MPPT Algorithms base Extracting Maximum Power from Wind Turbines

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***Abstract* — The state of wind turbine technology is defined by comparison of each type. Squirrel Cage Induction generators (SCIG) has the two modes of induction generators normally used for geared operation in fixed speeds and variable speeds, doubly fed induction generators (DFIG), and wound rotor induction generator (WRIG) while the types of synchronous generator defined by Wound rotor synchronous generator (WRSG) and Permanent Magnet Synchronous Generators (PMSG) can operate gearless. These all types of induction and synchronous generator defined with advantages and disadvantages. Cause of higher demand of power from wind energy system, off shore installations is becoming more popular.**

Keywords:- Wind Turbine, SCIG, WRSG, PMSG, HCS , MPPT, TSR, WECS, Gearbox.

I. INTRODUCTION

Wind energy has long attracted lots of attention as a clean source of power. Wind power is stated by Wind turbines. Most Wind Turbines today are onshore or land-based. Wind Turbines have increased in size along the years, starting from a few KW to the multi MW systems found installed nowadays. Different configurations of generators and electronic convertors help achieve high and stable output power. The latest annual wind reports of 2011 have stated that the installed wind power worldwide 239GW is enough to supply 3% of the world's demand in electric power.

The paper is defined into the following Sections. Section II shows the general configuration,topologies and MPPT algoithms of a wind turbine and its conversion equations. In Section III the three different types of induction generators commonly in use for wind turbine systems will be listed and they are; Doubly Fed Induction Generators, Squirrel Cage Induction generators and Permanent Magnet Synchronous generators. Section IV different types of synchronous generator and Section V defined of conclusion of various types of generator used [2].

$$TSR = \text{Linear speed of blade outermost tip/Free upstream wind velocity}$$

$$TSR = \omega . R/V$$

II. WTs CONFIGURATION,TOPOLOGIES & MPPT Algorithms

In the history of WT, there were two types of WTs use; the fixed speed and the variable speed WT. Until the end of the 90's the fixed speed WT was more in use but nowadays, a new technology is use which is called the variable speed wind turbine. This type is turbines achieve maximum aerodynamic efficiency over a wide range of wind speeds. Typically, most common type of wind turbines are horizontal axis configuration (HAWT), [3] which is three rotor blades, with the mechanical parts and the generator mounted in a nacelle. This nacelle is positioned high up on tower. The blades of some large scale WTs can reach up to 140 m in diameter with a rotational speed between 5 and 25 rpm. Wind turbine with Variable-speed operation and pitch control systems [2] [1].

TORQUE-SLIP CHARACTERISTICS

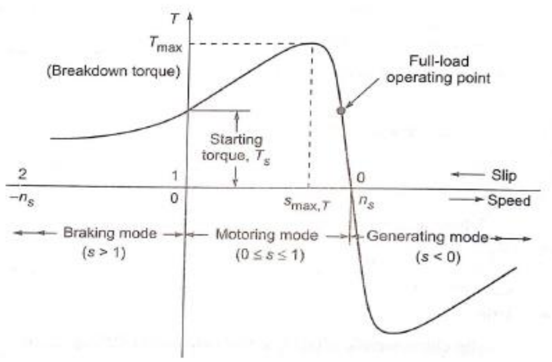

Fig.1. Torque-Slip Characteristics [3]

The torque slip curve for an induction motor gives us the information about the variation of torque with the slip. The slip is defined as the ratio of difference of synchronous speed and actual rotor speed to the synchronous speed of the machine. The variation of slip can be obtained with the variation of speed that is when speed varies the slip will also vary and the torque corresponding to that speed will also vary. More details can be seen in the references. [6].

[1] The power contained in the wind is given by the kinetic energy of the flowing air mass per unit time. That is,

Pair = 0.5.ρ.A.Vw3

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Where Pair is the power contained in the wind (watts) ρ is a air density (kg/m3), A is the swept area (m2), Vw is the velocity of the wind.

MAXIMUM POWER PONT TRACKING ALGORTIHMS:

The following section describes the various conventional methods of MPPT in WECS.

A. Hill Climb Search (HCS) method:

HCS method of MPPT makes use of the inverted U shaped graph between power and rotor speed. As there is a definite peak power corresponding to a particular rotor speed, the algorithm compares the present power at an instant to the power obtained at the previous step. If the power is found to be increasing, then the duty cycle of the gating pulse applied
to the converter switches are increased to drive the operating point more towards the peak power. If the power is found to
be decreasing, then the duty cycle is reduced. The primary advantage of this method is its simplicity and independence from wind turbine characteristics. A severe limitation of the HCS method is its inability to track the maximum power
point in cases of abruptly varying wind conditions. In normal HCS methods the increments/decrements given to the duty cycle are fixed.

B. Tip Speed Ratio (TSR) ratio:

TSR method tries to modify the rotational speed of generator so as to maintain an optimum TSR. The limitation of this
method is that wind speed needs to be known along with the turbine rotational speed measurements. This adds to the system cost, especially when considered for use with small scale wind turbines.

C. Power Signal Feedback (PSF):

PSF method uses a reference power, which is the maximum power at that particular wind speed. This in itself presents an
issue, as the prior knowledge of the wind turbine characteristics and wind speed measurements is required.
Once this reference power is obtained from the power curve for a particular wind speed, a comparison with the present
power yield is done. The error produced then drives a PI control algorithm. PI control refers to Proportional (P), Integral (I) control. It has a P and I part that are manipulated to reduce the error between a known set point and the instantaneous values of the measured values

III. TYPES OF INDUCTION GENERATOR

[3] There are mainly three types of Induction generators used in wind power generation are following of

A. SCIG (Squirrel Cage Induction Generator)
B. WRIG (Wound Rotor Induction Generator)
C. PMSG (Permanent Magnet Synchronous Generators)

A. *SCIG (Squirrel cage Induction Generator)*

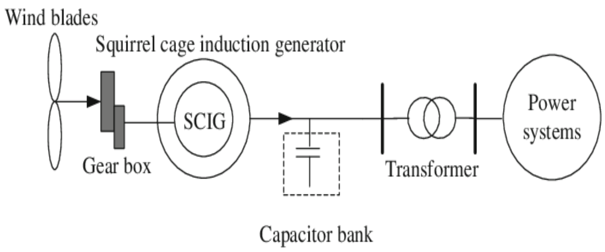

Fig.2. Schematic of a SCIG [1]

It is very robust and less maintenance is needed only bearings lubrication. The rotor is made of metallic bars and short with end rings. In some cases, a SCIG used for variable-speed wind energy generation with a full-scale power electronic convertor. To elaborate more power from the wind is difficult because this can cause generator overload. So pitch angle regulation is needed to achieve an optimal power extraction,
[1] [3] A schematic of a SCIG is presented in Fig.1.The SCIG operates completely in minimum ranges of wind speeds through a gearbox. Variations in the rotor speed of the SCIG are very small as the only speed variations that can occur are changes in the rotor slip. Due to this fact, the SCIG was widely considered as fixed-speed.

Advantages of SCIG:

- SCIG is a very popular for simplicity and robust construction,
- For SCIG requires no brushes for operation, which are every times necessary for the operation,
- Metallic rotor bars are very well resistant to vibrations and dirt,
- It doesn’t have current harmonics since it has no frequency conversion,
- Easy and cheap for mass production.
- SCIG type wind turbine have the benefit of avoiding short circuit powers from the grid because the control system limits any fault current from the grid side convertor going into the system.

Disadvantages of SCIG:

- Required of Two full scale converters for operation,
- It does not have the advantage using reduced size power converters as in the PMSG, for variable speed operation,
- It can’t function as a multi-pole direct drive mode (gearless),
- There is a big problem with gear box maintenance.
- It is highly noisy.

B. *WRIG (Wound Rotor Induction Generator).*

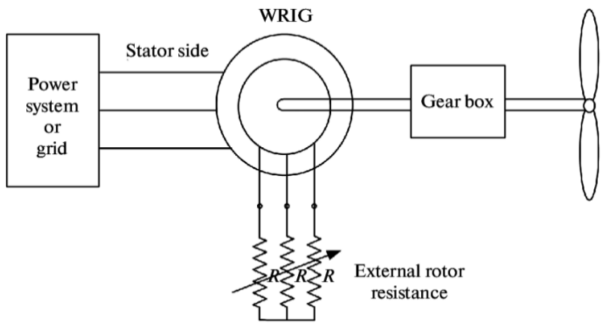

Fig.3. Schematic of a PMSG [1]

A schematic of a PMSG is presented in Fig.3. To couple the slow spinning turbine rotor blade to generators like the PMSG and the SCIG, high speed multiple stage gearboxes which is ratio of 1:100, medium-speed single-stage gearboxes ratio is 1:10 are needed.

Today's wind turbines high-speed multiple stage gearboxes have proven to be less reliable than expected by manufacturers thus requiring replacement at 5 to 7 years from beginning of operation, and that is a much earlier than their expected design life of 20 years. On shore-based wind turbines have a major issue of decreased reliability and longevity so this becomes a critical matter to look into for offshore installations. In this case, main wind turbine manufacturing companies have started manufacturing of wind turbines with this type of generators for mainly offshore installations. This type is the most efficient generator with power losses of about 65% of that of a typical PMSG [1] [3].

Advantages of PMSG:

- Due to absence of gearbox lower maintenance cost,
- With the elimination of the gears and bearings improved reliability and longevity which are by themselves the main cause of faults in the generators,
- Lower weight,
- High efficiency and energy yield

Disadvantages of PMSG:

- Higher cost,
- Outer diameter of the direct drive PMSG is almost twice the size of that of the conventional geared-drive SCIG,
- Low maturity as it being a new technology,
- Increased mass and weight that can reach to critical positions especially for wind turbine above 3MW.

C. *PMSG (Permanent Magnet Synchronous Generators)*

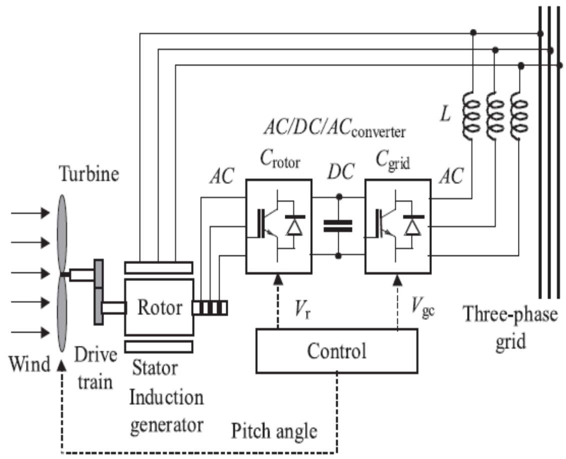

Fig.4. Schematic of a PMSG [4]

A schematic of a PMSG is presented in Fig.2. PMSGS is a wound- rotor induction generator and the most commonly used in the wind industry. In the PMSG, the stator terminals are directly connected to the three phase grid and the rotor are connected to grid via slip ring and convertor. A gearbox is needed to couple the rotor to the generator due to the difference in the rotor and generator speed ranges. These convertors are usually of variable frequency and back to back or AC/DC/AC voltage source type. They are made up of two IGBT converters: rotor side converter (RSC) and grid side converter (GSC) with a DC-link connection [3] [2].

This converter decouples the line grid frequency and the turbine rotor frequency, which in enables variable speed operation. The rotor voltage is applied from the power converters. The Rotor Side Convertor (RSC) fully controls the generator like in the control of active and reactive powers, and controlling harmonics, while the Grid Side Converter (GSC) controls the power factor.

Advantages of PMSG:

- Mechanically and electrically simpler than other generator types. The 3 stage geared PMSG is the lightest and low cost solution,
- Converter Rating is only 25-30% in PMSG as compared to 100% of total nominal power of the generator,
- Can reach to about 30% of synchronous speed, thus has a wide range of speeds,
- The converter compensates the reactive power and ensures smooth grid integration,
- High efficiency and energy yield.
- Ability to produce more output than its rated power without being overheated.
- Ability of transferring maximum power both in sub-synchronous and super synchronous modes [2] [1].

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Disadvantages of PMSG:

- For wind turbines based on PMSGs, gearboxes are still a necessity since a multiple pole PMSG with low speed,
- Difficulties associated in complying with grid fault ride-through,
- Due to bearings and gear faults, medium reliability and reduced longevity.

Table I: Annual energy yield/ total cost of three different wind generator systems [1]

COST	SCIG	DFIG	PMSG
Gearbox	220	220	-
Converter	120	40	120
Generator cost	287	320	432
Total Cost	1837	1870	1982
Annual energy yield Mwh	6705	7690	7890
Annual Energy yield	3.63	4.11	3.98

IV. Types of Synchronous Generators used in Wind Turbines

There are mainly two types of Synchronous generators used in wind power generation are following of

A. WRSG (Wound Rotor Synchronous Generator)
B. PMSG (Permanent Magnet Synchronous Generator)

A. WRSG (Wound Rotor Synchronous Generator)

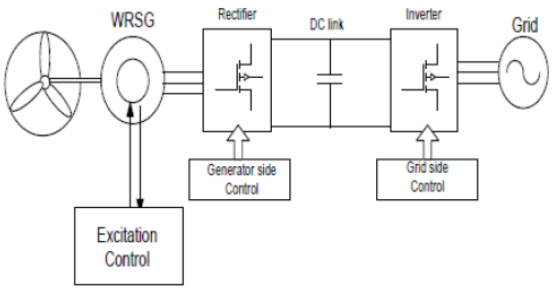

Fig.5. Schematic of WRSG [3]

[2] The amplitude and frequency of the voltage can be fully controlled by the power electronic converter at the generator side, so that the generator is fully controllable in wide range, even in low speeds. In addition, it has the opportunity of controlling the flux for minimized loss in different power ranges, because the excitation current can be controlled by means of the power converter on the rotor side. Moreover it does not require the use of permanent magnets which would represent a large fraction of the generator costs. Therefore it is the most used direct-drive generator in market.

Advantages of WRSG:

- It's Suitable for high power generation.
- There is Independent control of real and active power.
- Improved power factor since it is self-excited generator.
- There is no need of gearbox [2].

Disadvantages of WRSG:

- It is necessary to excite the rotor with DC, with slip rings and brushes or brushless exciter, employing a rotating rectifier and the field losses are inevitable.
- To excite the winding of the rotor it requires additional converter.
- Comparison with induction generator higher maintenance cost [1].

B. *PMSG (Permanent Magnet Synchronous Generator)*

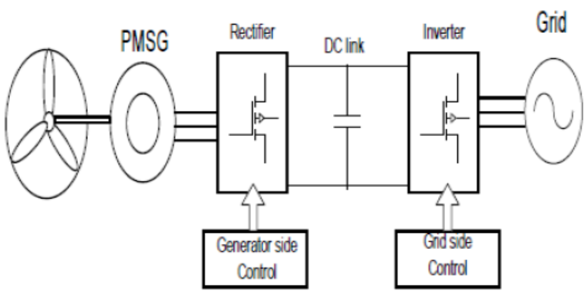

Fig.6. Schematic of a PMSG [3]

The most popular converter topology for PMSG based WECS is back to back frequency converter. Advantages of this technology are that, it provides active and reactive power control and also increases power factor because of Pulse Width Modulation techniques.

Advantages of PMSG:

- PMSG is Light weight and small size in construction.
- It has Low losses and high efficiency.
- There is no need of external excitation current.
- There is no need of gearbox [4].

Disadvantages of PMSG:

- It is useful for small wind turbines, for large wind turbines the size of the magnet has to be increased.
- Due to atmospheric conditions is a big problem demagnetization of permanent magnet [3].

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V. CONCLUSION

This paper has reviewed very clear that Variable speed operation is very still attractive due to the fact that machines with this technology exhibited reduced mechanical stress and increased power capture. As mentioned above the market share of the fixed speed concept has decreased quickly, where the demand for variable speed wind turbine has increased. When compared with other variable speed wind turbines that need a full-scale power converter to operate, the main advantage of the PMSG is that only 30% of the generated power goes through the power converter and this alone may have substantial cost advantages even with low cost of future converters and power electronics. If overall efficiency, reliability and availability are a critical requirement, the direct-drive PMSG wind generator systems come into play because of omitting the gearbox. They are usually larger, but that might not cause any disadvantage for the offshore wind energy where there is no mater of land and space hindrance and where there is abundant wind speed.

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