A Review of Power Converter and MPPT algorithms for Wind Energy Conversion System

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ABSTRACT

Wind power is the most reliable and developed renewable energy source over past decades. With the rapid penetration of the wind generators in the power system grid, it is very essential to utilize the maximum available power from the wind and to operate the wind turbine (WT) at its maximal energy conversion output. For this, the wind energy conversion system (WECS) has to track or operate at the maximum power point (MPP). However, making a choice on an exact MPPT algorithm for a particular case requires sufficient proficiency because each algorithm has its own merits and demerits. For this reason, an appropriate review of those algorithms is essential. However, only a few attempts have been made in this concern. In this paper, different available MPPT algorithms are described for extracting maximum power which are classified according to the power measurement i.e. direct or indirect power controller. Merits, demerits and comprehensive comparison of the different MPPT algorithms also highlighted in the terms of complexity, wind speed requirement, prior training, speed responses, etc. and also the ability to acquire the maximal energy output. This paper serves as a proper reference for future MPPT users in selecting appropriate MPPT algorithm for their requirement.

Keywords: WECS, MPPT, Power Converter etc.

INTRODUCTION

Due to the increasing environmental concern the old ways of power generation by burning fossil fuel has been substituted by much suitable and environment friendly renewable sources. A renewable source has the advantages that it is abundant, clean, and becoming increasingly economical. In fact, renewableenergy sources help in reducing about 70 million metric tons of carbon emissions per year that would have been produced by fossil fuels. Among various types of renewable energy sources, wind energy is one of the fastest growing renewable energy sources. Shown in Figure 1is a histogram of the global cumulative wind power capacity from 2000 to 2015. As can be seen in this figure, the global cumulative wind power capacity has been explosively increased from about 17.4 GW in 2000 to 432.419 GW in 2015, and the growth rate is expected to continue in the coming years.

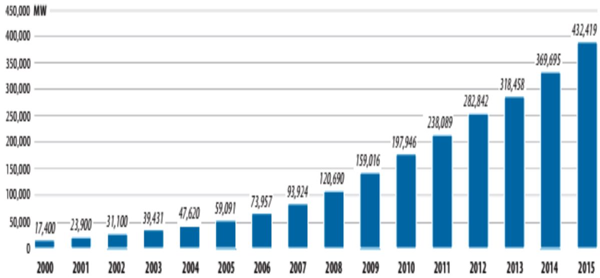

Figure 1: Global cumulative wind power capacities

In wind energy conversion systems (WECSs), the key technologies include wind turbine technology, power electronics technology, and system control technology. For the wind turbines, based on the orientation of the rotation axis of the wind turbine, there are horizontal-axis wind turbines and vertical-axis wind turbines. In the horizontal-axis wind turbines, the rotation axis of the wind turbine is parallel to the ground, while in the vertical-axis wind turbines, the rotation axis is perpendicular to the ground. Compared to the vertical-axis wind turbines, horizontal-axis wind turbines have higher wind energy conversion efficiency, which are widely applied in the wind energy industry. The wind turbines can also be classified as fixed-speed wind turbines and variable-speed wind turbines based on whether the operation speed is controllable.

II POWER CONVERTERS FOR WECS

Power electronics devices have been applied in WECSs since the 1980s, when a thyristor based soft-starter was applied to a SCIG system which was directly connected to the grid [1]. The thyristor based soft-starter was used for limiting the current surge during start up. In the 1990s, the emergence of the rotor resistance control approach made it possible that the WRSG can be controlled to operate at variable speed. Although the speed range is only limited to 10% above the synchronous speed of the generator, this progress has improved the energy capture efficiency of the wind turbine due to the application of the converter controlled variable resistance. Nowadays, back-to-back converters are widely used in WECSs, either in reduced power (reduced power means that only the 30% of the rated power is processed by the power converters) for DFIG systems shown in Figure 2, or in full power (full power means that the power generated by the generator up to its rated power is processed by the power converters) for PMSG/SCIG/WRSG systems which can be seen in Figure 2.

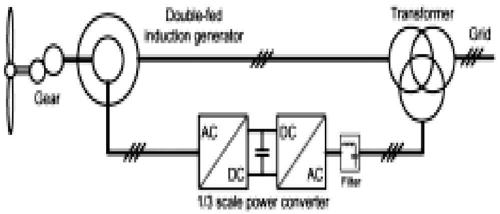

Figure 2: DFIG with partial-scale power converters

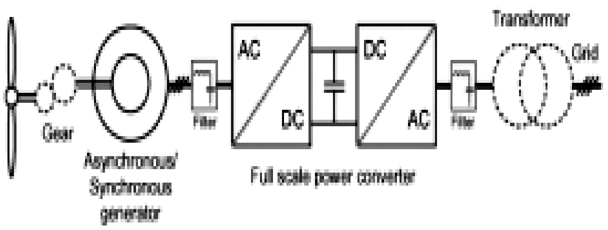

Figure 3: Wind turbine generators with full-scale power converters

The back-to-back power converters, which decouple the wind turbine from the grid, possess the capability to regulate the operation speed of such wind turbine generators, control the active and reactive powers injected into the grid, and improve the power quality. Conventional two-level back-to-back power converters have been widely applied in wind power industry and their reliability has been well proved. With the development of the semiconductor devices and the digital control technology, multilevel converters were investigated and commercialized during recent years, which helps in improving the power level and the power quality of the wind energy generation systems.

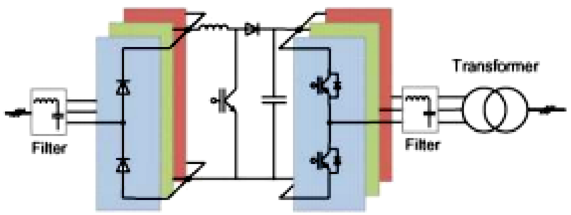

Figure 4: Two-level back-to-back converters with passive rectifier

The most widely applied power converters for the best seller range 1.5-3.0 MW WECSs are the two-level back-to-back voltage source converters (VSCs) [2]. Figure 4 and 2.4 are showing two typical two-level back-to-back VSCs.

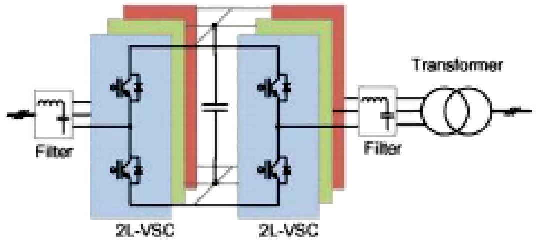

Figure 5: Two-level back-to-back converters with active rectifier

Shown in Figure 4 is a two-level back-to-back converter with a passive diode rectifier and a DC chopper. Figure 1.6 shows a two-level back-to-back converter with an active rectifier, as well as an active inverter connected to the grid. As can be seen in Figure 4 and 5, the insulated gate bipolar transistors (IGBTs) are used as the power switches. Although recent developments have make the IGBT with higher-voltage blocking capability closer to the integrated gate-commutated thyristor (IGCT), the IGBT based two-level back-to-back VSCs are applied mainly in the low-voltage, low/mediumpower drive industries [3]. As introduced in [4], to increase the voltage level, as well as the power level of the conventional two-level back-to-back VSCs, series-connected power switches can be applied as shown in Figure 6. Based on this topology of power switches connection, the series connected IGBTs distribute the voltage and power stress on the single IGBT in the conventional two-level VSCs, which improves the voltage and power level of the two-level VSCs. With the application of the series-connected IGBT two-level high power inverters, the multi-pulse rectifiers become attractive selections for the high power back-to-back VSCs. These types of rectifiers help in reducing the input current harmonics which is beneficial for the generators in wind turbine systems. Figure 7 shows the 12, 18, and 24 pulse rectifier circuit configurations.

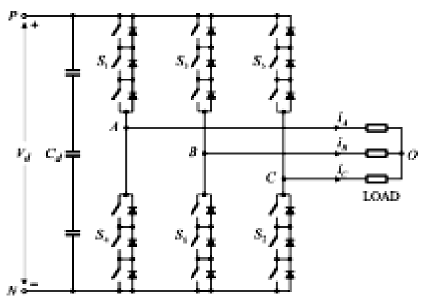

Figure 6: Two-level VSC with series-connected power switches

Although the series-connected IGBT VSC has greatly improved the voltage and power level of the two-level VSC, it contributes nothing to reduce the dv/dt (the voltage change, dv, within the time interval, dt), or to improve the power quality [3]. Based on this concern, the multilevel converters were investigated and commercialized.

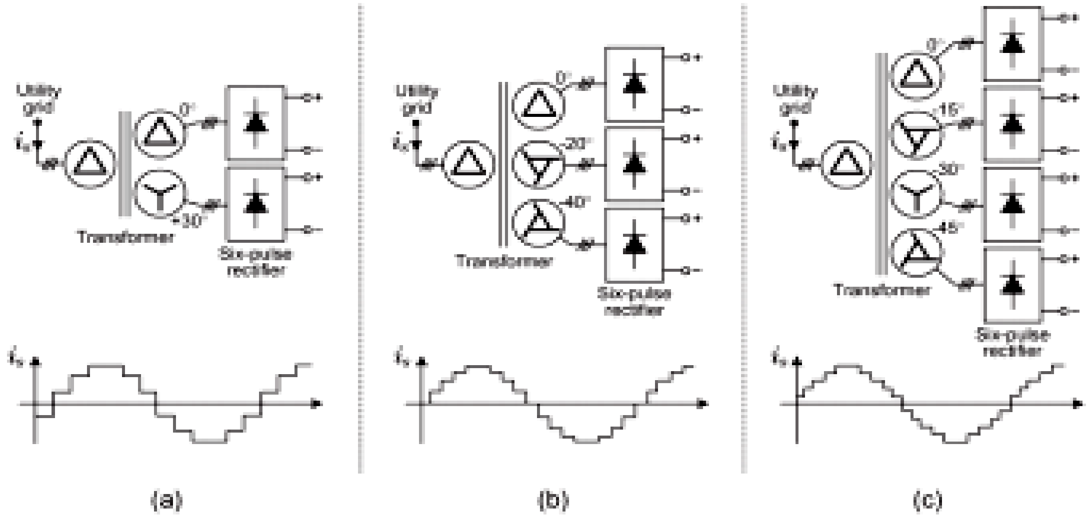

Figure 7: Multi-pulse diode rectifier circuit configuration and input current: (a) 12 pulse, (b) 18 pulse, and (c) 24 pulse [4]

A. Neutral point Clamped Multilevel Converter for WECs

The NPC multilevel converter was proposed in [5] [6] in the early 1980s. It can be structured as three level, five level, and even seven level or more. However, the three level NPC converters is the most applied type in industry. In each leg of the three-level NPC converter, there are four power switches which are clamped with diodes to a midpoint of the capacitor bank as shown in Figure 8. To this converter, all conventional pulse width modulation (PWM) approaches are applicable [5].

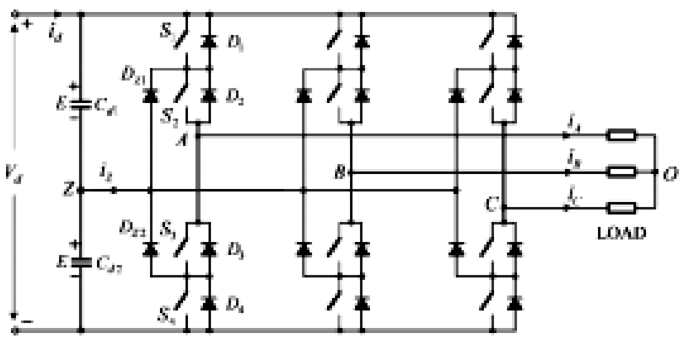

Figure 8: Topology of the NPC converter

Since the commutation voltage of all the power switches in the NPC converter is only half of the DC bus voltage, the NPC converter is very suitable for the high power, medium voltage drives (2.3-4.16 kV) [4]. What is more, since the conduction of the power switches only shares half of the DC bus voltage, the dv/dt is greatly reduced. The output line-to-line voltages of the NPC converter consists of three voltage levels, which result in reduced harmonics in the output voltages and improved power quality. The main drawback of the NPC converter is that the power losses on the power switches are unevenly distributed, which reduces the reliability of the NPC converters [7].

B. Cascaded H-Bridge Converters

The concept of cascaded H-bridge (CHB) converter was first introduced in [8]. After that in the late 1990s, the CHB converter was further studied and tested in [9]. The CHB converter consists of series connected H-bridge power cells. A typical H-bridge power cell is shown in Figure 9. The series-connected power cells naturally increase the voltage and power level of the CHB converters. The number of the power cell mainly depends on the operation voltage, the harmonic requirements, and the budget for the system [10]. What is more, for a CHB multilevel converter with k power cells, it will be able to generate level output voltages, which results in reduced harmonics in the output voltages and improved power quality [9]. The main drawback of the CHB converter is that it requires large number of dc sources for the H-bridge, which increases the cost.

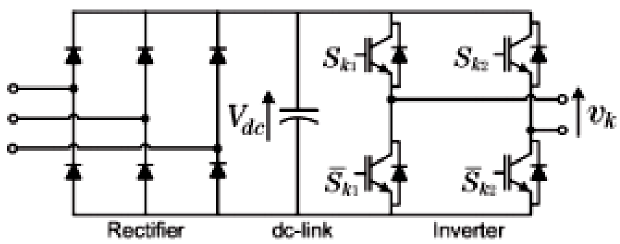

Figure 9: CHB power cells

III MPPT FOR WECS

Wind generation system has been attracting wide attention as a renewable energy source due to depleting fossil fuel reserves and environmental concerns as a direct consequence of using fossil fuel and nuclear energy sources. Wind energy, even though abundant, varies continually as wind speed changes throughout the day. Amount of power output from a WECS depends upon the accuracy with which the peak power points are tracked by the MPPT controller of the WECS control system irrespective of the type of generator used. MPPT are used to extract the maximum available wind power.

A. Tie Speed Ratio Control

TSR control is possible with wind speed measurement or estimation. In [11], a wind speed estimation based MPPT controller is proposed for controlling a brushless doubly fed induction generator WECS. The block diagram of the TSR controller is shown in Figure 10. The optimum rotor speed ω_{opt}, which is the output of the controller, is used as the reference signal for the speed control loop of the machine side converter control system.

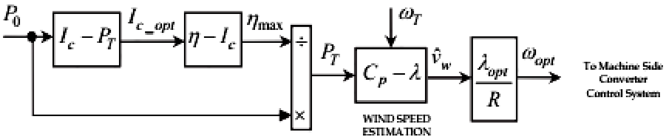

Figure 10: Generation of optimum speed command

The method requires the total output power P_0 of the WECS and rotor speed as input to the MPPT controller. Using P_0 as the input to a look-up table of $I_c - P_0$ profile, optimum winding current I_{c_opt} is obtained. The maximum generator efficiency η_{max} is estimated at a particular control current optimized operating point using a stored efficiency versus optimum current characteristic of the generator. In the algorithm presented the relations I_c versus P_T and I_c versus η were implemented using RBF neural networks. Then, generator input power P_T is calculated from the maximum efficiency η_{max} and the measured output power P_0. The next step involves wind speed estimation which is achieved using Newton Raphson or bisection method. The estimated wind speed information is used to generate command optimum generator speed for optimum power extraction from WECS. For details of the proposed method please refer to [11]. The method is not new; similar work was earlier implemented for controlling a Brushless Doubly Fed Generator by Bhowmik et al [12]. In this method the Brushless Doubly Fed Generator was operated in synchronous mode and input to the controller was only the output power of the WECS.

B. Power Signal feedback control

PSF control along with feedback linearization is used by [13] for tracking maximum power point. The input-output feedback linearization is done using active-reactive powers, d-q rotor voltages, and active-reactive powers as the state, input and output vectors respectively. The references to the feedback linearization controller are the command active and reactive powers. The reference active power is obtained by subtracting the inertia power from the mechanical power which is obtained by multiplying speed with torque. A disturbance torque observer is designed in order to obtain the torque. A fuzzy logic based PSF controller is presented in [14]. Here, a data driven design methodology capable of generating a Takagi-Sugeno-Kang (TSK) fuzzy model for maximum power extraction is proposed. The controller has two inputs and one output. The rotor speed and generator output power are the inputs, while the output is the estimated maximum power that can be generated. The TSK fuzzy system, by acquiring and processing the inputs at each sampling instant, calculates the maximum power that may be generated by the wind generator, as shown in Figure 11.

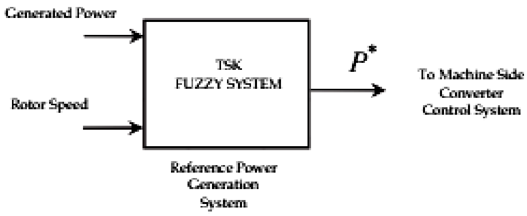

Figure 11: TSK fuzzy MPPT controller

The approach is explained by considering the turbine power curves, as shown in Figure 12. If the wind turbine initially operates at point A, the control system, using rotor speed and turbine power information, is able to derive the corresponding optimum operating point B, giving the desired rotor speed reference ω_B . The generator speed will therefore be controlled in order to reach the speed ω_B allowing the extraction of the maximum power P_B from the turbine.

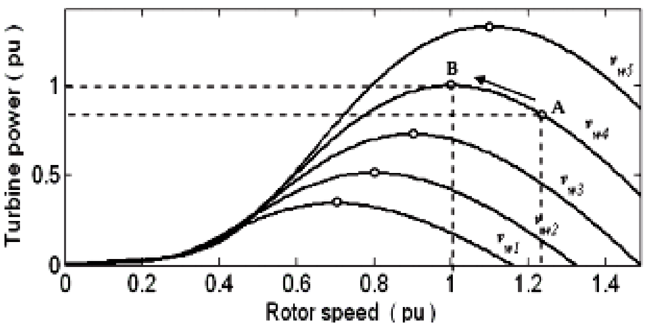

Figure 12: Turbine power curves

C. Hill Climb Search Control

HCS control method of MPPT controls are presented in [15-17]. In [15], a simple HCS method is proposed wherein output power information required by the MPPT control algorithm is obtained using the dc link current and generator speed information. These two signals are the inputs to the MPPT controller whose output is the command speed signal required for maximum power extraction. The optimum speed command is applied to the speed control loop of the grid side converter control system. In this method, the signals proportional to the P_m is computed and compared with the previous value. When the result is positive, the process is repeated for a lower speed. The outcome of this next calculation then decides whether the generator speed is again to be increased or decreased by decrease or increase of the dc link current through setting the reference value of the current loop of the grid side converter control system. Once started, the controller continues to perturb itself by running through the loop, tracking to a new maximum once the operating point changes slightly. The output power increases until a maximum value is attained thus extracting maximum possible power.

The HCS control method presented in [16] operates the generator in speed control mode with the speed reference dynamically modified in accordance with the magnitude and direction of change of active power. Optimum power search algorithm proposed here uses the fact that $dP_0/d\omega = 0$ at peak power point. The algorithm dynamically modifies the speed command in accordance with the magnitude and direction of change of active power in order to reach the peak power point.

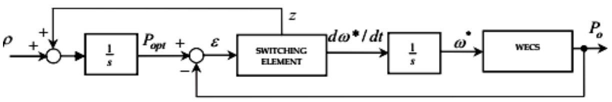

Figure 13: Sliding mode extremum seeking MPPT control

In [17], the proposed MPPT method combines the ideas of sliding mode (SM) control and Extreme seeking control (ESC). In this method only the active power of the generator is required P_{opt} as the input. The method does not require wind velocity measurement, wind-turbine parameters or rotor speed etc. The block diagram of the control system is shown in Figure 2.12. In the figure ρ is the acceleration of P_{opt}. When the sign of derivative of ε changes, a sliding mode motion occurs and ω^* is steered towards the optimum value while P_0 tracks P_{opt}. The speed reference for the vector control system is the optimal value resulting from the MPPT based on sliding mode ESC.

IV PROBLEM FORMULATION

The most widely used variable-speed wind turbine topology, in present, is the doubly fed induction generator (DFIG) wind turbine, equipped with a partial-scale power converter. However, the topology with PM synchronous generator and full-scale converter has also an increasing market share today. Compared with the induction generator, the permanent magnet synchronous generator is more efficient, smaller in size and easier to control. The efficiency of the PMSG wind turbine was assessed to be higher than other variable speed wind turbine concepts. Meanwhile, PMSG presents also some disadvantages like high costs for the permanent magnets and a fixed excitation, which cannot be changed according to the operational point. The PMSG can be operated in variable speed, so that the maximum power can be extracted. Traditionally, wind turbine generators are operating best at high speeds and require step-up gearboxes. A multipole direct driven PM generator, connected to the grid through a full scale converter, can be operated at low speeds, so that the gearbox can be omitted. Direct driven applications are increasingly applied due to the fact that a direct driven generator has reduced overall size, lower installation and maintenance cost, a flexible control method and quick response to wind fluctuation and load variation. The full scale converter consists of a back-to-back voltage source converter (VSC) - a generator side converter and the grid side converter, connected through a DC link. The capacitor decoupling, offers the possibility of separate control for each converter. The grid side converter controls the power flow in order to keep the DC-link voltage constant, while the generator side converter controls the torque and the speed. Also having this configuration the PMSG is more isolated from the grid, which makes possible to control the fault currents in the PMSG, that arise from external faults in the grid.

V CONCLUSION

Due to increasing penetration of wind energy system in the power system grid a proper MPPT algorithms is necessary. Here in this paper discuss the different type of MPPT system used for tracking the maximum power. Also the power converter plays a key role in the power conversion in the WECS. In this paper discuss the different type of power converter is used for energy conversion for connecting to grid. And the last a problem associated in the wind energy system is also discussed.

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