Power Electronics Converters and Wind Turbine

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Abstract—This Wind power is **one of the most promising renewable energy present decade. There is a widespread use of wind turbines in the distribution networks and more and more wind power stations, acting as power plants, are connected directly to the grid. As the grid penetration and power level of the wind turbines increase more and more, the wind power starts to have significant impacts to the power grid system. Therefore, more advanced generators, power electronic systems, and control solutions have to be introduced to improve the characteristics of the wind power plant and make it more suitable to be integrated into the power grid. Meanwhile, there are also some emerging technology challenges, which need to be further clarified and investigated. This paper gives an overview and discusses some development trends in the technologies used for wind power systems.**

Index Terms— power electronics converters, pulse width modulation, wind energy conversion, wind farms, wind turbine control. Maximum power point tracking

I. INTRODUCTION

The steady growth of installed wind power together with the up scaling of the single wind turbine power capability has pushed the research and development of power converters toward full-scale power conversion, lowered cost pr kW, increased power density, and also the need for higher reliability. In this project, power converter technologies are reviewed with focus on existing ones. There is a widespread use of wind turbines in the distribution networks and more and more wind power stations, acting as power plants, are connected directly to the transmission networks. As the grid penetration and power level of the wind turbines increase steadily, the wind power starts to have significant impacts to the power grid system. Therefore, more advanced generators, power electronic systems, and control solutions have to be introduced to improve the characteristics of the wind power plant and make it more suitable to be integrated into the power grid.[1] First, the developments of technology and market are generally discussed. Next, several state-of-the-art wind turbine concepts, as well as the corresponding power electronic converters and control structures, are reviewed, respectively[2]

II. NEED FOR PEC IN WIND TURBINE

A. Modern power electronics in WPP

Power electronics has changed rapidly during the last 30 years and the number of applications has been increasing, mainly due to the developments of the semiconductor devices and the microprocessor technology. For both cases, the performance is steadily increasing, and at the same time, the price of de- vices is continuously falling. In order to improve reliability and reduce cost, the number of components is going down by a higher level of integration. The power electronic device technology is still undergoing important progress, including some key self-commutated devices, such as insulated gate bipolar transistor (IGBT), MOSFET, integrated gate commutated thyristor (IGCT), MOS-gate thyristors, and silicon carbide FETs. The breakdown voltage and/or current carrying capability of the components are also continuously increasing. Important re- search is going on to change the material from silicon to silicon carbide. This may dramatically increase the power density of the power converters. Power electronic converters are constructed by semiconductor devices, driving, protection, and control circuits to perform voltage magnitude and frequency conversion and control. A converter, depending on the topology and application, may al- low both directions of power flow. There are two different types of converter systems: grid commutated and self-commutated converter systems. The grid commutated converters are mainly thyristor converters with high power capacity of 6 or 12 or even more pulses. A thyristor converter consumes inductive reactive power and it is not able to control the reactive power. Thyris tor converters are mainly used for very high voltage and power applications, such as conventional HVDC systems Self-commutated converter systems normally adopt pulse- width-modulated (PWM) control methods; the semiconductors with turn-OFF ability, such as IGBTs, are mainly used. This type of converter may transfer both active power and reactive power. in both directions (ac–dc or dc–ac). This means that the reactive power demand can be delivered by a PWM converter. The high-frequency switching of a PWM converter may produce harmonics and inter harmonics, which, in general, are in the range of some kilohertz. Due to the high frequencies, the harmonics are relatively easier to be removed by small-size filters. Fig. 1 shows a typical power electronic . converter consisting of self-commutated semiconductors such as IGBTs.[3]

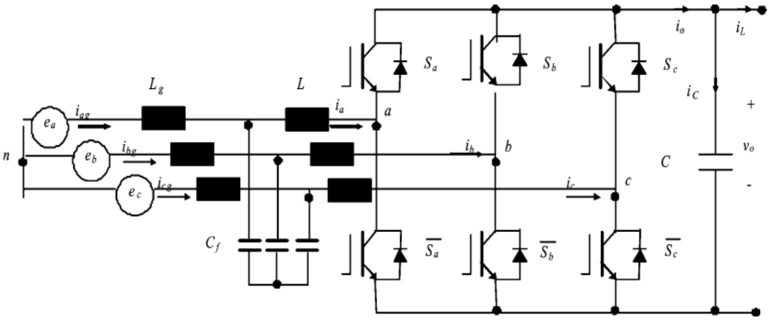

Fig 1. Circuit diagram of a VSC with IGBTs

B.DFIG with partial-scale power converter

This wind turbine concept is the most popular concept in renewable energy nowadays and it has been extensively used since 2000s. As shown in Fig.2, a power electronics converter (PEC) is used in conjunction with the DFIG. The stator windings of DFIG are directly connected to the power grid, whereas the rotor windings are connected to the power grid by the converter with normally 30% capacity of the wind turbine.

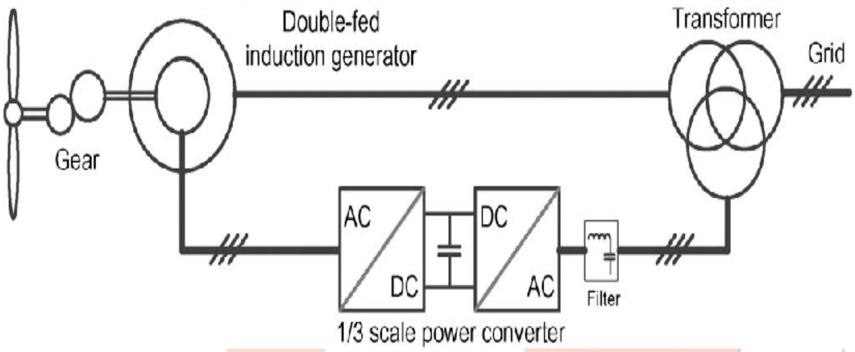

Fig.2 DFIG with partial-scale power converter

In this concept, the frequency and the current in the rotor can be easily regulated and therefore variable speed in wide range can be obtained to a satisfactory level. The smaller converter capacity makes this concept very popular seen from the cost point of view. In this main disadvantage are, the use of slip rings and the power controllability in the case of grid faults [4] these disadvantages may comprise the reliability and may be difficult to completely satisfy the future grid requirements. The two-level pulse width modulation voltage source converter (2L-PWM-VSC) is the most popular used converter topology as far as the DIFG-based wind turbine concept is concerned as the power rating requirement for the converter is limited. Normally two 2L-PWM-VSCs are configured in a BTB structure in the WTS, which is called two-level BTB (2L-BTB). A technical advantage of the 2L-BTB converter is the full power controllability (four quadrants operation) with a relatively simple structure and few number of components, which is well-proven robust and reliable performances with advantage of low cost

C.A/SG with full-scale power converter

Another important concept which is popular for the new developing wind turbines is shown in Fig.2 In this a full-scale power converter is used to interconnect the power grid and stator windings of the generator, there for all the generated power from the wind turbine can be regulated. The asynchronous generator, wound rotor SG (WRSG) or permanent magnet SG (PMSG) can be reported used in this topology. The elimination of slip rings, simplicity, no gearbox, full power and speed controllability as well as better grid support are the chief advantages compared with the DFIG-based concept. The more complex and expensive power electronic components plus the higher power losses in the converter are the main disadvantages for this concept As the converter used in this concept needs to carry all the generated power by wind turbines, the 2L-BTB converter topology at this power level(up to 10MW) may suffer from large switching loss and many devices may need to be connected in parallel and the cabling in case of low voltage level can be a great design/physical challenge. Therefore, it becomes very difficult for a single 2L-BTB topology to achieve appreciable good performance for the full-scale wind power converter, even though having the low cost. To handle the growing power with the exiting 2L-BTB technology, some multicell converter configurations are introduced (i.e., parallel/series connection of 2L-BTB converter cells) for achieving higher voltage and power level, multilevel converters are becoming more popular in the full-scale converter based technologies. The three-level neutral point diode clamped (3L-NPC) topology is one of the most commercialized and popular multilevel topologies on the market. Similar to the 2L-BTB, it is usually configured as a BTB structure in the wind power application. The 3L-BTB converters gives one more output voltage level and less dv/dt stress compared with the 2L-BTB, thus it is possible to convert the power at medium voltage with lower current, less paralleled devices, and smaller filter size. The midpoint voltage fluctuation of the dc bus is the big drawback of the. 3L-NPC BTB. One of the solutions for this problem is to use redundant switching states. It is, however, found that the loss distribution is unequal between the outer and inner switching devices in a switching arm , and this problem might lead to a derated power capacity when it is practically used.

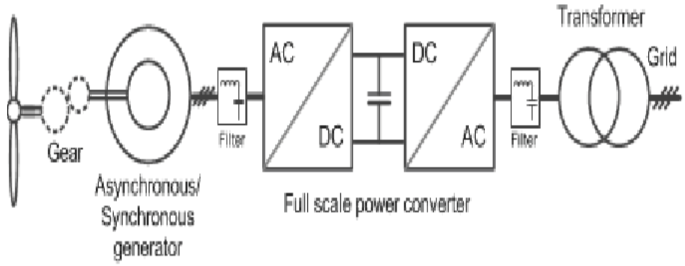

Fig 3 DFIG with full-scale power converter

II. POWER ELECTRONICS FOR INTEGRATION AND CONTROL OF WIND TURBINES

Power electronic technology, plays an important role for efficiently converting electric power in wind power systems. the In variable-speed wind power turbine it is an essential part for integrating these units to achieve high efficiency and high performance in power systems. Thyristors are used as soft-starters in a fixed-speed wind turbine system where wind power generators are directly connected to the grid. The power electronic converters are very useful to match the characteristics of wind turbines with the grid, including frequency, voltage, control of active and reactive power, harmonics, etc

A.Soft -starter for fixed-speed wind turbines

The concept of directly connecting a wind turbine to the grid which is given by Danish is widely used in early wind turbine systems. This scheme consists of an SCIG, connected via a transformer to the grid and operating at an almost fixed speed. The power is controlled aerodynamically either by stall control, active stall, or pitch control. This configuration of the fixed-speed is shown in Fig. 3. The main advantages of wind turbines with induction generators are the simple and cheap construction and no need of synchronization device . These scheme are attractive because of low cost and reliability. But there are some drawbacks too: 1) the wind turbine has to operate at constant speed; 2) it requires a stiff power grid to enable stable operation; and 3) it may require a more expensive mechanical construction in order to absorb high mechanical stress, because wind gusts may cause torque pulsations on the drive train Connecting the induction generators to power system produces transients that are short duration with very high inrush currents, thus causing disturbances to both the grid and high torque spikes in the drive train of wind turbines with a directly connected induction generator.. This type of a transient disturbs the grid and limits the acceptable number of wind turbines. The high starting currents of induction generators can effectively limited by a thyristor soft-starter.

The limiting of current on soft-starter, based technology is achieved by typically limiting the rms value of the inrush current to a level below two times of the generator rated current. The soft-starter has a limited thermal capacity and it is short circuited by a contractor, which carries the full-load current, when the connection to the grid has been completed.

In addition reduce the impact on the grid, the soft-starter also effectively dampens the torque peaks associated with the peak currents, and hence reduces the loads on the gearbox Variable-speed operation of a wind turbine system has many advantages. These wind turbine can increase or decrease its speed if the wind speed and torque increases or decreases, due to this quality there is less wear and tear on the tower, gearbox, and other components in the drive train. Along with this, variable-speed systems can increase the production of the energy and reduce the fluctuation of the power injected into the grid. In variable-speed systems, the generator is normally connected to the grid through a power electronic system. For synchronous generators and induction generators without rotor windings, a full rated power electronic system is connected between the stator of the generator and the grid, where the total power production must be fed through the power electronic system and in induction generators with rotor windings, the stator of the generator is connected to the grid directly,[4] and the rotor is connected to a power-electronic-controlled resistor or connected to the network through slip rings and a power electronic converter.

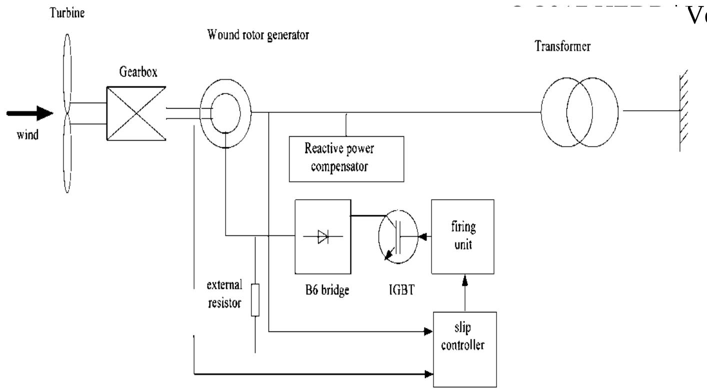

Fig.4Cage-induction-generator-based fixed-speed wind turbine with power electronic soft-starter

B. Wounded Rotor Induction Generator With Rotor Resistance Control (Dynamic Slip Control):

In this scheme, the rotor windings are connected with variable resistors. The equivalent resistance of the circuit can be varied by an electronic control system, as shown in Fig. 4. The higher the resistance of the rotor windings, the higher the slip is. In this way, the generator speed can be varied in a limited range. Previously, the connection are done with brushes and slip rings, which is requires more maintenance as compared with the simple design of a cage rotor induction machine..[6] This scheme also needs a soft-starter. Both cage induction generators and rotor- resistance-controlled wounded induction generators need to operate at a super synchronous speed to generate electricity. Both of them draw reactive power that must be supplied from the grid or from other compensation equipment, such as capacitor banks or additional power electronic equipment. In order to reduce the cost capacitor banks are normally used. Modern megawatt-class turbines have thyristor switched capacitors (TSCs) which provides more dynamic compensation. Static Var compensators (SVC) are needed to improve the dynamic responses of the wind farm

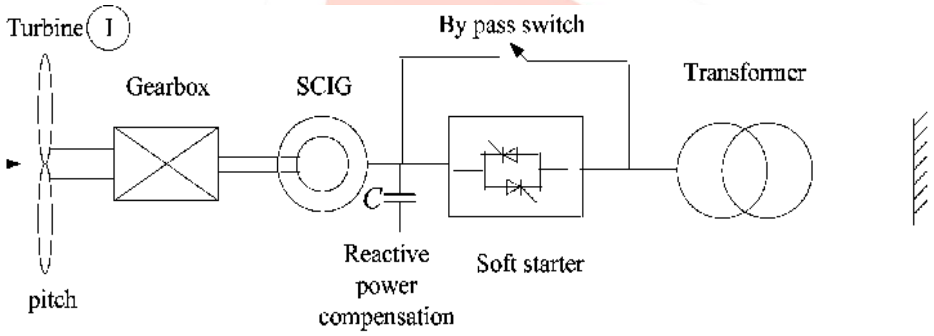

Fig. 5 Wound rotor induction generator with a rotor resistance converter

C. Doubly Fed Induction Generator: In doubly fed induction generator (DFIG) stator is connected to the grid directly, while the rotor of the generator is connected to the grid by electronic converters through slip rings, as shown in Fig. 5. These type of generator can deliver energy to the grid at both super synchronous and sub synchronous speeds. The slip is varied with the help of power electronic circuit. Great advantage of this is that only a part of the power production is fed through the power electronic converter. Hence, the nominal power of the power electronic converter system can be less than the nominal power of the wind turbine. Normally the nominal power of the converter may be about 30% of the wind turbine power, which enables a rotor speed variation in the range of about ±30% of the normal speed. By controlling the active power of the converter, it is possible to vary the rotational speed of the generator, and hence the speed of the rotor of the wind turbine. Self-commutated converter systems, such as IGBT-based switching converters, are generally used for this type of system. As shown in Fig. 5, the DFIG normally uses 2L-BTB converter, which consists of two bidirectional converters sharing a common dc link, one connected to the rotor and the other one to the grid. The power electronic converters for variable-speed generators have the ability to control both the active and reactive power delivered to the grid. This enables optimizing of the grid integration with respect to steady-state operation conditions, power quality, voltage, and angular stability. The reactive power to the grid from the generation unit can be controlled as zero or to a value required by the system operator within the converter rating limit. filters are necessary to reduce the harmonics as the harmonics generated by the converter are in the range of some kilohertz..The DFIG system also special operation strategies provide the high-quality power to the grid. The acoustical noise from the wind turbines can effectively be reduced since the system can operate at a lower speed when the wind becomes quiet. The dynamic response and controllability are excellent in these turbines in comparison with traditional induction generator systems. The DFIG needs neither a soft-starter nor a reactive power compensator.
Following are the main functions of control system of a variable-speed wind turbine with DFIG:

- For optimum operation point control system adjust the power drawn from the wind turbine.
- It limit the power in the case of high wind speeds;

It regulate the reactive power exchanged between the wind turbine and the grid. An example of an overall control scheme of a wind turbine with a doubly fed generator system is shown in Fig.5:there are two control levels in this scheme ,namely DFIG control level and wind turbine control level.

The DFIG control level performs the control of the rotor- side and the grid-side back-to-back converters. A vector control method is adopted for the rotor controller, while two cross- coupled controllers adjust the speed and power of the system. Main object of these two controllers are to track the optimum operation point, limit the power in the case of high wind speeds, and control the reactive power exchanged between the wind turbine generator and the grid. Grid-side converter keeps a constant dc-link voltage while injecting the active power to the grid. Proportional–integral (PI) controllers uses internal current loops in both converters.

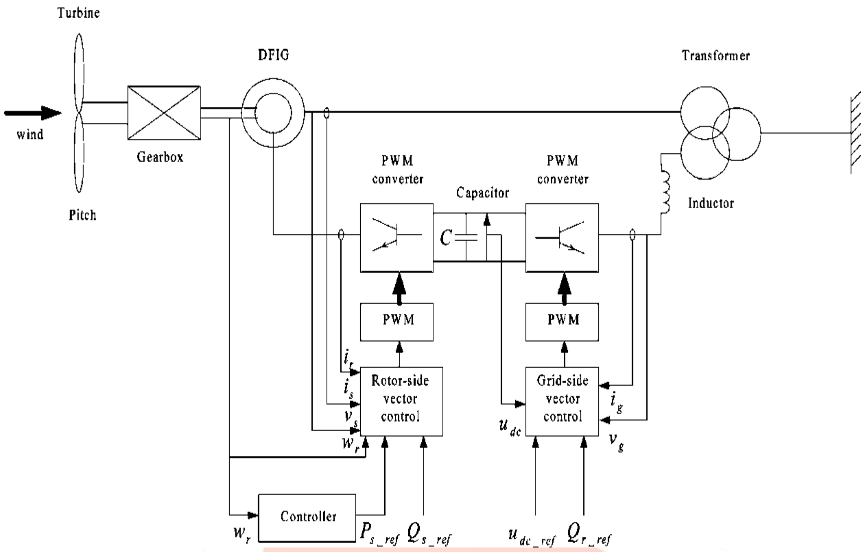

Fig. 6 Wound rotor induction generator with a rotor resistance converter

D. Wind Turbine Systems With Full Rated Power Electronic Converters: Full rated power electronic converters can also be applied with Cage induction generators and synchronous generators to integrate these two with power system. The wind turbines with a full- scale power converter between the generator and grid gives very good performance. Normally, a back-to-back voltage- source converter (VSC) is used in order to achieve full control of the active and reactive power, with synchronous generators, diode rectifiers may be used but when diode rectifiers used, it becomes difficult to fully control the whole system. Since the generator is decoupled from the grid in this system, In this scheme wide variable frequency range operation of the generator is possible while the generated active power will be sent to the grid through the grid-side converter that can be used for controlling the active and reactive power independently. Fig.7 shows four possible schemes with full-scale power converters. All four schemes have almost the same controllable characteristics since the generator is decoupled from the grid by a dc link. The grid-side converter enables the system to control active and reactive power very fast. However, the drawback is system become more complex with use of more sensitive electronic parts. Scheme shown in Fig.7(a) and (b) uses gearbox. The wind turbine system with a cage rotor induction generator and full rated power electronic converters is shown in Fig. 7(c) and (d). The last scheme uses PMs, so it become more attractive due to low cost..

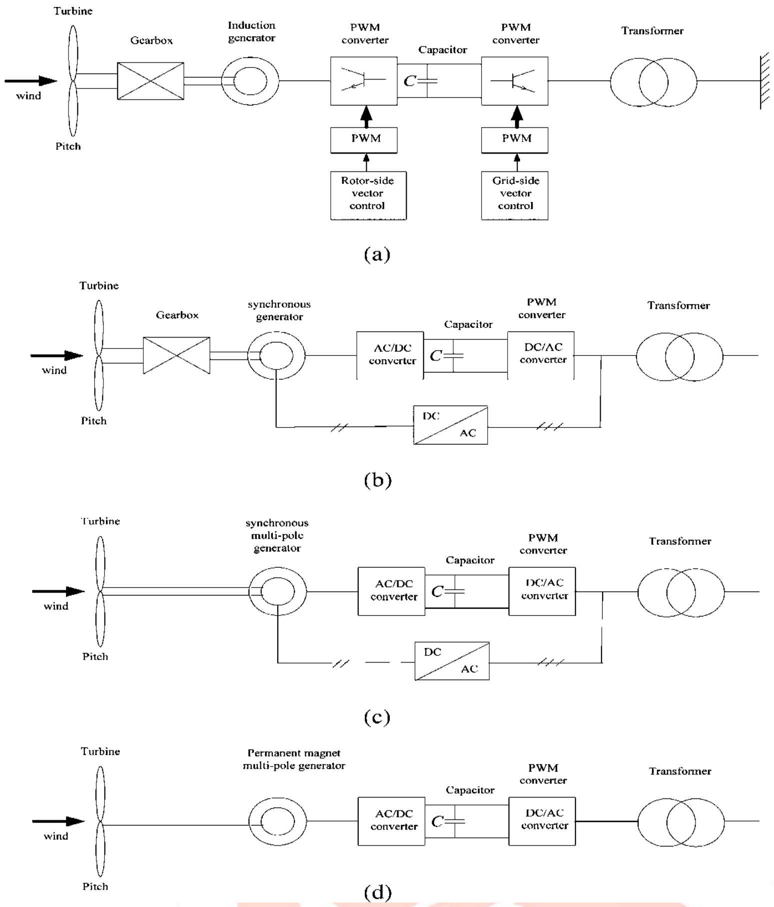

Fig.7 Wind turbine systems with full-scale power converters. (a) Induction generator with gear. (b) Synchronous generator with gear. (c) Multiple synchronous generator. (d) Multiples PM synchronous generator

III. Maximum Wind Power Control

As discussed previously, variable-speed wind turbines are able to operate at an optimal rotation speed as a function of the wind speed. The power electronic converter may control as the turbine rotation speed to get the maximum possible power by means of a maximum power point tracking (MPPT) algorithm.

In this way, it is also possible to avoid exceeding the nominal power if the wind speed increases. At the same time, the dc-link capacitor voltage is kept as constant as possible. For achieving decoupling between the turbine-side converter and the grid-side converter. The grid-connected converter will work as an inverter, generating a PWM voltage whose fundamental component has the grid frequency, and also being able to supply the active nominal power to the grid during the optimal efficiency wind speed range, the wind generator may be adjusted to follow the maximum power point. [5]There are some methods to perform MPPT control for wind turbines PWM voltage whose fundamental component has the grid frequency, and also being able to supply the active nominal power to the grid

A) TSR Control: Fig.8 shows this type of MPPT controller, which requires the wind speed measured by an anemometer. The controller regulates the wind turbine speed to maintain an optimal TSR .though, the accurate wind speed is difficult to obtain. In addition to this the use of an external anemometer increases the complexity and cost of the system

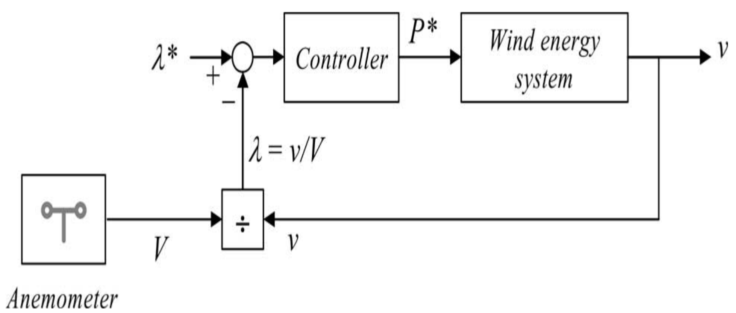

Fig.8. Block diagram of the TSR control

B) Pgnal Feedback (PSF) Control: This control, Shown in Fig. 9, it requires the knowledge of the maximum power curves of the turbine, which may be obtained through simulations or some practical knowledge . The speed of the wind turbine is used to select the stored power curve, which gives the target power to be tracked by the system. In many cases, this power curve may be substituted by a predictor or an observer of the wind speed as a function of the power and the wind-turbine speed.

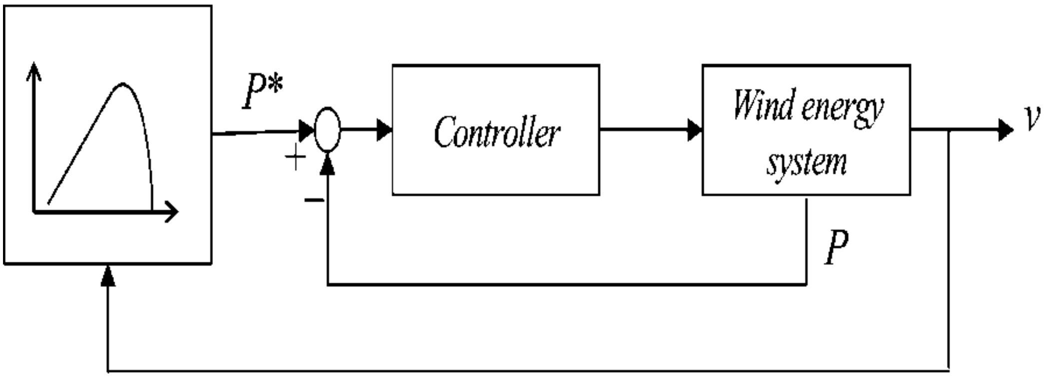

Fig.9 Block diagram of the PSF control.

Hill Climbing Searching (HCS) Control: This control scheme is similar to MPPT schemes used in photovoltaic systems .When the wind-turbine speed increases, the output power should normally increase, otherwise the speed should be decreased (see Fig. 10). Though, this method may be ineffective for large wind turbines, because it is difficult for the large turbines to adjust the speed fast. In practice, MPPT controllers may use combinations of the above three technique

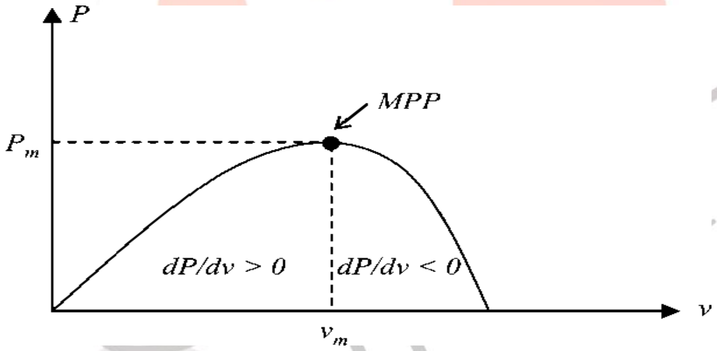

Fig. 10 Block diagram of the HCS control

IV. CONCLUSION

This paper gives the overview of different power electronic. Converters in WTSs with special attention paid to the many possible topologies at low voltage and medium voltage. Now trend is moving towards higher power level, and it is necessary to go for higher voltage and there for multilevel single cell structures or multicell modular structures that can even use standard low voltage power converter modules are becoming more popular. Brief review of the wind energy conversion systems and modern power electronics is presented here. Then maximum power point tracking methods are also discussed.

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