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A NEW GENERATOR TOPOLOGY FOR WIND POWER GENERATION

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Abstract

This paper illustrates the concept of an electrical machine designed for wind turbine application. Recent studies in this domain propose the use of dual magnetic circuit through a double stator or double rotor for various applications. As a reference wind generator developed using an outer rotor developed with a dual magnetic circuit. To design a generator with capabilities of delivering electrical power output through connection with a wind turbine, generators on the basis of slots-poles combination configuration were designed with interior permanent magnet implementation on rotor using numerical design tool. Through this software finite element analysis is applied to the models and analyzed based on the magnetic flux results. The model configuration of 12S-10P is selected as it provides an increase of 33% in magnetic flux flow. Furthermore, the machine is further modeled under two modes of half motoring and only generating operation to increase the capability of wind turbine operation under the low wind speed. The efficiency obtained when simulated under various low wind speed condition is an average of 75% under half motoring condition while when operated in completely generating mode under the optimum wind condition the efficiency lies in the region of 75%.

Keywords: Double stator, Generator topology, Low wind speed span, Operating capability, Wind energy.

1. Introduction

With the advancement of the society, it is now generally accepted that combustion method for electromechanical conversion of energy such as the burning of fossil fuels ends up contributing significant negative effect on the earth climate [1-2]. Hence the focus is shifted towards the development of energy harvesting procedure through the renewable resources such as solar, hydro, wind etc. resulting in the fastest growth of wind energy sector among other various forms of energy [3-5]. A generator falls under the category of dynamic machine. Generally, in a generator, a mechanical force comprising either of kinetic energy or potential energy is responsible for rotating the generator. The core components of a generator are the rotor which provides the required field through the rotation and the stator which holds the armature windings on itself. The use of permanent magnets are on the rise in designing the electrical machines as they provide the ability for precise control and better efficiency [6-8].

Based on the wind speed characteristics of Malaysia the typical wind speed ranges from as low as 0 m/s to 13m/s with a highest mean daily wind speed of 3.8 m/s recorded at Mersing, Johor [9-10]. Technically it is not possible to have the wind turbine operates at high speed due to mechanical limitation such as tearing, however on the upper limit of the wind speed pitch control are responsible to maintain the working of wind turbine, in case of further increase of speed the wind turbine has to be shut down to prevent excessive wear and destruction. Ideally, for the wind turbine to start operating, around 3.5 m/s - 5 m/s wind speed is required [11-12]. Furthermore, by having a generator that is able to operate beneath the typical starting operating speed of 3m/s - 5m/s, the operating capability of the wind turbine power generation system can be increased and discontinuity could be decreased. The continuous change in the wind speed poses the biggest factor in the discontinuity of the wind energy conversion smooth operating as well as low wind speed in Malaysia. When the wind speed is very high, a shutdown is required due to mechanical constraints while when the speed is very low, the operation is also in need of cutting off due to variable low wind speed unable to move the generator in constant rpm. The following phenomenon is showed in Fig. 1.

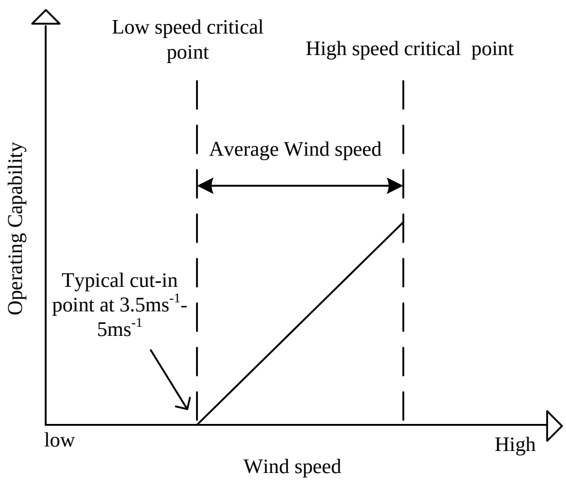


Fig. 1. Typical wind turbine operating conditions

2. Design Approach

2.1. Operational modes

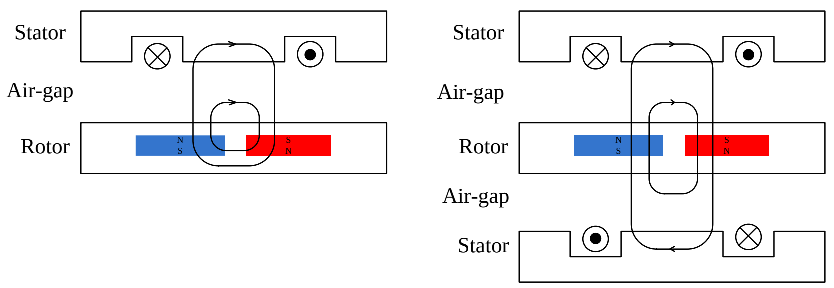
A typical wind generator operates on the principle of both motoring and generating. At first, it operates as a motor in order to move the blades from the static position into motion, the machine continues to act as a motor until the blades have enough momentum to match the force provided by the wind speed and is capable of rotating under wind speed and then switches to generation mode. For the optimization process in terms of increasing operating capability on lower wind speed, the designed model can be made to operate in two different modes as stated in Table 1.

Table 1. Modes of operation.

Modes	Description
Half Motoring	In this mode, in order to move the wind turbine blades into motion when the wind speed is under the low critical, the machine will act as half motoring. The concept is to magnetize the half of the machine while supplying the current to reduce the power required to move the wind blade. With the increase in the efficiency, the mode will help in increasing the power generation capability under low wind operating conditions.
Generating	When the blade speed is under the ideal operating range or reached the critical cut in point and pitch control is able to maintain the constant rpm of the generator, the machine will switch into the full generating mode.

2.2. Proposed design

To achieve the mentioned objectives a basic model is selected based on a conventional single stator as shown in Fig. 2(a). As a reference wind generator developed using an outer rotor developed with a dual magnetic circuit is proposed. The dual circuit can be done using a double rotor or double stator, however, the addition of the rotor induces less effectiveness as the generator would not be able to operate under low wind speed, and hence an outer stator is used in this research design application. This result into the addition of double coil windings and hence twice the magnetic flux as shown in the Fig. 2(b) is feasible due to increase in the electrical loadings. Furthermore, the modes of operation in both motoring and generating is capitalized with the use of two stators.



(a) Conventional model flux path **(b) Proposed design flux path**

Fig. 2. Magnetic flux flows in conventional and proposed design.

In a single stator single rotor, machine magnetic flux density is given by Eq. (1).

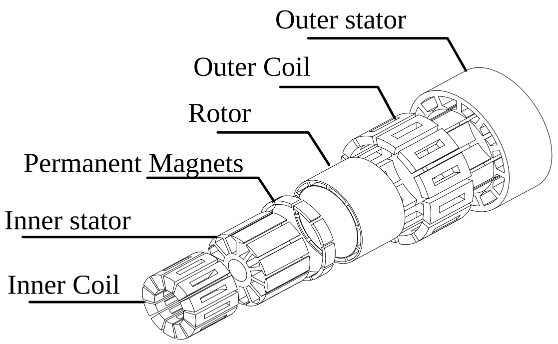
$$\text{Magnetic flux Density} = \frac{nNi}{\pi d} \tag{1}$$

where *n* is number of the stator, *N* is number of coil turns in the stator winding, *i* is the current in Ampere and *d* is machine diameter.

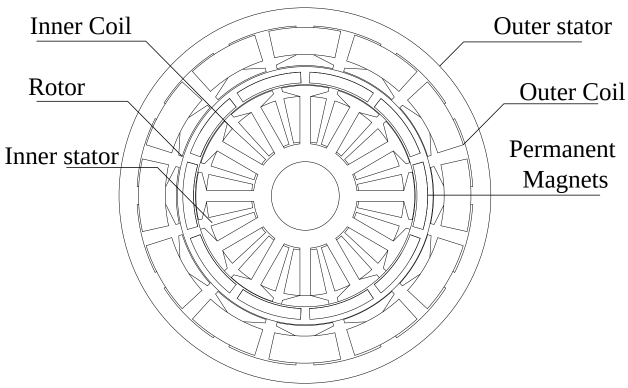
For multiple stator and single rotor, the Eq. for magnetic flux density becomes as Eq. (2).

$$\text{Magnetic flux density} = \frac{2\,Ni}{\pi d} \tag{2}$$

Based on the designed concept, the generator designed is shown in the Figs. 3(a) and 3(b).



(a) Exploded view



(b) 12S-10P front view

Fig. 3. Proposed design.

The parameters selected are based on the standard design mathematical equations as well as on commercially available generator designs to keep the commercial aspect in mind while designing [12]. The process of machine characteristic evaluation is based on the concept of the field distribution in the magnetic core. When analyzing a synchronous generator performance, the magnetic field is only known roughly. To calculate the performance, the Finite Element Method (FEM) is used. The magnetic field distribution is solved by Maxwell's equation system [13 -15]. The parameters of the designed generators are shown in Table 2. After doing the analysis based on finite element method with various configurations with a different slot poles combination, a configuration of 12 Slots-10 Poles is selected. The designed generator is tested for operations at various wind speed conditions to test the performance evaluation of the system as in Fig. 4.

Table 2. Parameters of the designed machine.

Parameter	Value
Stator pole arc length	13.24 mm
Outer Stator pole arc length	15.54 mm
Rotor diameter	30.75 mm
Air gap length	0.5 mm
Arc length of the permanent magnet	18.69 mm
Number of magnets	10
Number of inner stator poles	12
Number of outer stator poles	12
Stack length	50 mm
Turns per phase in the outer stator coil	55
Turns per phase in the inner stator coil	36
Rated current per phase	5A

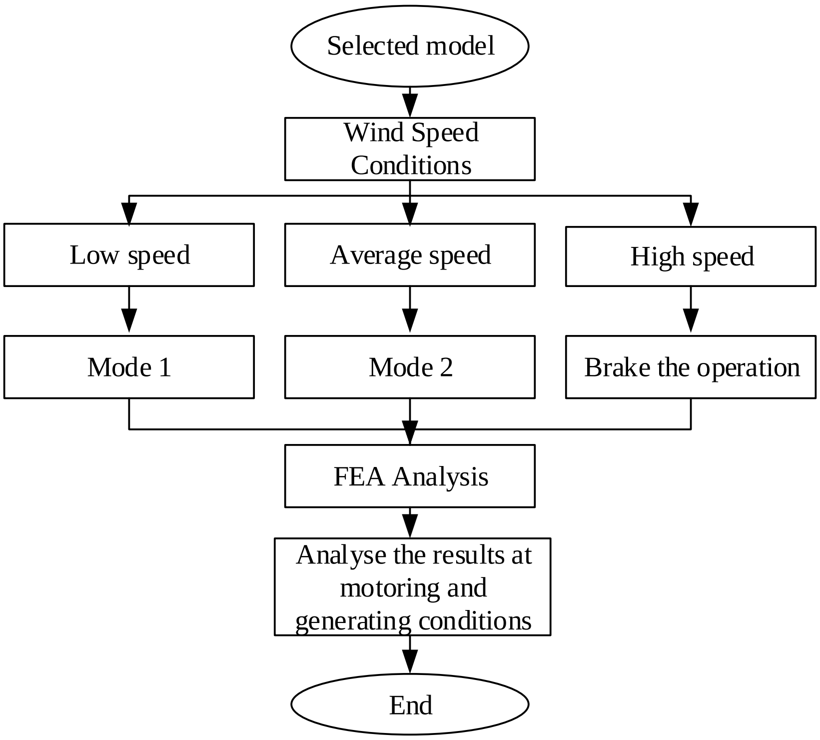


Fig. 4. Modes of operation analysis procedure.

To design a machine is to have the knowledge to model it considering cost, durability, compliance with the laid down specification and consumer requirement to provide an economic solution. Some factors that affect the performance of the machine are as follows:

Power constant can be calculated using Eq. (4)

$$P_t = \frac{T.\omega}{I} \tag{4}$$

where T is the torque in Nm and I is current in the coil in Ampere and ω is angular speed.

Generator constant is given by Eq. (5)

$$K_g = \frac{P_t}{i} \tag{5}$$

The core loss due to winding by Eq. (6)

$$P_{ic} = I^2 R \tag{6}$$

where P_{ic} is the resistive power loss in watts.

The generator constant square density for the designed generator is as in Eq. (7). The generator constant square density is used as a comparative analysis parameter. It helps in comparing generator capacity by comparing power density to the volume of the machine as a ratio

$$G = \frac{P_m}{V} = \frac{K_g/P_{ic}}{V} \tag{7}$$

where P_m is the generator constant and V represents the volume of the machine. In order to calculate the efficiency of the machine under the different modes of operation, efficiency is given by Eq. (8)

$$\text{Efficiency}, \eta = \frac{P_{out}}{P_{out}+P_{ic}+P_i} \tag{8}$$

where P_{out} is output power, P_{ic} is copper loss and P_i is iron loss

3. Results and Discussion

3.1. Machine characteristics

The result obtained through analysis of the selected model which is the configuration of 12S-10P gives the smoothest magnetic flux flow as shown in the Fig. 5. The flux is divided evenly among the three phases of the coil.

Upon the selection of the machine, to analyse different angles of operation under the constant speed, the machine was simulated under different cases designed through case-control by adjusting the angle starting from zero to 90 degree and the results are then recorded and plotted to analyse. Table 3 tabulates the data of the two best slots-poles configurations selected on the basis of smooth and evenly distributed magnetic flux output from the various slot-poles configurations simulated, to justify the selection of 12S-10P machine selection.

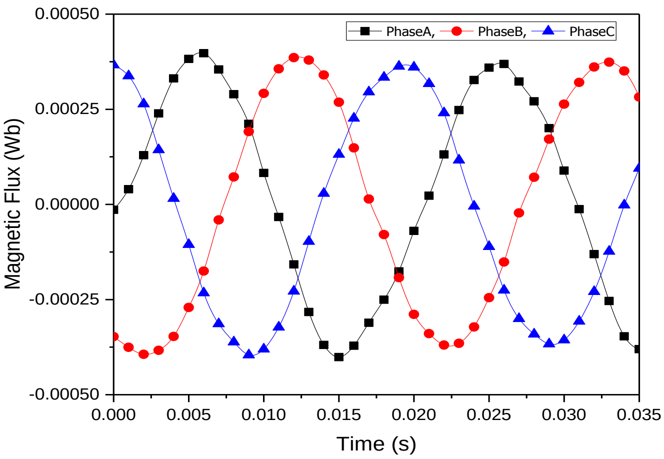


Fig. 5. Flux for 12S-10P.

Table 3. Performance parameters.

Parameter	12S-10P
I [A]	5
T_{avg} [Nm]	**0.031**
P_t [Nm/A]	0.0062
K_g [Nm/A/W$^{-(1/2)}$]	0.002024
G [(Nm)^2/A^2/W$^{-(1/2)}$/mm^3]	**4.47743E-11**

The generator constant as well as the average torque provided by the 12S-10P machine was greater than the other machine, indicates its suitability for wind turbine application.

3.2. Operating characteristics at various modes of operation

The designed machine has been operated under the two different modes, first as simultaneous motoring and generating under the wind speed lower than 3.5m/s and generating mode under the optimum operating wind speed of 3.5m/s to 6.5 m/s with an increment of 0.5m/s. The efficiency calculated is shown in Table 4.

From the comparative analysis it can be seen that at the lower speed (rpm), i.e., 537, 672, 806 the efficiency is higher when operated under the Mode 1 operation when compared to being operated under mode 2 operation (generating), however when the wind speed reaches under the optimal speed range which is 941 rpm (3.5m/s), the mode 2 which is complete generation, provides a higher efficiency at 73.16% compared to mode 1 which operates at an efficiency of 70.19%. An average of 75% efficiency is obtained when operated under the various wind speed conditions in both modes. Based on the data collected, it can view that the operating range of wind turbine will be higher on the low wind speed range, hence the new generator topology will enable the wind turbine to operate before the typical cut-in speed range of 3.5 m/s to 5 m/s at an efficiency of around 75%.

Table 4. Modes of operation comparative analysis.

Mode 1	**Motoring & Generating**				
Speed (rpm)	403	537	672	806	941
Efficiency, η (%)	78.9	76.6	79.65	71.77	70.2
Mode 2	**Generating**				
Speed (rpm)	537	672	806	941	1075
Efficiency, η (%)	53.38	58.18	68.27	73.16	75.15
Speed (rpm)	1210	1344	1479	1613	1748
Efficiency, η (%)	75.21	75.24	75.26	75.21	75.16

4. Conclusions

A double stator, single rotor 12S-10P machine has been designed on the basis of proposed concept and evaluated through FEA methods optimized to increase the capability of wind turbine operating range under low wind speed condition through the means of two different operating modes. The two different modes capitalize the presence of double stator configurations while delivering high efficiency in the region of 75% under each mode.

Nomenclatures

d	Machine diameter
$\mathcal{G}$	Generator constant square density
i	Current
$\mathcal{K}_g$	Generator constant
k	Natural number
N	Number of coil turns in the stator winding
N_r	Number of poles
N_s	Number of slots
n	Number of stator poles
$\mathcal{P}_i$	Iron loss
$\mathcal{P}_{ic}$	Core/Copper loss
$\mathcal{P}_{out}$	Output power
P_t	Power constant
q	Number of phases
$\mathcal{R}$	Resistance
$\mathcal{T}$	Torque
$\mathcal{T}_{avg}$	Average Torque
$\mathcal{V}$	Volume

Greek Symbols

ω	Angular speed
η	Efficiency

Abbreviations

FEA	Finite Element Analysis
FEM	Finite Element Method
WECS	Wind Energy Conversion System

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