ISSN: 0975-8585

Research Journal of Pharmaceutical, Biological and Chemical Sciences

Analysis of Switched Reluctance Generator for Wind Energy Conversion System.

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ABSTRACT

This article discuss with entire approach for switched reluctance generator (SRG) in variable wind energy conversion systems (WECS). The use of this paper is to offer an systematic review of wind turbine generator systems for stand- alone applications. The review concentrates on variable-speed wind turbines, as the future trend in wind energy conversion, in contrast with the traditional fixed-speed wind turbines. Indirect-drive and direct- drive turbines are comparatively evaluated. The concern about long-term accessibility of permanent magnet materials and its impact on the future of permanent magnet synchronous generator are presented. Having cost and efficiency in mind, viability of indirect-drive squirrel cage induction generator for complete wind energy conversion systems is analyzed. As a capable induction machine design, permanent magnet induction generator is also additionally reviewed. Conclude the potential of purposing switched reluctance machine, as a generator, in a direct-drive wind turbine system is reviewed.
Keywords: Wind Energy Conversion Systems(WECS),Switched Reluctance Generator (SRG), Wound Rotor Synchronous Generator (WRSG), Synchronous Generator(SG), Permanent Magnet Synchronous Generator (PMSG).

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INTRODUCTION

Energy is a significant role model and unavoidable things in all sectors of the world economy. The standard of an afforded country can be known by its per capita energy consumption. Recently the energy crisis occurs; because of the increase in the world's population, need of energy has also increased rapidly.

Wind turbines can be used to harness the energy obtainable in airflows. Now a day's turbine varies from 600 KW to 5 MW of rated power. Since the power output may be performing a cube of the wind speed, it will increase quickly with the increase in obtainable wind velocity. Recent advancements have led to airfoil wind turbines, which are additionally economical for a stronger mechanism's structure.

THE switched reluctance generator (SRG) has been recommended as a good alternative for applications in wind power generation as a results of its work over a wide vary of speeds at a high performance level [1], [2]. Moreover, the SRG has attractive features, such as its mechanical robustness, high performance, low manufacturing cost, and an absence of permanent magnetic elements [2]–[7]. The most drawback to the commercial use of the SRG are torque ripple, audible noise, the need for position sensors, the need for robust controls for a broad range of speeds, and the lack of methodologies for it selects magnetic design. A significant amount of effort has been invested in mitigating these obstacles as in [4], [8]–[10]. The popular of the current works has approached SRG electromagnetic project. In [11], a high efficiency small SRG, applied to variable speed wind generation, was estimated and built using finite element techniques. Building a prototype has confirmed the efficiency of the studied SRG. The investigate of projects and configurations using different number of poles were discussed by [12]–[15]. In [16], a 10 kW SRG-C was design to work in wind systems without using a gearbox. In [17], an axial reluctance generator was projected to operate at low speed. A complementary excitation winding was integrated to a C core SRG to increase the generated power [18]. The strategy adopted to control an SRG is directly related to the operating speed . [19].

Some researcher discussed the connection of an SRG to the electrical grid in wind power generation systems that have variable speed. In [20], [21], simulations of a speed-control system were designed using an adaptive neural network acting on the current control of an SRG connected to an electrical grid by means of a voltage source converter (VSC).

VARIABLE SPEED GENERATORS

Variable speed wind turbines are widely used in Wind Energy Conversion Systems. Variable speed operations of wind turbines give blessings over the constant speed operation. Basically, variable speed wind turbines use the high inertia of the rotating mechanical elements of the system as a regulator this aids to sleek power fluctuations and reduces the drive train mechanical stress in addition to that. Also, variable speed systems may lead to maximize the capture of energy throughout partial load operation. At first, wind energy conversion systems were supported on generators directly connected to the grid, hence the speed of these systems was constant (with synchronous generators) or quasi-constant (with asynchronous generators). The development of power, semiconductors has contributed enormously to variable speed wind energy conversion systems by interfacing the constant frequency of the grid to the variable frequency of the generator. Variable speed operation of wind turbines demands the appliance of variable speed generators, operative on the constant frequency of the grid. The variable speed operation of a wind, electric system yields higher outputs both in low and high wind speeds. Both horizontal and vertical axis turbines will exhibit gain under variable speed operation.

Doubly Fed Induction Generators

In variable speed wind turbines, the turbine is not directly connected to the utility grid. Instead, a power electronic interface is placed between the generators and also the grid is employed to produce to decouple and control the system. The Doubly fed induction generators based WECS, which is also known as improved variable speed WECS, is mostly used by the wind turbine industry. The term “Doubly-Fed” arrives from the very fact that the stator voltage is used from the grid and rotor voltage is affected by the power converter. It has the ability to control reactive power, and to decouple active and reactive power control by independent control over the rotor excitation current. In the case of a weak grid, the voltage may fluctuate, the DFIG may be ruled to develop, engage an amount of reactive power from the grid, with the aim of controlling voltage.

Synchronous Generator

The Synchronous Generator is much more expensive and complicated than an Induction Generator that is smaller in size. However, it has clear advantage equated with Induction Generator; namely, it does not have a reactive magnetizing current. The Synchronous Generator can be either wound rotor synchronous generator (WRSG) or a permanent magnet synchronous generator (PMSG), the latter is being the one which mostly employed by the wind turbine industry.

Wound Rotor Synchronous Generator (WRSG)

The stator windings of WRSGs are connected directly to the grid and thus the rotational speed is strictly fixed by the frequency of supply grid. The rotor winding is excited with direct current using slip rings and brushes, with a brushless exciter with rotating rectifier. Not like the Induction Generator, the Synchronous Generator doesn't need a reactive power compensation system. The rotor winding, through the DC flows, generate the exciter field which rotates with synchronous speed. The speed of the synchronous generator is determined by the frequency of the rotating field and by the quantity of pole pairs of the rotor. It has an advantage that it does not need a gearbox. But the price that has to be paid for such gearless design is more and heavy generator, and a full-scale power converter has to handle the full power of the system

Permanent Magnet Synchronous Generator (PMSG)

The PMSG is considered, as a better option than WECS, because of self excitation property, and permits operation at high power factor along with efficiency. In the Permanent Magnet (PM) machine, the efficiency is higher than the induction machine, because the excitation is allowed without any energy supply. However, the materials used for producing permanent magnets are expensive, and they are difficult to work out during manufacturing. In Addition to that, the use of PM excitation requires the use of a full scale power converter in order to adjust the voltage and frequency of generating voltage and the frequency of transmission respectively. The synchronous nature of the PMSG may cause problems during startup, synchronization and voltage regulation. Also it does not readily provide a constant voltage.

SWITCHED RELUCTANCE GENERATOR CONSTRUCTION

The SRM have double-salient electric machines with non-overlapping stator multiphase windings and with passive rotors. This is mainly due to its unique characteristics in terms of mechanical simplicity and robustness. The machine also offers potential with high efficiency, high reliable operation and inherent fault tolerance.

The rotor construction is very simple, because it consists of only laminated steel. The stator part consists of concentrated phase windings mounted around salient poles. Fig. 1 shows cross sectional view of Switched Reluctance Machine stator poles and windings. This is good in a commercial sense, as manufacturing cost is low. Besides, the absence of windings and permanent magnets on the rotor encourage high speed and high temperature operation of the Switched Reluctance Machines. Furthermore, it is convenient for heat management. Under normal operation, each phase of the switched reluctance generator is electrically and magnetically independent from others. This confirms improved system reliability.

The existing research shows that in the past decades the wind generation has become one of the hot topics in world wide. Generator has the lowest environmental impact of all energy sources; it occupies less land area per KWH than any other energy source apart from the rooftop solar energy.

- The green house effect of wind energy generator (WEG) is almost negligible compared with any other energy sources.
- Short time for construction and long work life
- Low cost and maintenance
- By using WEG it will help reduce the air pollution by reducing the carbon dioxide into our air.

• Due to the modern electronics, electrical and mechanical equipment the control of is excellent.

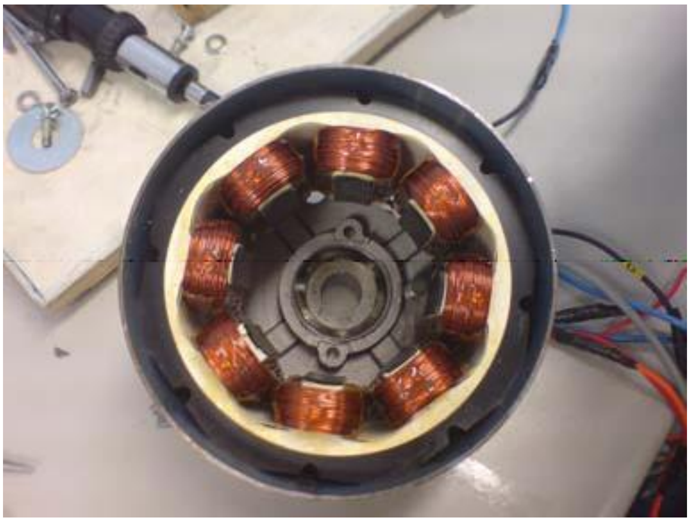

Fig 1: SRG Stator Poles and Windings

PRINCIPLE OF OPERATION

The SRG system consists of six major blocks, namely-SRM, Power Converter, Prime Mover, Controller, Position Sensor and Load. The basic Principle of operation can be explained with the help of inductance profile which is shown in Fig. 2 [22 -23].

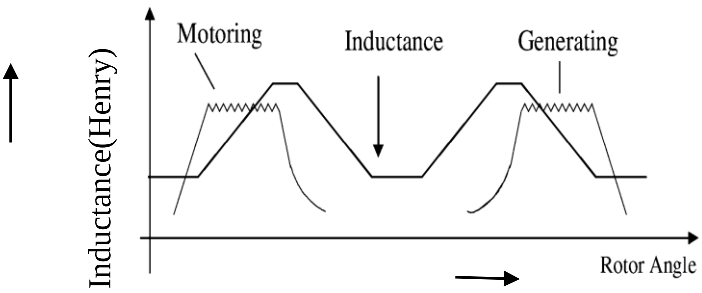

Fig 2: Inductance Vs Rotor angle

If saturation is neglected, then the inductance varies linearly with respect to the overlap between the stator and rotor poles. The *inductance is maximum* when the rotor and stator poles are *fully aligned* and *minimum* when the poles are *completely unaligned*. Motoring action is obtained when the phase is excited during the positive slope of the inductance profile. For generations, the machine phases are excited during the negative slope of the inductance profile.

SRG Based Wind Conversion System.

The most commonly used SRM is the classical half bridge converter which has two power switches and two diodes per phase as shown in the Fig .3

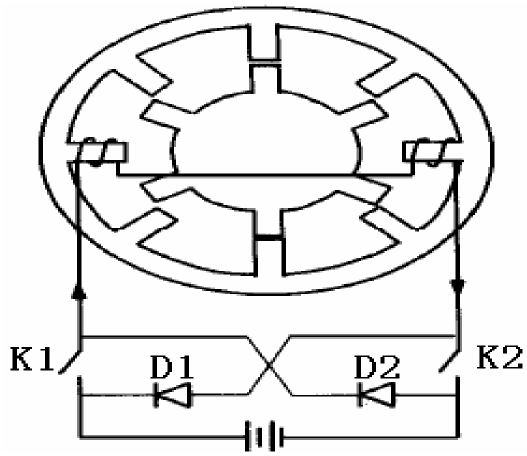

Fig 3: Cross Structure of SRG

There are two switches K_1, K_2 and two diodes D_1, D_2 in one phase, While the lower switch is in charge of commutation, the upper one is used to perform PWM switching control. When both K_1, and K_2 are turned on the winding is excited, the system absorbs energy from the prime mover and the excitation source. When both K_1, and K_2 are turned off, the winding will release energy through D_1, and D_2 the system offers electric energy to external loads. The main advantage of this converter is that each phase can be controlled independently [24-25].

Generating Mode

During the generating mode, both of the two switches are turned off with the circuit and current path being shown in Fig 4. This action will impose the negative DC -link voltage upon the active stator phase, At this time, the mechanical energy from prime mover is converted to electrical energy. The phase winding voltage equation in this mode can be written in Equation (4.4).

$$-V_o = R_S + L*(\frac{di}{dt}) + e, e < 0 \quad (1)$$

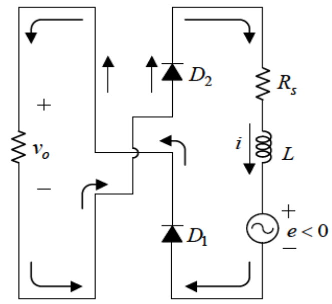

Fig 4: Generating modes of SRG

Control Methods for SRG

The heart of the SRG depends on its control strategy which is through proper switching of power electronic and Careful placement of the firing angles must be made to ensure continuous operation of the generator as well as maximizing its efficiency. Is has been mentioned that by increasing the excitation current, output power will increase as compared to increasing speed. Also the firing angles determine the area of flux linkage which corresponds to energy converted per stroke. Current research shows that the output power and voltage depend on angular speed and excitation voltage. By adjusting the excitation voltage the output power can be controlled . This shows the importance of firing angles on output power. Due to its inherent characteristics such as nonlinearity its optimal control is difficult to achieve. The main reason is because there are various combinations of firing angles that would produce the same amount of output power . This implies that its efficiency, torque ripple and dc link current are also different according to the various angle combinations. Hence as stated earlier most of the ongoing research on control of SRG is on ways to determine the optimal firing angles to achieve maximum efficiency. As observed, in generating mode single pulse operation is common for both low and high speed. The difference lies in the control strategies applied. Unlike in motoring single pulse mode is used for high speed whereas pulse width modulation for low speed.SRG control strategy based on the determination of the firing angles could be classified into three groups. These groups are:fixing both the turn on and turn off angles one of the angles may be fixed whilst varying the othervary both turn on and turn off angles As there will be variation in wind velocity, the best strategy is to vary both the turn on and turn off angles in order to achieve optimum performance.

SRG BASED WIND CONVERSION SYSTEM.

The tip speed ratio λ is defined as:

$$\lambda = \frac{\omega R}{v} \qquad (2)$$

Where, ω, R and V represent turbine rotational speed,

Turbine blade radius and the wind velocity respectively.

In general, the power captured from the wind turbine can be written as:

$$P_m = C_p(\lambda, \beta)\rho \frac{A}{2} v^3 \qquad (3)$$

Where *Cp (* λ , β) is the power coefficient, ρ is the air density, *V* is the wind speed, *R* is the blade radius, β is the blade pitch angle and λ is the tip speed ratio. The power curve speeds of a typical wind turbine are shown in Fig. 5. The value of maximum wind turbine output power per unit can be obtained by putting zero pitch angle and Betz limit, when the velocity of wind turbine is 12 m/s. It is not suitable for real time application. In this proposed paper, maximum power can be captured in different wind turbine speeds. Considering the generator efficiency *η*G, the total power produced by the WG *P* is

$$P = \eta G P_m \qquad (4)$$

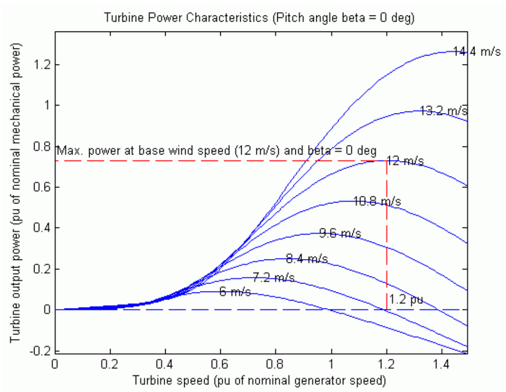

Fig 5: Turbine Output Characteristics (Zero Pitch angle)

The WG power coefficient is maximized for a tip-speed ratio Value *opts* when the blade pitch angle is *β* = 0◦. It is observed that, for each wind speed, there exists a specific Point in the WG output power versus rotating-speed characteristic where the output power is maximized. The value of the tip-speed ratio is constant for all maximum power points (MPPs), while the WG speed of rotation is related to the wind speed as follows:

$$\Omega_n = \lambda_{opt} \frac{V_n}{R} \quad (5)$$

Where Ω_n is the optimal WG speed of rotation of a wind Velocity V_n. Besides the optimal energy production capability, another advantage of variable-speed operation is the reduction of stress on the WG shafts and gears, since the blades absorb the wind torque peaks during the changes of the WG speed of rotation. The disadvantage of variable-speed operation is that a power conditioner must be employed to play the role of the WG apparent load. However, the evolution of power electronics helps reduce the power-converter cost and increases its reliability, while the higher cost is balanced by the energy production gain. The torque curves of the WG, consisting of the interconnected wind-turbine/generator system, for various generator output voltage levels under various wind speeds, are shown in Fig. 6. The generator is designed such that it operates in the approximately linear region corresponding to the straight portion of the generator torque curves, under any wind-speed condition.

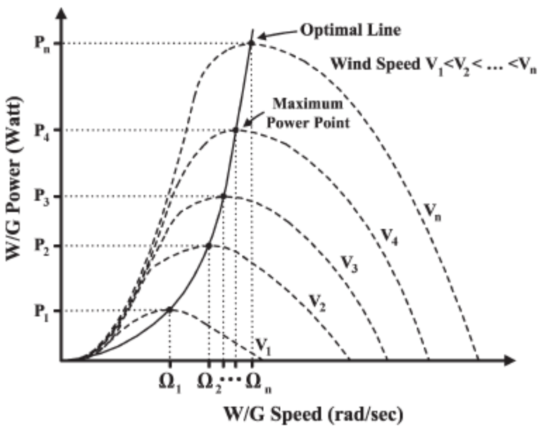

Fig 6: WG Power curves at various wind speeds

The wind turbine which extracts energy from the wind through the turbine blades that are attached to rotor shaft of the turbine is mechanically coupled to rotor shaft of the switched reluctance generator. Thus the translational form of mechanical energy of the wind is converted into rotational of mechanical energy by the turbine. The converter supplies the electrical energy needed by stator coil to produce magnetic flux in the stator core. Both the stator and the rotor of SRG are made of soft iron lamination materials and the both have salient poles. Only the stator poles are wound with copper coils, the rotor poles carry no coil. The overall performance of the SRG system depends largely on the efficiency of the wind turbine SR machine the power converter and the control unit in Fig 7, Main drawback of different small stand alone WECS based on the discussion made in Table 1.

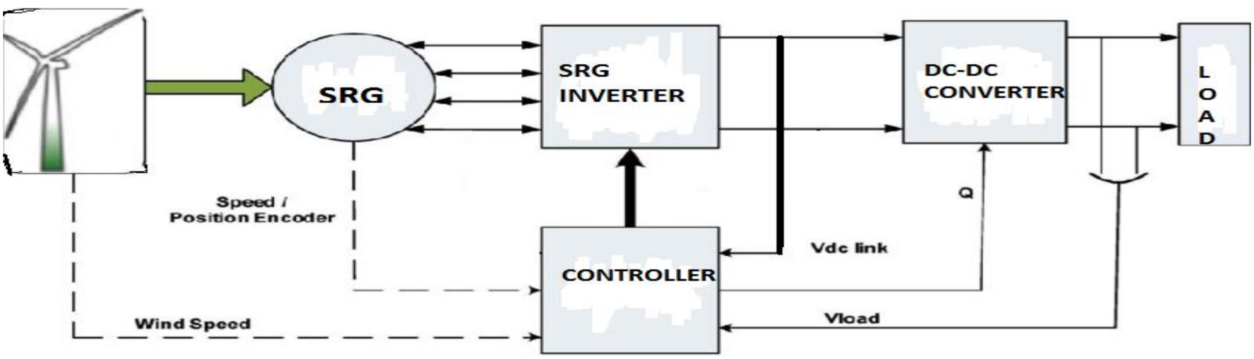

Fig 7: SRG Based WECS

Table 1: Drawbacks of different stand-alone WECS configurations

GENERATOR	DRAWBACKS
In direct - drive WECS	
WRIG	Gearbox problems, Problems of brushes and slip rings, Low efficiency, Limited speed range.
DFIG	Gearbox problems, Problems of brushes and slip rings, Transient problems due to limited ratings of the rotor power converter.
SCIG	Gear box problems, Low efficiency
Direct drive WECS	
WRSG	The need for external DC, source for rotor excitation, Brush problems in brushed exciter, Cost and complexity in brushless exciter.
PMSG	Cost of PM, Demagnetization problems of PM, Insecurity of PM supply in future, Cogging torque effect
SRG	High torque ripples, Acoustic noise,In early stages of development for WECS.

CONCLUSION

The paper gave an analytical review of different stand-alone wind energy conversion systems based on possible generator types, available in wind market and reported in the literature. The potential of SRG to serve in wind energy system was investigated .As a simple, robust, reliable and inexpensive machine with flexible control, SRG has been recommended to serve as a direct-drive generator in standalone WECS. However, a SRG- based wind energy system is still a comparatively immature technology. Thus, further analytical studies and experimental research will be required be for the SRG turbines can be placed in service.

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