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A MMC Based Three-Phase Wind Energy Inverter (WEI) With Flexible AC Transmission System

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Abstract:

A Power quality problem is an occurrence of nonstandard voltage, current or frequency that results in a failure or a misoperation of end user equipments. Utility distribution networks, sensitive industrial loads and critical commercial operations suffer from various types of outages and service interruptions which can cost significant financial losses. With the increase in load demand, the Renewable Energy Sources (RES) are increasingly connected in the distribution systems which utilizes power electronic Converters/Inverters. This paper presents a single-stage, three-phase grid connected solar photovoltaic (SPV) system. The proposed system is dual purpose, as it not only feeds extracted solar energy into the grid but it also helps in improving power quality in the distribution system. The presented system serves the purpose of maximum power point tracking (MPPT), feeding SPV energy to the grid, harmonics mitigation of loads connected at point of common coupling (PCC) and balancing the grid currents. The SPV system uses a three-phase voltage source converter (VSC) for performing all these functions. An improved linear sinusoidal tracer (ILST)-based control algorithm is proposed for control of VSC. In the proposed system, a variable dc link voltage is used for MPPT. An instantaneous compensation technique is used incorporating changes in PV power for fast dynamic response. The SPV system is first simulated in MATLAB along with Simulink and simpower system toolboxes.

Keywords — **Power quality (PQ), renewable energy, Photo Voltaic (PV) System**

INTRODUCTION

The role of power electronics in distribution systems has greatly increased recently. The power electronic devices are usually used to convert the nonconventional forms of energy to the suitable energy for power grids, in terms of voltage and frequency. In permanent magnet (PM) wind applications, a back-to-back converter is normally utilized to connect the generator to the grid. A rectifier equipped with a maximum power point tracker (MPPT), converts the output power of the wind turbine to a dc power. The dc power is then converted to the desired ac power for power lines using an inverter and a transformer. With recent developments in wind energy, utilizing smarter wind energy inverters (WEIs) has become an important issue. There a lot of single-phase lines in the United States, which power small farms or remote houses. Such customers have the potential to produce their required energy using a small-to-medium-size wind turbine. Increasing the number of small-to-medium wind turbines will make several troubles for local utilities such as harmonics or power factor (PF) issues.

A high PF is generally desirable in a power system to decrease power losses and improve voltage regulation at the load. It is often desirable to adjust the PF of a system to near 1.0. When reactive elements supply or absorb reactive power near the load, the apparent power is reduced. In other words, the current drawn by the load is reduced, which decreases the power losses. Therefore, the voltage regulation is improved 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 modern ways of controlling the PF of these power lines is to use small distribution static synchronous compensators (D-STATCOMs). The D-STATCOMs are normally placed in parallel with the distributed generation systems as well as the power systems to operate as a source or sink of reactive power to increase the power quality issues of the power lines. Using regular STATCOMs for small-to-medium-size single-phase wind applications does not make economic sense and increase the cost of the system significantly. This is where the idea of using smarter WEIs with FACTS capabilities shows itself as a new idea to meet the targets of being cost-effective as well as compatible with IEEE standards. The proposed inverter is equipped with a D-STATCOM option to regulate the reactive power of the local distribution lines and can be placed between the wind turbine and the grid, same as a regular WEI without any additional cost. The function of the proposed inverter is not only to convert dc power coming from dc link to a suitable ac power for the main grid, but also to fix the PF of the local grid at a target PF by injecting enough reactive power to the grid. In the proposed control strategy, the concepts of the inverter and the D-STATCOM have been combined to make a new inverter, which possesses FACTS capability with no additional cost. The proposed control strategy allows the inverter to act as an inverter with D-STATCOM option when there is enough wind to produce active power, and to act as a D-STATCOM when there is no wind. The active power is controlled by adjusting the power angle δ, which is the angle between the voltages of the inverter and the grid, and reactive power is regulated by the modulation index m.

II. SYSTEM DESCRIPTION

There are a large number of publications on integration of renewable energy systems into power systems. A list of complete publications on FACTS applications for grid integration of wind and solar energy was presented in some publications. In some published papers, new commercial wind energy converters with FACTS capabilities are introduced without any detailed information regarding the efficiency or the topology used for the converters. In one published paper, a complete list of the most important multilevel inverters was reviewed. Also, different modulation methods such as sinusoidal pulsewidth modulation (PWM), selective harmonic elimination, optimized harmonic stepped waveform technique, and space vector modulation were discussed and com-pared. Among all multilevel topologies, the cascaded H-bridge multilevel converter is very well known for STATCOM applications for several reasons. The main reason is that it is simple to obtain a high number of levels, which can help to connect STATCOM directly to medium voltage grids. The modular multilevel converter (MMC) was introduced in the early 2000s. With reference to some published papers describes a MMC converter for high voltage DC (HVDC) applications. This project mostly looks at the main circuit components. Also, it compares two different types of MMC, including H-bridge and full-bridge sub modules. In a publication new single-phase inverter using hybrid-clamped topology for renewable energy systems is presented.

The proposed inverter is placed between the renewable energy source and the main grid. The main drawback of the proposed inverter is that the output current has significant fluctuations that are not compatible with IEEE standards. The authors believe that the problem is related to the snubber circuit design. Several other applications of custom power electronics in renewable energy systems exist, including an application of a custom power interface where two modes of operation, including an active power filter and a renewable energy STATCOM. Another application looks at the current-source inverter, which controls reactive power and regulates voltage at the point of common coupling (PCC). An author propose an application of photovoltaic (PV) solar inverter as STATCOM in order to regulate voltage on three-phase power systems, for improving transient stability and power transfer limit in transmission systems. The authors called their proposed system PV-STATCOM. Similar to wind farms (when there is no wind), solar farms are idle during nights. We proposed a control strategy that makes the solar farms to act as STATCOMs during night when they are not able to produce active power.

1.MULTILEVEL INVERTER TOPOLAGIES

A typical MMC for an HVDC application contains around 300 sub modules connected in series in each valve and is therefore equivalent to a 301 level converter. Consequently the harmonic performance is excellent and usually no filters are needed. A further advantage of the MMC is that PWM is not necessary, with the result that the power losses are much lower than those of the 2-level converter, at around 1% per end. Finally, because direct series-connection of IGBTs is not necessary, the IGBT gate drives do not need to be as sophisticated as those for a 2-level converter. The MMC has two principal disadvantages. Firstly, the control is much more complex than that of a 2-level converter. Balancing the voltages of each of the sub module capacitors is a significant challenge and requires considerable computing power and high-speed communications between the central control unit and the valve. Secondly, the sub module capacitors themselves are large and bulky. A MMC is considerably larger than a comparable-rated 2-level converter, although this may be offset by the saving in space from not requiring filters. As

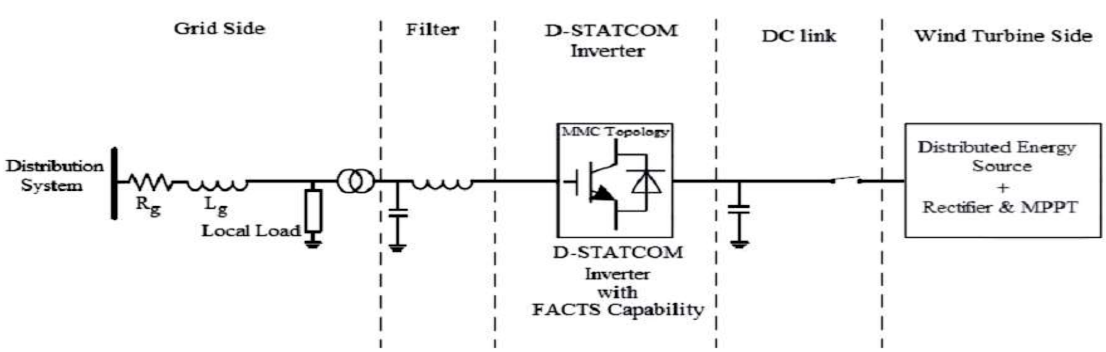

Fig. 1. Schematic of proposed renewable based distributed generation system

of 2012 the largest-capacity MMC HVDC system in operation is still the 400 MW Trans Bay Cable scheme but many larger schemes are under construction, including an underground cable interconnection from France to Spain consisting of two 1000 MW links in parallel at a voltage of ±320 kV.

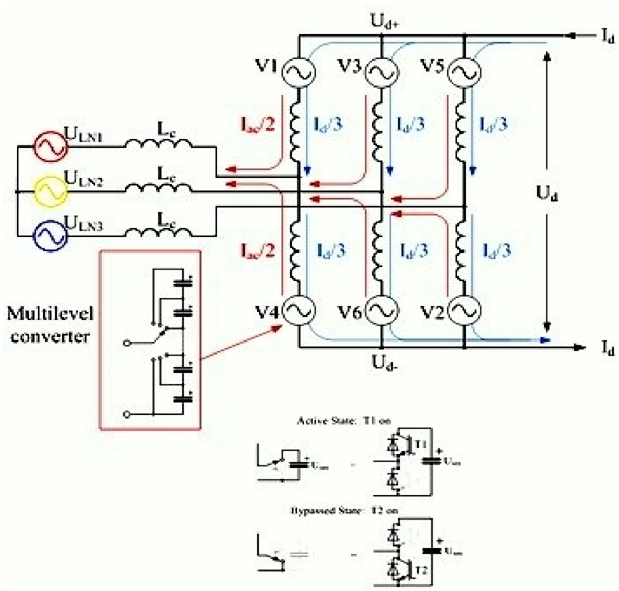

Fig. 2. Three phase MODULAR MULTILEVEL CONVERTER (MMC) for HVDC

B. Control System

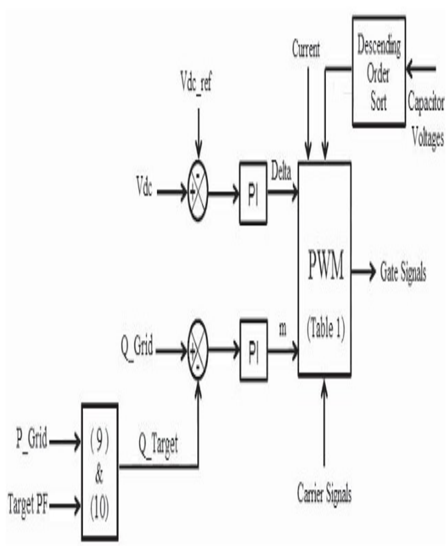

Fig. 3. Schematic of the Implementation controller system.

Fig.3 shows the complete Implementation controller system. The aim of the designed inverter is to transfer active power coming from the wind turbine as well as to provide utilities with distributive control of volt-ampere reactive (VAR) compensation and PF correction of feeder lines. The application of the proposed inverter requires active and reactive power tobe controlled fully independent, so that if wind is blowing, the device should be working as a normal inverter plus being able to fix the PF of the local grid at a target PF (D-STATCOM option), and if there is no wind, the device should be only operating as a D-STATCOM (or capacitor bank) to regulate PF of the local grid. This translates to two modes of operation:1) when wind is blowing and active power is coming from the wind turbine: the inverter plus D-STATCOM mode. In this, the device is working as a regular inverter to transfer active power from the renewable energy source to the grid as well as working as a normal D-STATCOM to regulate the reactive power of the grid in order to control the PF of the grid and 2) when wind speed is zero or too low to generate active power: the D-STATCOM mode. In this case, the inverter is acting only as a source of reactive power to control the PF of the grid, as a D-STATCOM. This option eliminates the use of additional capacitor banks or external STATCOMs to regulate the PF of the distribution feeder lines. Obviously, the device is capable of outputting up to its rated maximum real power and/or reactive power, and will always output all real power generated by the wind turbine to the grid. The amount of reactive power, up to the design maximum, is dependent only on what the utility asks the device to produce. Generally, (1) and (2) dictate the power flow between a STATCOM device and power lines

$$P_S = (E_S E_L)/X \ \mathrm{Sin}\ \delta \qquad 1$$

$$Q_S = -(E_S E_L \ \mathrm{Cos}\delta - E_L^2)/X \qquad 2$$

where X is the inductance between the STATCOM (here as inverter) and the grid which is normally considered as output filter inductance added to the transmission line inductance. The root mean square (RMS) voltage of the STATCOM (=inverter) is given as E sand is considered to be out of phase by an angle of δ to the RMS line voltage E 1. .

In the proposed control strategy, active and reactive power transferred between the inverter and the distribution grid is controlled by selecting both the voltage level of the inverter and the angle δ between the voltages of inverter and grid, respectively. The amplitude of the inverter voltage is regulated by changing the modulation index m and the angle δ by adding a delay to the firing signals which concludes

$$P_S = -(m E_S E_L)/X \ \mathrm{Sin}\delta \qquad 3$$

$$Q_S = -(m E_S E_L \ \mathrm{Cos}\delta - E_L^2)/X \qquad 4$$

III. MATLAB MODELEING AND SIMULATION RESULTS

This is divided into two parts. First shows the design of an 11-level MMC inverter was carried out in MATLAB/Simulink. The simulation time is 20 seconds and contains severe ramping and de-ramping of the wind turbine. The goal is to assess the behaviour of the control system in the worst conditions. Second part shows the design of 17 level inverter showing the improved power factor and less THD.

Case 1: Implementation of 11-LEVEL INVERTER

The following figures describe the 11 level inverter and its sub components. Fig 4 shows the simulation circuit diagram for 11 level inverter. As inverter used is a 3 phase system each phase has a multi module converter. Depending on the level of the inverter number of sub modules is presented.

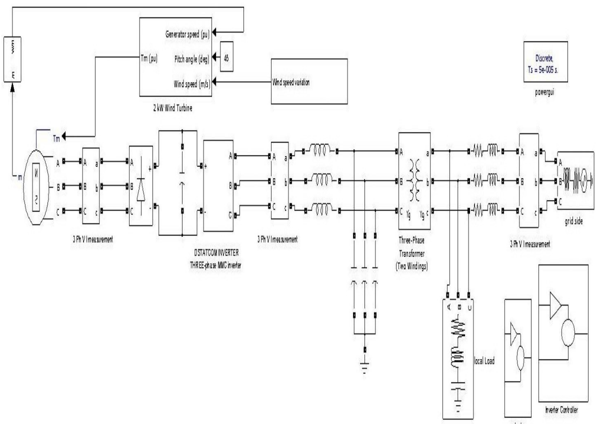

Fig.4 Simulation circuit diagram for 11 level inverter.

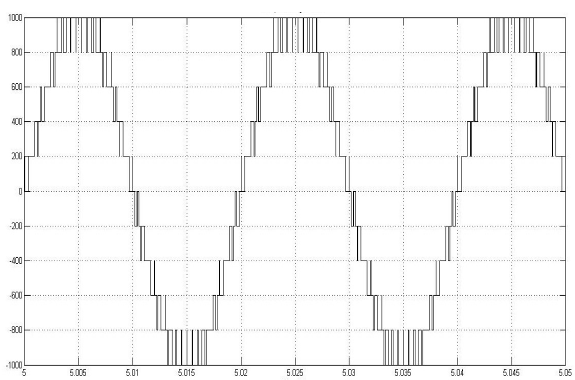

Fig5. Simulated output voltage of an 11-level inverter.

As soon as the active power comes from the wind turbine, the controller system increases the value of the power angle in order to output more active power to the grid. Therefore, the active power provided from the feeder lines to the load is decreased, and as a result the reactive power from the feeder lines is decreased. Consequently, the modulation index is increased by the controller system to inject more reactive power needed by the load. And fig 6 shows the grid voltage and current.

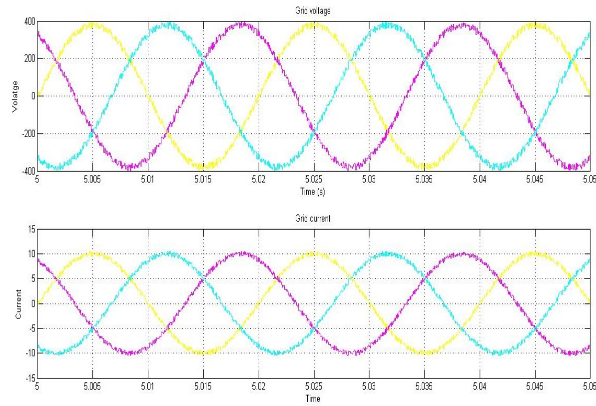

Fig.6 Grid voltage and Current

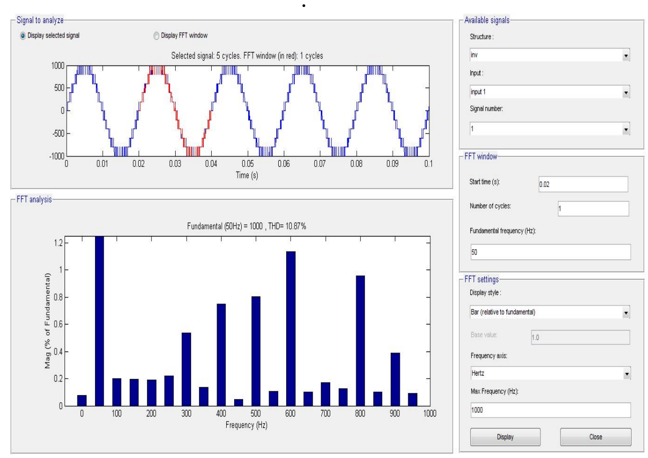

Fig7 THD analysis report

Fig 7 shows THD analysis report. By this can say that THD of the system 10.87%.

Case 2: Implementation of 17-LEVEL INVERTER

The simulation circuit diagram of 17 level inverter is the same but number sub modules presented in the inverter are different. The following figures describe the 17 level inverter and its sub components. Fig 8 shows the simulation circuit diagram for 17 level inverter. As inverter used is a 3 phase system each phase has a multi module converter. Depending on the level of the inverter number of sub modules is presented.

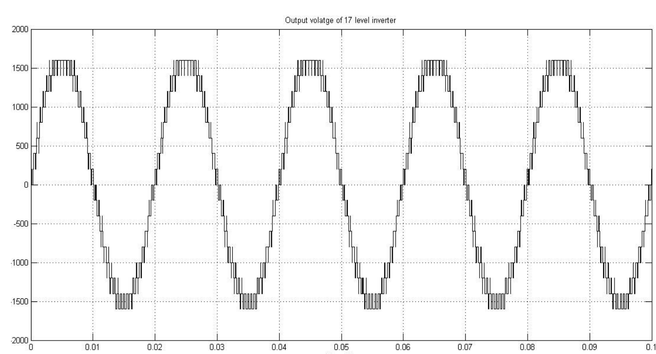

Fig 8 Output voltage of 17 level inverter

In the figure the output voltage is from -1700 to 1700 voltage level clearly saying that it is alternating. By keeping the filters at the output of the inverter we convert into the smoother waveform.

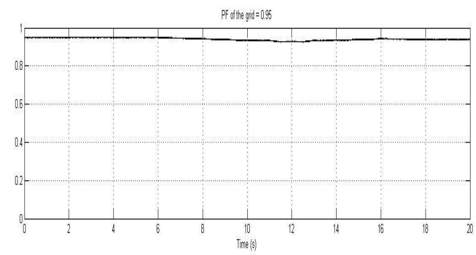

Fig 9 Power factor of the grid

Fig 8 shows power factor = 0.95 of the grid with improved. As the power factor is the major consideration the small change will increase system performance. Finally we say that 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 δ in order to output more active power to the grid in order to decrease the dc link voltage. The modulation 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. Fig 10 shows THD analysis report. By this can say that THD of the system 2.39%.

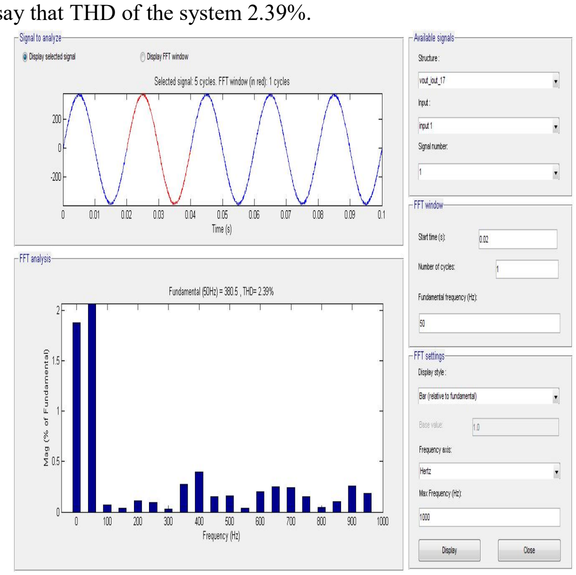

Fig 10 THD analysis report of 17 level inverter

Comparison statement

	THD	Power Factor
11 level inverter	**10.87%**	**0.9**
17 level inverter	**2.39%**	**0.95**

Table 1 Comparison statement

By seeing above table 1 we can say THD was reduced and power factor is increased. In seventeen level inverter, what happens was that 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 δ in order to output more active power to the grid in order to decrease the dc link voltage.

V. CONCLUSION

In this project, the concept of a new multilevel inverter with FACTS capability for small-to-mid-size wind installations is presented. 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 PF of the grid. Clearly, depending on the size of the compensation, multiple inverters may be needed to reach the desired PF. 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 simulation results for an 11-level inverter and 17 level inverter with D-STATCOM capability are simulated in MATLAB simulink. Active power, reactive power, power factor and THD of 11 level inverter with facts capability are presented which within specified ranges. Power factor and THD of 17 level inverter with D-STATCOM capability are improved as compared with corresponding parameters of 11 level inverter with facts capability.

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