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A Study Of Single-Phase Multi-Level Inverter With D-STATCOM For Grid Connected Wind Turbines

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Abstract: This paper presents the design and comparison of multi-level inverter with D-STATCOM for wind energy systems using Modular Multi-level Converter (MMC). The aim of the work is to design different levels of inverter with FACTS devices to provide utilities with more knowledge about the distribution systems, specifically at the end points. Hence made the comparison between these levels of inverters where the output of the system does not vary with the levels of inverter but the Total Harmonic Distortion (THD) of the system will reduces as the level increases. This inverter is placed between the wind turbine and the distribution grid where the active and reactive power is regulate which is required by the grid. Simulations of the proposed inverter with 5 level and 7 level have been done in MATLAB/Simulink. The simulation results validate the performance of the proposed control strategy.

Keywords: Modular Multi-level Converter (MMC), Multi-level inverter, STATCOM, Total Harmonic Distortion (THD), Wind energy system.

I. INTRODUCTION

The electric utility industry has begun to update more and more in recent years. New issues such as global warming, toxic emissions, energy cost, a broadening power market, and increasing demand have affected the growth of the power industry. Over the past decade, the willingness of utilities to invest in large-scale power plants has decreased and utilities have started shifting to smaller distributed energy sources closer to loads. Renewable energy systems offer several advantages over conventional energy sources such as natural gas or coal. They are clean sources of energy that can be found in most regions without emitting any greenhouse gases. Renewable energy is abundant and free, and generally not affected by political instability. The main disadvantage of renewable energy sources is that they are mostly located in remote areas and far away from large loads. In addition, the use of renewable energy sources is limited by the fact that they are not always available. Nowadays, with recent developments in semiconductor technologies, power electronic devices have been enormously deployed in power systems to control the active and reactive power flow. A power electronic device is one that consists of a number of semiconductor components that is used to perform a specific function in a system. There are a number of advantages to use power electronic devices, but the most important is the capability to control and manage the flow of electrical power. Using power electronics has made it possible to connect AC or DC sources with different voltage or frequency levels to each other. Among all power quality concerns, controlling the active and reactive power transferring to or from the grid requires major attention.

Power electronic-based flexible AC transmission System (FACTS) devices have been developed in order to provide more knowledge and control on power systems. Traditionally, capacitor banks have been used to control the reactive power on a power grid, but with deployment of power electronics in power systems, STATCOMs were born and received more and more attention during recent years.

The aim of this work is to combine the two concepts of inverters and D-STATCOMs into a so-called D-STATCOM inverter in order to enjoy the benefits of an inverter with DSTATCOM capability without any additional cost. A multilevel D-STATCOM inverter is a power electronic device that is placed between a renewable energy source and a distribution grid not only to provide active power, but to control reactive power on the system. Multi-level converters have several advantages compared to the conventional two level converter. They have the capability to perform at a lower switching frequency, they have lower total harmonic distortion (THD), and they have less across switches and therefore less voltage stress on the devices [2],[3],[4],[5],[6]. The proposed D-STATCOM inverter in this paper could replace existing inverters used for renewable energy systems, specifically for small- to mid-sized wind applications. The

D-STATCOM inverter is a cost-effective inverter with a DSTATCOM's capability to regulate active and reactive power on distribution systems. Deployment of DSTATCOM inverters can provide utilities with more information and control, specifically at end points that utilities do not monitor adequately. The unique contribution of this work is to combine the two concepts of inverter and D-STATCOM using modular multi-

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level converter (MMC) topology in a single unit, which is in series with the renewable energy source, without any additional cost. Fig. 1 shows a complete configuration of the proposed MMC inverter with FACTS capabilities.

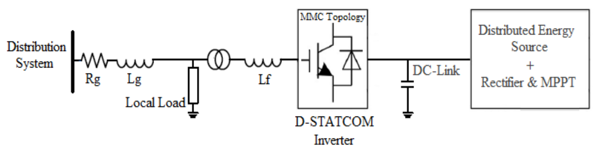

Fig. 1. Complete configuration of the proposed D-STATCOM inverter system

2. DETAILS OF INVERTER WITH D-STATOM

2.1. Configuration of the MMC Topology

At this time, the modular multilevel converter (MMC) is the newest topology for large scale commercial applications. Fig. 2 shows the configuration of the MMC topology. 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 are kept balanced. It requires only one DC source which is proper for renewable energy inverters, it is easy to design for higher levels, and it can deliver active and reactive power regardless of the load characteristics. MMC has a modular design based on identical converter cells [9],[10],[11] which make it a suitable choice for high-level applications. The main drawback of this topology is that it requires large capacitors in comparison with similar topologies which may affect the total cost of the inverter. However, this problem can be alleviated by the lack of need for any snubber circuits. Each leg of an n-level MMC inverter consists of several basic sub modules (SMs) and two inductors which are in series.

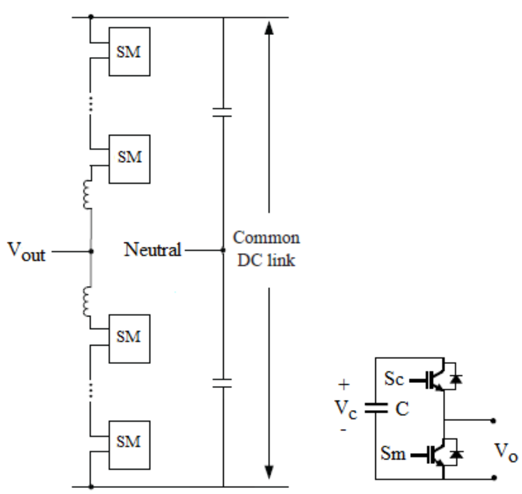

Fig. 2. Configuration of the MMC topology and its sub-module

2.2. Study of Different levels of inverters

Here the inverter is designed for 5-level and 7-level in which the D-STATCOM is used along with the inverter design. Simulation result obtained is same for both levels but the Total Harmonic Distortion (THD) is different for both systems. As the level of the system increases the THD reduces. Thus we can increase the level of the system for more stable and less distortion power system.

2.3. Proposed Control Strategy

This inverter is designed to control the flow of active and reactive power between the wind turbine and the grid. It is able to provide utilities with distributive control of VAR compensation and power factor (PF) on feeder lines. To enhance the reactive power control of the proposed inverter, it is equipped with the additional D-STATCOM option. This option permits the inverter to deliver reactive power fully independent from the wind speed. When the wind speed is too low to generate active power, the inverter acts as a source of reactive power to control the PF of the grid, like a D-STATCOM. The inverter is able to control the active and reactive power regardless of the input active power required by the DC link. Generally, there are two modes of operation for D-STATCOM inverter when it is connected to the grid: 1) when active power is gained from the wind turbine, which is called inverter mode, 2) when no active power is gained from the wind turbine, which is called D-STATCOM mode. The active and reactive power flow of the D-STATCOM is governed by:

$$P_s = \frac{mE_sE_L}{x}\sin\delta \quad \& \quad Q_s = \frac{mE_sE_L\cos\delta - E^2{}_L}{x}$$

Where E_s, E_L, δ and m are the voltage of the STATCOM, voltage of the line, power angle, modulation index, and inductance between the inverter and the grid, respectively. The steady state operation of the D-STATCOM inverter is controlled by adjusting δ and m, so that it provides the desired amount of active power and reactive compensation. The modulation index is used to control the active power while the power angle is used to control the reactive power transferring between the wind turbine and the grid. Fig. 3 shows the proposed control system.

The control system consists of three separate parts. The first part is to define the modulation index which is done by comparing the actual reactive power on the grid with the required reactive power considering the target power factor (PF). The second part is to define the power angle which is done by comparing the DC link voltage with a reference voltage defined by the specifications of the inverter. The defined values of modulation index and power angle are applied to the reference sinusoidal signal which is required to generate the PWM signals. The third part of the control system is to select the required SMs to generate the proper gate signals. Generally, the controller measures the SMs' capacitor voltages and sorts them in descending order. The suitable switching pattern will be chosen based on the direction of the current flowing through the switches.

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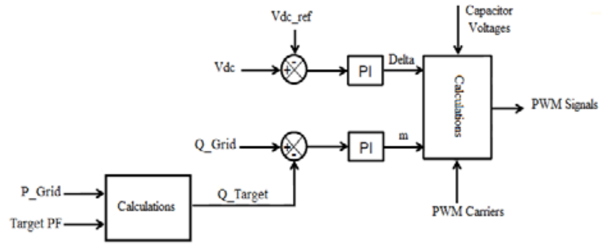

Fig. 3. The proposed controller system

To maintain the SM capacitor voltages balanced, a carrier-based PWM (CPWM) method is used to control the voltages of the capacitors [12],[13]. For a 5-level MMC inverter, this technique requires four in-phase carriers that are displaced with respect to the zero-axis. The output voltage level is determined by comparing a sinusoidal signal reference with these four carriers. In a 5-level inverter, at each instant four SMs should be chosen based on their capacitor voltages considering the direction of the current.

Depending on the output voltage level, if the current is positive, the SM capacitors are being charged, and therefore a number of SMs with lowest capacitor voltage should be chosen. Likewise, if the current is negative, the SM capacitors are being discharged, and therefore a number of SMs with highest capacitor voltage should be chosen. Generally, when the output voltage of a SM is equal to zero, it is called *off* and when the out voltage of a SM is equal to its capacitor voltage, it is called *On*.

3. RESULTS AND DISCUSSION

All the simulations of the proposed 5-level MMC inverter were done in MATLAB/Simulink shown in Fig.4. the output voltage of the D-STATCOM is now compare with the 7-level inverter which is shown in Fig.5.

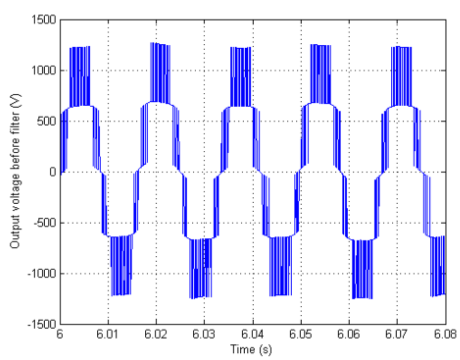

Fig. 4. Output voltage of the 5-level D-STATCOM inverter

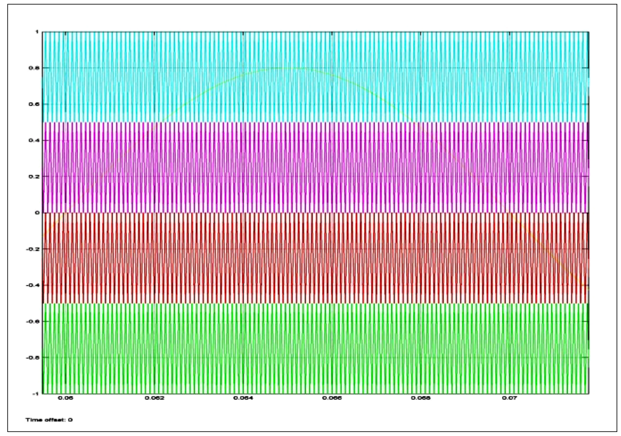

Fig. 5. Output voltage of the7-level D-STATCOM inverter

The Total Harmonic Distortion (THD) of the 7-level inverter is shown in Fig.5 have less harmonics than the 5-level. Thus by increasing the number of levels of inverter, the distortion will be reduced. The output of given system for both level is same.

Fig. 6 shows the power factor of the grid which is constant on the target PF of 0.90 regardless of the input power from wind turbine. Power angle and modulation index are shown in Fig. 7, respectively.

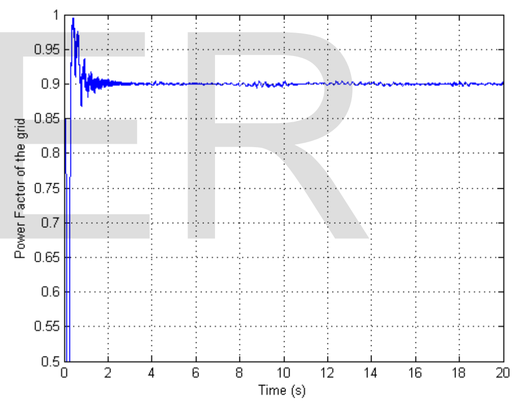

Fig. 6. Power factor of the grid

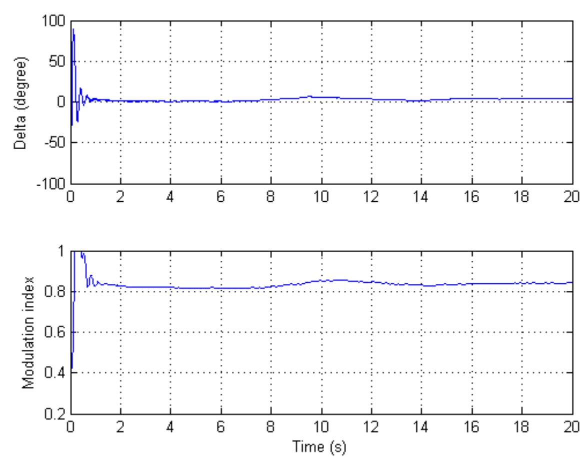

Fig. 7. Power angle and modulation index

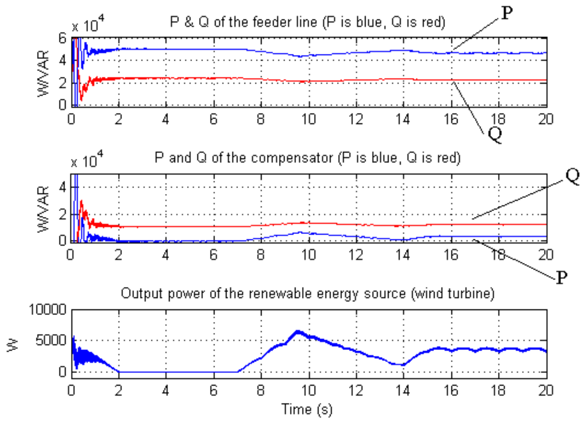

Fig. 8. Active and reactive power of the feeder line, active and reactive power of the D-STATCOM inverter, and the output power of the wind turbine

CONCLUSIONS

In this control system the inverter of D-STATCOM for 5-level and 7-level are simulated and compared. The renewable energy source like wind energy source system is used to provide the continuous and pure power supply at the distribution side of the system. As the output power of the wind turbine is not vary with the different levels of inverter the total cost of the system is reduced. But the Total Harmonic Distortion (THD) of the system is reduced to a maximum extent. Thus FACTS devices like D-STATCOM can be used in small and mid-size wind application with less distortion in the system. The proposed device provides an inverter and D-STATCOM in a single unit without any additional cost. The proposed DSTATCOM inverter can provide utilities with more knowledge at end points of the distribution lines. The goal is to increase the penetration of renewable energy systems, specifically wind, to the distribution systems.

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