Travelling Field Generator Implemented in Wind Turbine Applications

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ABSTRACT— ***Electrical generators are the starting point of a power system network, they produce electrical energy sufficient enough to feed the consumers. Almost all the generators used for this purpose are AC generators, by also using windmills we extract energy from the wind. A dual rotor wind turbine according to the present invention includes a rotatable drive shaft, a first rotor assembly connected to the drive shaft, a second independently-rotating rotor assembly coupled to the drive shaft rearward of the first rotor assembly. This type of generators has a very large frictional and rotational losses, the vibrations produced in the tower will also be very high due to two rotating parts. The maintenance cost will also will be high. This paper mainly concentrates on the reduction of the losses produced in the dual rotor generator without sacrificing its advantages. In other words, here we are making the generator a single rotor type and we are simulating the second rotor rotation by means of a series of electromagnet and power electronic switches which are switched in a particular manner***

KEYWORDS:- Dual Rotor Generator, Electromagnet, Travelling Field Generator

1. INTRODUCTION

In electricity generation, an electric generator is a device that converts mechanical energy to electrical energy. A generator forces electric current to flow through an external circuit. The source of mechanical energy may be a reciprocating or turbine steam engine, water falling through a turbine or waterwheel, an internal combustion engine, a wind turbine, a hand crank, compressed air, or any other source of mechanical energy. Generators provide nearly all of the power for electric power grids. The reverse conversion of electrical energy into mechanical energy is done by an electric motor, and motors and generators have many similarities. Many motors can be mechanically driven to generate electricity and frequently make acceptable generators. The operating principle of electromagnetic generators was discovered in the years of 1831 to 1832 by Michael Faraday. The principle, later called Faraday's law, is that an electromotive force is generated in an electrical conductor which encircles a varying magnetic flux. He also built the first electromagnetic generator, called the Faraday disk, a type of homopolar generator, using a copper disc rotating between the poles of a horseshoe magnet. It produced a small DC voltage. This design was inefficient, due to self-cancelling counter flows of current in regions that were not under the influence of the magnetic field. While current was induced directly underneath the magnet, the cur- rent would circulate backwards in regions that were outside the influence of the magnetic field. This counter flow limited the power output to the pickup wires, and induced waste heating of the copper disc. Later homo polar generators would solve this problem by using an array of magnets arranged around the disc perimeter to maintain a steady field effect in one current-flow direction. Another disadvantage was that the output voltage was very low, due to the single current path through the magnetic flux. Experimenters found that using multiple turns of wire in a coil could produce higher, more useful voltages. Since the output voltage is proportional to the number of turns, generators could be easily designed to produce any desired voltage by varying the number of turns. Wire windings became a basic feature of all subsequent generator designs. A direct-current (DC) generator is a rotating machine that supplies an electrical output with unidirectional voltage and current. The basic principles behind the operation are the same as that of synchronous generators. Voltage is induced in coils by the rate of change of the magnetic field through the coils as the machine rotates. This induced voltage is inherently alternating in form since the coil flux increases and then decreases, with a zero average value. The field is produced by direct current in field coils or by permanent magnets on the stator. The output, or armature, windings are placed in slots in the cylindrical iron rotor. A simplified machine with only one rotor coil is used now. The rotor is fitted with a mechanical rotating switch, or commutator, that connects the rotor coil to the stationary output terminals through carbon brushes. This commutator reverses the connections at the two instants in each rotation when the rate of change of flux in the coil is zero. ie., when the enclosed flux is maximum (positive) or minimum (negative). The output voltage is then unidirectional but is pulsating for the simple case of one rotor coil. In practical 2-pole machines, the rotor contains many coils symmetrically arranged in slots around the periphery; all connected in series. Each coil is connected to a segment on a multi-bar commutator. In this way, the output voltage consists of the sum of the induced voltages in a number of individual coils displaced around half the periphery. The magnitude of the output voltage is then approximately constant, containing only a small ripple. The voltage magnitude is proportional to the rotor speed and the magnetic flux. Control of output voltage is normally provided by control of the direct current in the field. For convenience in design, direct-current generators are usually constructed with four to eight field poles, partly to shorten the end connections on the rotor coils and partly to reduce the amount of magnetic iron needed in the stator. The number of stationary brushes bearing on the rotating commutator is usually equal to the number of poles but may be only two in some designs. The field current for the generator may be obtained from an external source, such as a battery or a rectifier. In this case, the generator is classed as separately excited. Alternatively, it may be noted that the output of the DC generator is unidirectional and therefore may be used as a source to supply its own field current. In this case, the generator is referred to as shunt-excited. It has the advantage of requiring no independent electrical supply. Residual magnetic flux in the iron poles produces a small generated voltage as the machine is brought up to speed. This causes a field current that increases the flux and in turns the generated voltage. The voltage builds up until saturation in the iron limits the voltage produced. The stable value of generated voltage can be adjusted over a limited range by adjusting the value of a resistor placed in series with the field coil. Direct-current generators were widely used prior to the availability of economical rectifier systems supplied by alternators. For example, they were commonly employed for charging batteries and for electrolytic systems. In some applications, the direct-current generator retains an advantage over the alternator-rectifier in that it can operate as a motor as well, reversing the direction of power flow. An alternator, by contrast, must be fitted with a more complex rectifier-inverter system to accomplish power reversal. Another type of DC generators which came recently is the dual rotor generator .When a wind mill system expels or accelerates mass in one direction, the accelerated mass causes a proportional but opposite force on that system. The spinning blade of a single rotor wind turbine causes a significant amount of tangential or rotational air flow. The energy of this tangential air flow is wasted in a single-rotor propeller design. To use this wasted effort, the placement of a second rotor behind the first takes advantage of the disturbed airflow. Contra-rotation wind energy collection with two rotors, one behind the other, can gain up to 40% more energy from a given swept area as compared with a single rotor. Other advantages of contra-rotation include no gear boxes and auto centering on the wind (no yaw motors/mechanism required). Counter-rotating turbines can be used to increase the rotation speed of the electrical generator. When the counter-rotating turbines are on the same side of the tower, the blades in front are angled forwards slightly so as to avoid hitting the rear ones. If the turbine blades are on opposite sides of the tower, it is best that the blades at the back be smaller than the blades at the front and set to stall at a higher wind speed. This allows the generator to function at a wider wind speed range than a single-turbine generator for a given tower. To reduce sympathetic vibrations, the two turbines should turn at speeds with few common multiples, for example 7:3 speed ratio. Overall, this is a more complicated design than the single-turbine wind generator, but it taps more of the wind's energy at a wider range of wind speeds. Most wind turbines in the world are single rotor systems, which provide simplicity, reliability and durability. Over the years, improvements have enhanced energy conversion efficiency of these single rotor systems. For example, blades have better aerodynamic characteristics, gears with reduced noise have better torque transmission efficiency, and alternators have better electrical efficiency. However, despite these improvements, single rotor systems are able to convert only a small fraction of the total wind stream energy into electrical energy.

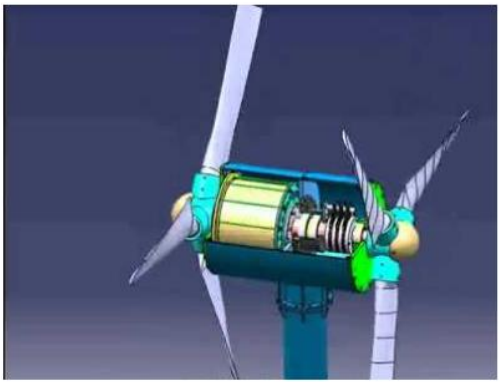

Figure 2.8: Dual Rotor Wind Turbine

These generators are able to produce a larger electrical output than that of a conventional windmill with the same wind speed. Due to this reason most of the single rotor windmills in China are now replaced by dual rotor generators due to lesser size and higher rating .From the above figure we can see that one blade is attached to the magnetic field windings or to a permanent magnet and other blade is attached to the conductors. So, as the blades are rotating in the opposite direction the rate of change of flux increases which in turn produces a greater output. The advantage of this type of generator also comes with a greater disadvantage because as there are two rotating parts the vibrations ,frictional and heat loss produced in the machine will be much higher and the maintenance of these generators are costly .

This generator works directly on the principle of Faradays law. That is, the emf produced in the conductor is directly proportional to the rate of change of flux. This paper introduces a new type of generator by rectifying the demerits of the dual rotor generator .If we can make generator having a single rotating part and yet can produce the same effect as that in the dual rotor generator then the disadvantages of the dual rotor generator can be avoided and an efficient generator can be made. This paper mainly deals with such type of generator. The proposed scheme does not require a second rotor, only a power electronic switching devices with a microcontroller is needed.

2. PROPOSED MODEL

The principle behind the working of this type of generator is same as that of a permanent magnet generator which is guided by Faradays laws of electromagnetic induction. That is, when a conductor is moved perpendicular to the magnetic field then an EMF is induced in it and the induced EMF is directly proportional to the rate of change of magnetic flux. Here we mainly stress on the second point which is the rate of change of flux, if we can however increase the rate of change of flux without changing the rotor speed then the EMF produced in the conductors also rises to another level. For better understand ability let us consider a permanent magnet generator, the relationship of the EMF induced in it is as given below

$$E = \varphi PZN/\ 60 \qquad (1)$$

Where, E = EMF induced in the conductor P = Number of poles Z = Number of conductors N = Speed of the rotor in rpm = Magnetic Flux. This equation can be simulated in MATLAB is as shown below, here we can see that we have assigned values for each quantity. The value P1 which is 60 in conventional case is to convert the speed to rotation per second. That is how many rotations are there in one second; this number of rotations is manly depended upon the speed with which the rotor rotates. But the speed of the rotor cannot be increased beyond a limit in the case of windmills as well as hydropower plants because of the availability of the wind and high vibrations in the rotor. The magnetic flux also cannot be increased due to saturation of the core and there is a limit to the amount of conductors which can be placed in the rotor. So the only way to increase the output voltage is to increase the number of rotations in one second that is to increase the rate of change of magnetic flux linkage by rotating the magnetic field in the opposite direction of the rotor. This field rotation is done by switching the field as same as that in switched reluctance motor.

The construction of this type of generator will be same as that of a switched reluctance motor (SRM) the only difference is that the rotor consists of conductors in the case of magnets as shown in the figure below. The figure shown consists of 8 poles. In this type of motor increased number of poles increases the continuity of the magnetic field rotation.

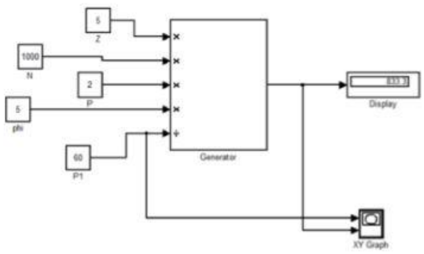

Figure 3.1: Simulink Model of a DC Generator

number of poles is less this may ripple in the output voltage. The switching of the magnetic fields can be either in the clockwise or in the anticlockwise wise direction according to the direction of rotation of the rotor, if the rotor is rotating in the clockwise direction then the magnetic field switching should be programmed in the anticlockwise direction that is both rotation must be in the opposite direction to increase the rate of change of flux. Switching can be controlled by a series of switches which may be MOSFET or IGBT. The switching pulse controlling and the firing circuit algorithm is explained later.

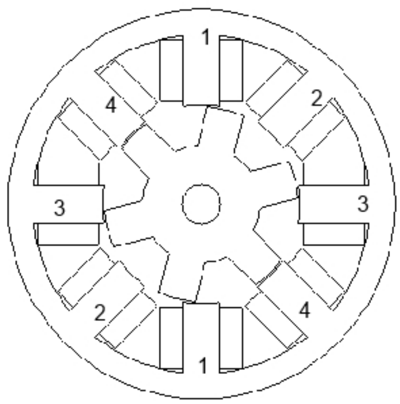

Figure 3.2: Simple Model of TFG

At first the poles 11 is given a DC pulse which will energizes the upper and lower coils where the upper coil will be north pole and lower coil will be south pole in the next instant 11 will be switched off and 22 will be switch on, this simulates a moving or a travelling magnetic field thus the name travelling field generator. The switches are fired according to the order in which the magnetic field have to rotate, but there is a complication after the instant 44 because after 44 we are again giving pulses to 11 which in turn makes the upper 1 north and lower 1 south which breaks the rotation, for the continuity in rotation we have to make the lower 1 north and the upper 1 south .So we reverse the supply voltage feeding the coil 11 till it reaches 11 again after one cycle of rotation. This is repeated and thus a rotating magnetic field can be maintained. The rotational speed can be varied by varying the timing of the firing pulses.

3. CONTROL CIRCUIT

The control of firing pulses given to the switching circuit is done using microprocessors such as PIC, Atmega-8 etc. Here Atmega-8 IC is used. The figure of the IC is as given it has 28 pins and each of these pin can be configured according to our need. Here in this circuit the pins 14 to 17 in the Atmega8 IC is used to trigger the Mosfets which are connected such that the DC current is driven through the coils in the forward direction which makes the coils in the right half north and the coils in the left half south. And the pins 23 to 26 are configured such that it triggers the Mosfets which are connected such that the DC current is driven through the coils in the reverse direction, which makes the left side coils north pole and right side coils south pole. The coils are fed using a DC source having a rating of 12V,5A. The header file include < avr/io.h > includes the appropriate input/output definitions for the device that has been specified by the compiler command-line switch. This is done by diverting to the appropriate file < avr/ioXXXX.h > which should never be included directly. Some register names common to all AVR devices are defined directly within< avr/common.h >, which is included in< avr/io.h >, but most of the details come from the respective include file. The header filesinclude < util/delay.h > are wrappers around the basic busy-wait functions from< util/delaybasic.h >. They are meant as convenience functions where actual time values can be specified rather than a number of cycles to wait for. The idea behind this is that compile-time constant expressions will be eliminated by compiler optimization so floating-point expressions can be used to calculate the number of delay cycles needed based on the CPU frequency passed by the macro FCPU. Simply speaking it is a convenience functions for busy-wait delay loops. Here 300ms delay is given to each mosfet.

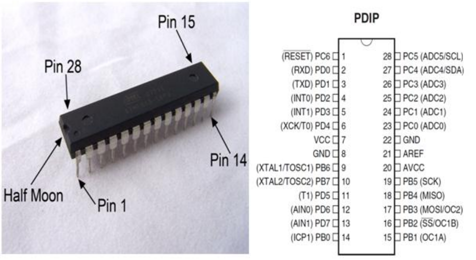

Figure 3.3: Atmega8 IC and its pin configurations

AVR studio 4 is used to program the IC. The program code used here is as shown below. Simulation of the control and firing circuit is done in a simulation software known as protues and the circuit diagram of the same is shown in Fig3.5.

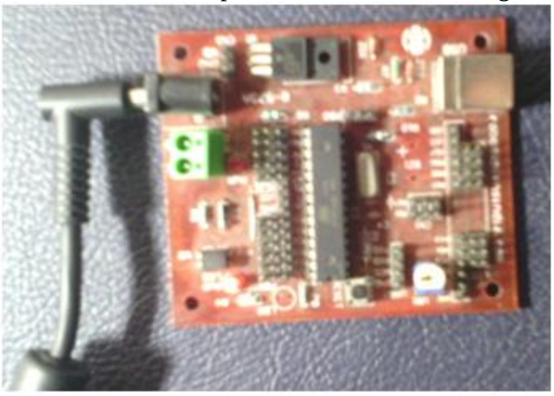

Figure 3.4: Atmega8 IC mounted in AVR development board

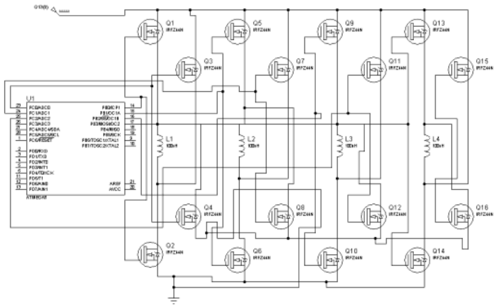

Figure 3.5: Field Switching Circuit

4. EXPIRIMENTAL SETUP

In this chapter we are mainly setting up the main parts of the TFG so that it can be practically tested. The output or the result of the experiment is not depicted here, only a beta version of the TFG is presented here.

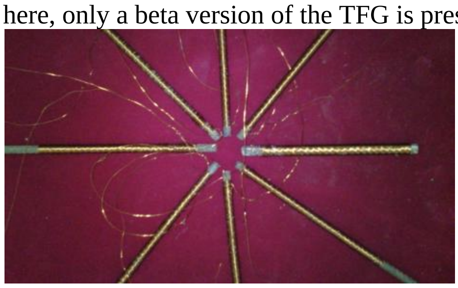

Figure 4.1: Field coils having eight pole paths

The above figure 4.1 shows the field windings which are used in the TFG(beta version).From the diagram itself we can understand that it consists of eight pole paths, where these pole paths are just electromagnets which acts as a path for the magnetic field to travel. At an instant there will be only two poles as the time passes the poles will shift to the adjacent electromagnet. The time of pole shifting from one pole path to the other pole path is determined by the control circuit which gives the firing pulses to the mosfet array. The mosfet array used here is as shown in Fig 2.4.

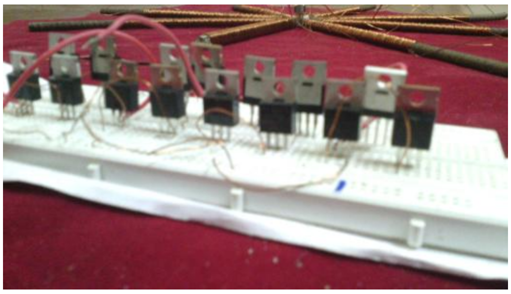

Figure 4.2: MOSFET Array

These mosfets are used for the switching of the field winding, for a single pair of field windings we need two sets of mosfets because the current has to be driven in both the directions. So the mosfet array consists of 16 mosfets connected in a particular manner, the mosfets used here is IRZF44N which has voltage rating of 55V and current rating of 45A.The field coils are wound using insulated copper wire having a gauge of 28,each pole has at least 715 turns. Sufficient cooling has to be given to it so that the insulation of the wire can withstand the heat produced due to switching. The next important part is the rotor, here for this beta version the rotor use is that of a toy motor having a rating of 12V.This rotor is mainly used for motors, so the winding which is done here is also that of a DC motor type. So the output obtained will not be as precise. There will be a considerable amount of losses and other efficiency problems. A pair of split rings is used to extract the electricity produced in the rotor. The setup of field coils and the armature is as shown in Fig 4.3.

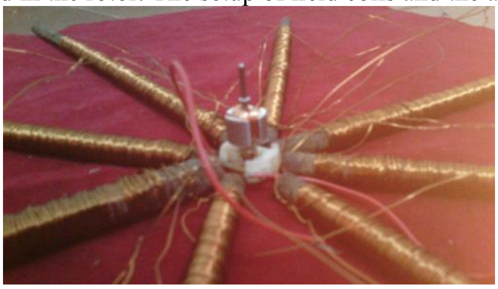

Figure 4.3: Field coils with armature winding

5. CONCLUSION

In conclusion, the article presents a new kind of travelling field generator system for off- shore wind farm, so when the wind energy hits the rotor blades it rotates in a particular speed. According to the blade pitch the rotor will rotate clock wise or anti clock wise. Now if the wind velocity or the output voltage of the wind turbine is below a reference speed or voltage then the sensing circuit will sense it and gives command to the field switching circuit, which makes the field travel in the opposite direction which in turn simulates an artificial wind velocity inside the generator by making an increase in the relative speed be- tween the rotor and the field thus a constant output voltage is obtained even if the wind velocity changes continually. Dual rotor wind turbine is now being implemented in various country's to achieve a greater relative velocity even in the midst of low wind velocity, TFG is such a kind of generator which is motivated from the dual rotor wind turbine .Even if this technology is not practically implemented or tested. Theoretically it is an efficient and enhanced version of the conventional Dual rotor wind turbine and it is the future of wind energy extraction.

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