline silicon
- (iii) Gallium Arsenide (GaAs)
- (iv) Cadmium Telluride (CdTe)
- (v) Copper Indium Diselenide (CuInSe<sub>2</sub>)

The efficiency of a PV cell is defined as the ratio of peak power to input solar power. The efficiency will be maximum, if we track the maximum power from the PV system at different environmental situation such as solar irradiance and temperature by using various methods for maximum power point tracking.

When two identical cells are coupled in series, the short circuit current of the system would stay same but the open circuit voltage would be twice. When two cells are connected in parallel. The open circuit voltage of the system would remain same as open circuit voltage of a single cell. But the short circuit current of the system would be twice as much as of a single cell.

### III. PULSEWIDTH MODULATION TECHNIQUE

The advent of the transformer less multilevel inverter topology has brought forth various pulse width modulation (PWM) schemes as a means to control the switching of the active devices in each of the multiple voltage levels in the inverter. The best efficient method of controlling the output voltage is to incorporate pulse width modulation control (PWM control) within the inverters. In this technique, a fixed dc input voltage is supplied to the inverter and a controlled ac output voltage is attained by adjusting the on and-off periods of the inverter devices. The voltage type of PWM inverters have been applied widely to such fields as power supplies and motor drives. This is because: (1) such inverters are well adapted to high-speed self turn-off switching devices that, as solid-state power converters are recently developed with advanced circuits; and (2) they are operated stably and can be controlled well.

The PWM control technique has the following advantages:

- (i) The output voltage can be controlled without any additional components.
- (ii) With this type of control, lower order harmonics can be eliminated or minimized along with its output voltage control. The filtering requirements are minimized as higher order harmonics can be filtered easily.

The commonly used PWM control techniques are:

- (i) Sinusoidal PWM
- (ii) Space vector PWM.

The performance of these control method is usually judged based on the following parameters: a) Total harmonic distortion (THD) of the voltage and current at the output of the inverter, b) Switching losses within the inverter, c) Peak-to-peak ripple in the load current, and d) Maximum inverter output voltage for a given DC rail voltage.

### IV. PROPOSED MODULATION TECHNIQUE

This technique includes the carrier based PWM. These are the classical and most widely used methods of pulse width modulation. They have as common characteristic sub cycles of constant time duration, a sub cycle being defined as the total duration  $T_s$  during which an active inverter leg assumes two successive switching states of opposite voltage

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polarity. Operation at sub cycles of constant duration is reflected in the harmonic spectrum by two salient sidebands, centred on the carrier frequency, and extra frequency bands around integral multiples of the carrier.

The multi carrier modulation technique is very appropriate for a multilevel inverter circuit. By using this technique along with the multilevel topology, the low THD output waveform without any filter circuit is possible. Switching devices, in addition, turn on and off only one time per cycle. That can conquer the switching loss difficulty, as well as EMI problem. The PWM switching pattern developed for the proposed inverter is given below.

TABLE I

Voltage level	Status	n <sub>UpperArm</sub>	n <sub>LowerArm</sub>	V <sub>out</sub>
1	$V_r \geq V_{c1}, V_{c2}, V_{c3}, V_{c4}, V_{c5}, V_{c6}, V_{c7}, V_{c8}, V_{c9}, V_{c10}$	0	10	$5v_{dc}/10$
2	$V_r < V_{c1}, V_r \geq V_{c2}, V_{c3}, V_{c4}, V_{c5}, V_{c6}, V_{c7}, V_{c8}, V_{c9}, V_{c10}$	1	9	$4v_{dc}/10$
3	$V_r < V_{c1}, V_{c2}, V_r \geq V_{c3}, V_{c4}, V_{c5}, V_{c6}, V_{c7}, V_{c8}, V_{c9}, V_{c10}$	2	8	$3v_{dc}/10$
4	$V_r < V_{c1}, V_{c2}, V_{c3}, V_r \geq V_{c4}, V_{c5}, V_{c6}, V_{c7}, V_{c8}, V_{c9}, V_{c10}$	3	7	$2v_{dc}/10$
5	$V_r < V_{c1}, V_{c2}, V_{c3}, V_{c4}, V_r \geq V_{c5}, V_{c6}, V_{c7}, V_{c8}, V_{c9}, V_{c10}$	4	6	$v_{dc}/10$
6	$V_r < V_{c1}, V_{c2}, V_{c3}, V_{c4}, V_{c5}, V_r \geq V_{c6}, V_{c7}, V_{c8}, V_{c9}, V_{c10}$	5	5	0
7	$V_r < V_{c1}, V_{c2}, V_{c3}, V_{c4}, V_{c5}, V_r \geq V_{c6}, V_{c7}, V_{c8}, V_{c9}, V_{c10}$	6	4	$-v_{dc}/10$
8	$V_r < V_{c1}, V_{c2}, V_{c3}, V_{c4}, V_{c5}, V_r \geq V_{c6}, V_{c7}, V_{c8}, V_{c9}, V_{c10}$	7	3	$-2v_{dc}/10$
9	$V_r < V_{c1}, V_{c2}, V_{c3}, V_{c4}, V_{c5}, V_r \geq V_{c6}, V_{c7}, V_{c8}, V_{c9}, V_{c10}$	8	2	$-3v_{dc}/10$
10	$V_r < V_{c1}, V_{c2}, V_{c3}, V_{c4}, V_{c5}, V_r \geq V_{c6}, V_{c7}, V_{c8}, V_{c9}, V_{c10}$	9	1	$-4v_{dc}/10$
11	$V_r < V_{c1}, V_{c2}, V_{c3}, V_{c4}, V_{c5}, V_r \geq V_{c6}, V_{c7}, V_{c8}, V_{c9}, V_{c10}$	10	0	$-5v_{dc}/10$

Fig. 3. Operating regions for an 11-level CMC inverter

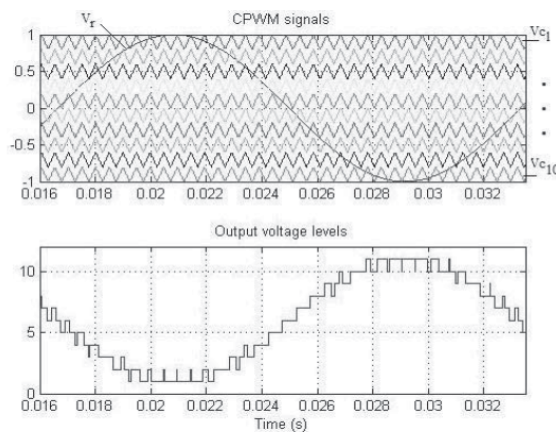


Fig. 4 CPWM waveforms for an 11-level CMC inverter, and the generated output voltage levels.

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With the development of high technique industries, the requirements to power quality have become severe. Utility distribution networks, sensitive industrial loads and critical commercial operations all suffer 80% from various types of outages and service interruptions which can cost important financial loss per incident based on process down-time, production, idle work forces, and other factors. The presently power quality problems mainly includes unbalance, flicker, harmonics, sag, dip, swell, and interruption. These power quality problems may lead to abnormal operations of facilities or even trip the protection devices. Therefore the protection and enhancement of electrical power quality has become an important scenario today.

A static synchronous generator operated as a shunt connected static VAR compensator whose capacitive or inductive output current can be controlled independent of the AC system voltage in a Distribution system. As per this thesis, D-STATCOM can be used at this primary distribution to regulate the bus voltage (11KV) and correct the power factor. Voltage source converter (VSC) is provided to offer bus voltage control and power factor correction. A simple multifunction controller is provided to offer D.c bus voltage control, power factor correction and a.c voltage control of the distribution bus (11KV).

Now days, PI controller selected for some ac to dc application. Because PI controller doesn't modify anything in the stability, but PID controller reduces the steady state error and also increases the stability. The proposed controller consists of three major functions. The first function is to control the active and reactive power transferred to the power lines, the second function is to keep the voltages of the SMs' capacitors balanced, and the third function is to produce desired PWM signals. Fig.5 shows the complete proposed controller system.

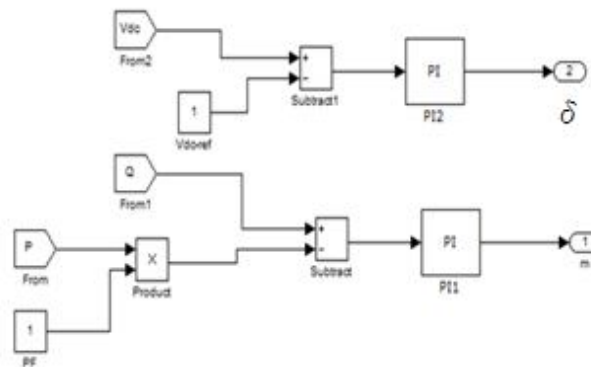


Fig.5 Schematic diagram of the proposed controller system

Where,

**m** → To control the reactive power compensation and its main task is to make the PF of the grid equal to the target PF.

**δ** → the control parameter to adjust the active power control between the inverter and the grid.

The target reactive power for the grid is resolute and is compared with the actual value of the reactive power of the grid. Using a PI compensator will decide the desired value for the modulation index. The power angle is also determined by comparing the actual dc voltage of the inverter with a reference value. A PI compensator determines the desired value for the power angle.

Control scheme has some units as follows,

1. Power measurement
2. Fast Power Detector
3. DC Voltage control
4. Phase locked loop

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5. Compensation Current control
6. PI controller
7. Pulse-width-modulated pattern generator

The THD in output voltage obtained in second scheme is 13.49% while for cascaded H-Bridge inverter the minimum THD found upto 5 stages is 14.99%. This shows that if the stages of the converter in first scheme (Cascaded H-Bridge) are 5 or less, the THD will be more i.e. the power quality will be poor as compare to second scheme. Also the switches used and the output level in first scheme having 5 stages are 20 and 6 respectively. While the switches used and output level in second scheme are 10 and 15 respectively.

This project shows only the comparison of two schemes without the use of filter. The THD obtained in output load voltage may always be reduced below 5% by using filter in both schemes. In first scheme, for 8 stage converter, the THD obtained in voltage is found to be 2.6%. However, the cost of this scheme becomes very large as compare to second scheme due to large number of switches used.

## IV. SIMULATION RESULTS

The design of an 11-level MMC converter was carried out in MATLAB/SIMULINK.

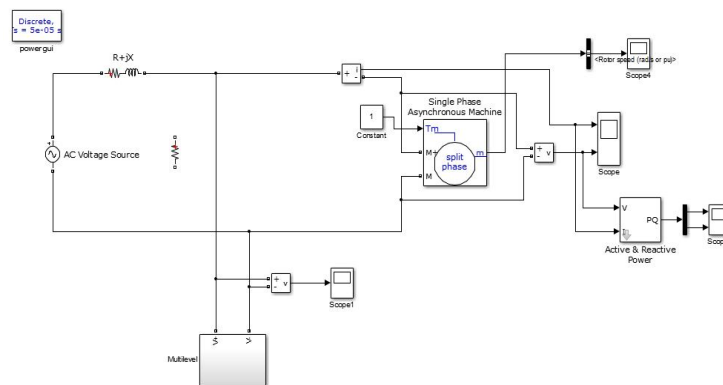


Fig.6 Simulation diagram of main circuit

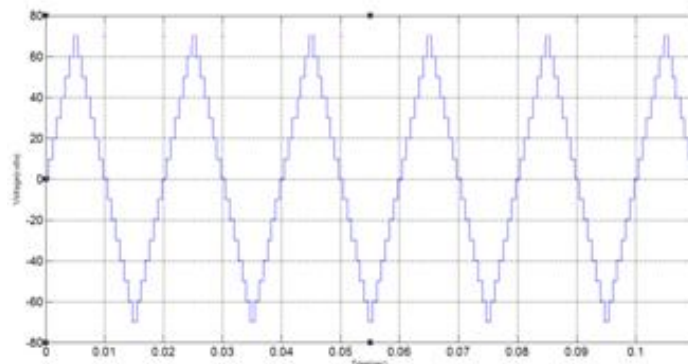


Fig. 7 D-STATCOM Multilevel Output

Fig. 7 shows the output voltage of the inverter where the switching frequency and the values of the LC filter is 2 kHz, 5 mH, and 10  $\mu$ F, respectively. The efficiency of the inverter is close to 0.95. The experimental output voltage

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THD and current TDD is 2.7 and 2.12%, respectively. The load PF is set to 0.65 and the target PF is 0.9. In this case, the job of the inverter is to fix the PF at the target PF regardless of the input active power from the solar emulator.

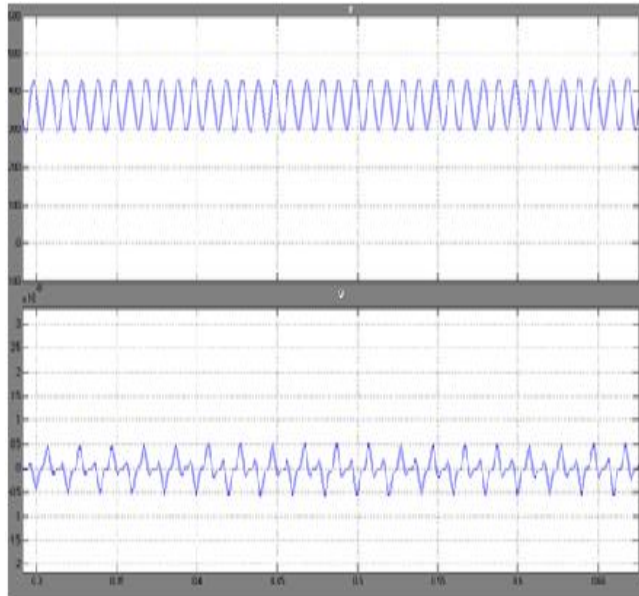


Fig.8 Real and Reactive power Output

Fig. 8 shows the output active and reactive power from the solar turbine. In the simulation, the local load makes the PF 0.82. When the simulation starts, the inverter provides enough compensation to reach the target PF 0.90.

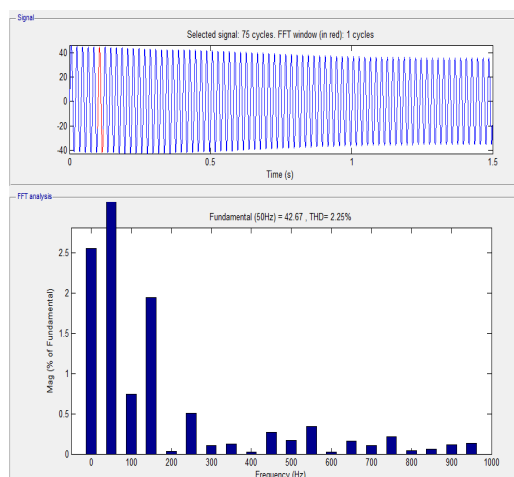


Fig.9 THD analysis waveform

The inverter transfers the whole active power of the wind, excluding its losses, to the grid. The amount of reactive power is dictated by the target PF. When the active power from the wind turbine increases, the controller increases the power angle  $\delta$  in order to output more active power to the grid in order to decrease the dc link voltage. The modulation



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index  $m$  is also increased when the inverter is supposed to inject more reactive power to the grid.

The transient response of the PI controllers used to control the modulation index and delta can be adjusted by changing the proportional and integral coefficients of the controllers. The practical results show that the performance of the proposed controller strategy is sufficiently close to the simulation result.

## VI. CONCLUSION

This paper presented an eleven-level cascade H-bridge inverter, which uses PLL and MPPT with separate solar panels as DC sources to interact with the power grid. The proposed system demonstrates the application of a new inverter with FACTS capability in a single unit without any additional cost. Replacing the traditional renewable energy inverters with the proposed inverter will eliminate the need of any external STATCOM devices to regulate the Reactive power of the grid. Clearly, depending on the size of the compensation, multiple inverters may be needed to reach the desired THD. This shows a new way in which distributed renewable sources can be used to provide control and support in distribution systems. The proposed controller system adjusts the active power by changing the power angle (delta) and the reactive power is controllable by the modulation index  $m$ . The entire PV system structure and its interaction with the grid through PLL and MPPT algorithms were shown by the simulation and experimental results.

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