PERFORMANCE ANALYSIS OF AFPM GENERATOR DIRECT DRIVEN WIND TURBINE WITH STORAGE SYSTEM

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Received Date: January 2, 2013

Abstract

Direct-drive type with no acceleration rare and the windmill blades attached to the disc surface of Axial Flux Permanent Magnet generator (AFPM) realizes simple structure and omission of central dynamic transformation achieves very high energy conversion efficiency of the generator. The generator itself consists of two magnets rotors that return together directly coupled to the blades. In this research study, one magnet rotor is on each side of the stator and each magnet rotor contains 16 Neodymim-Iron-Boron (NdFeB). The stator contains 12 coils wound with copper wire and cast into plastic resin, in line with and between the paths of each magnet. The AFPM generator direct drive wind turbine converts the mechanical energy by the rotating shaft as the wind pushing 3 wooden blades into 3-phase alternating current (AC) electricity that varies in frequency. In order to get this generated power into a battery bank, three-phase bridge rectifier is connected to the three terminals of the machine. The alternator will start 48 volt charging batteries system at about 140 rpm in 4m/s wind speed and reach rated output of 1.8 kW at 375 rpm in 10m/s wind speed. This machine is specially designed for battery charging and it's probably quite useful and cost effective for remote locations that are not connected to the national grids where conventional methods of energy supply are expensive or impractical.

Keywords: AFPM generator, Battery charging, Bridge rectifier, Direct-drive type, Wind speed

Introduction

Small-scale wind energy could help decrease our reliance on declining and costly supplies of oil. Another benefit of wind energy is that, unlike oil, coal and nuclear energy, the wind is not owned by major energy companies or controlled by foreign nations. Wind energy can help nations reduce global warming and devastating changes in our climate. Wind is also a free resource. The cost of wind is not subject to price increases. A typical small wind turbine has rotor that is directly coupled to AFPM generator which produces electricity at 12/24/48 volt direct current for battery charging. AFPM machine is used direct driven small wind generator application for stand alone system. This stand-alone tends to supply power to private houses, farms and other remote area of Myanmar. This research of wind generator is operated in a direct battery charging application where the wind generator is directly connected to a rectifier-battery combination. In this study, 3Φ, 1.8 kW AFPM generator for small wind turbine is constructed with the technical parameter of the implemented design data.

Anatomy and Characteristics of AFPM Topologies

AFPM machines have been developed in a number of topologies, namely the single-sided machine, the double-sided machine with twin external stators and internal rotor and the double-sides machine with internal stator and twin external rotors. The double-sided AFPM machine with the double outer PM-rotor has the highest torque production capacity due to the higher volume of PM material used. The double-sided outer-rotor topology is the coreless AFPM machine of choice for small-scale wind generator applications.

The AFPM machine is used in a direct-driven wind generator application which requires a low operating speed. In order to maintain frequency at rotating speeds, high pole numbers are required. The drawback of a low-speed direct-driven AFPM generator is that it requires high torque which requires a larger diameter, which affects the material cost of the machine. If the diameter of the wind generator is too large, it will disturb the airflow around the turbine hub and have a negative effect on the cooling capabilities of the AFPM generator.

In AFPM air-cored stator winding, the windings are not kept in position within iron slots, but with the use of epoxy resin. Therefore, with the absence of stator teeth and the stator back yoke there is no cogging torque and no iron losses in the stator. Slotless AFPM machines can be regarded as high efficiency machines due to the absence of the rotor core losses which are normally present in the rotor back yoke and permanent magnets. In AFPM topology, permanent magnet material Nd-Fe-B is used. The magnetic field of the AFPM is the axial flux direction. The magnets arranged in N-S-N-S pattern around the circumference of the rotors. When opposite poles face each other, the path of the magnetic flux travels from one magnet face, straight to the magnet face opposite. Then this travels through the steel rotor plate to the next magnet and back across the gap to the coil of wire. The field passing through this area is a "magnetic flux."

The rotor of the AFPM machine consists of two interconnected steel disks with permanent magnets attached on the outsides circumference on the inner surfaces of the opposing rotor disks. The steel rotor disks are multifunctional, as the rigid steel construction maintains the necessary air-gap length between the opposing magnet poles while providing the flux return path between the rotor poles. As the iron losses in the rotor are very small and can for all practical reasons be neglected, the rotor disks can be manufactured from solid iron, as opposed to laminated iron. The combination of the coreless stator and the permanent magnets, both having a permeability of close to unity, creates a large effective air-gap. In order to maintain acceptable values of magnetic flux within the large air-gap, a much higher volume of permanent magnet is required.

The permanent magnets can either be mounted on the surface of the rotor disks or be embedded into the rotor disk. The AFPM generators discussed in this study are of the surface-mounted topology. Surface mounting of permanent magnets is the preferred placement type due to the ease of the manufacturing of the smooth rotor disks, thereby, lowering the cost of the machine. Another advantage is that the surface-mounted permanent magnets naturally act as fans which have a ventilation effect on the stator windings at higher rotating speeds. The added cooling feature of the spinning permanent magnets allow for higher stator current densities before excessive stator winding temperatures damage or irreversibly demagnetize the permanent magnets. Besides, lower centrifugal forces allow for the permanent magnets to be glued onto the surface of the rotor disks, instead of requiring further mechanical means such as through- magnet fastening screws when the direct-driven AFPM generator operates with low rotating speed.

B_p= the peak air-gap flux density
N_t = the number of turns per coil
r_e = the average adjust of the stator winding
l_a = the active length of the stator winding
k_p = the pitch factor of the winding
k_d = the distribution factor

In AFPM type of wind turbine, the design of the outer diameter is very important for calculation of output power because the larger diameter is not reliable and stable for all the system. According to the equation (1), the outer diameter of AFPM can be designed for 1.8kW. The RMS value of the sinusoidal phase voltage of the winding, E_{gen} is calculated by following Equation (2) [1]. By using above equations, 1.8kW AFPM generator is designed the following specifications for the practical action of small wind turbine.

Table 1. Practical Action of Small Wind Turbine for Battery Charging

1	Rated power	1.8kW
2	No: of blade	3
3	Blade material	wood, fiber coating (Jameinan)
4	Diameter of blade	15 fts
5	Cut-in speed	3 m/s
6	Cut-out speed	25 m/s
7	Rated speed	10 m/s
8	Generator type	axial flux permanent magnet type (two sided system)
9	No: of magnet	16×2=32
10	Type of magnet	Nd-Fe-B, Grade 42 and epoxy coated
11	Diameter of magnet rotor	17in
12	Diameter of stator	22in
13	No: of coils	12in
14	No: of turns per coil	80 turns
15	Magnet wire size	AWG #13 Guage or SWG #15
16	Connection type	star (Y connection)
17	Rectifier	Bridge rectifier (50 A) with damping load and electrical break system 48V
18	Inverter	48V DC, 220V, Output(2kVA)
19	Battery	200Ah (12 nos)
20	Tower high	33 fts (6 in dia of cast iron pipe)
21	Steel rope	250 fts (0.5 in dia)
22	Mechanical control	Tail vane (furling system),7.5 ft length

In this research work, this type of wind turbine is designed and constructed based on 10ft Hugh Piggotts Design. According to the above specifications of small wind turbine, 1.8kW AFPM generator can be implemented the following construction process. This research of wind generator is operated in a direct battery charging application where the wind generator is directly connected to a rectifier-battery combination. The rectifier-battery combination consists of a three-phase full-bridge diode rectifier directly connected to a battery bank. When rectifying the 3-phase power so that DC battery is charged, the current is also much smoother for electrification in rural area.

Construction Feature of Direct Driven Wind Turbine

In this research work, three-phase axial flux permanent magnet (AFPM) generator direct driven wind turbine is constructed for battery charging system in wind power application in the rural electrification. . The arrangement of suitable machine is produced according to the calculation of technical design parameter. To install 1.8 kW wind turbine, the following procedure should be done 1.Magnet rotor 2.Casting stator 3.Assembly of the alternator 4.Blades 5.Tail and 6.Raise the wind turbine step by step:

Magnet Rotors

Each magnet rotor is built on a steel disk made of magnetic material. The disk has holes to mount it to the hub. Alignment of the rotors is critical in the operation of the alternator; they must always go together the same way with alternating magnetic poles facing one another. The first magnet is placed on the bottom magnet rotor. The template is pinned to it and made of wood. But the magnet is strongly attracted to the steel disk [8]. There are 16 magnetic blocks (Nd-Fe-B, Grade 42) on each rotor and size of the one magnetic block is 3in× 1in× 0.5in. The 16 magnets for each disk need to be spaced around the disk with alternating poles facing up to adjust the polarity (N S N S). The magnet rotors dropped into the mould carefully. Then fiberglass resin is poured into the mould and over the tops of all the magnets. When the resin is completely setup, the rotor can be removed from the mould. Making magnet rotor is completely finished according to the construction procedure as shown in Figure 1.

Figure 1. Construction of rotor discs

Casting Stator

The stator is the very important part of the wind turbine. It describes how to wind the coils of enameled copper wire, and cast them in resin, using the jigs and moulds. This copper wire has been coated with a very thin layer of insulating material. This means that when it is wound into coils, the individual coils do not short-circuit one another where they touch. In order to make an electrical contact with magnet wire, it is necessary to either scrape or burn off the coating to expose the copper wire inside. The reel of winding wire is mounted on an axle, then in line with the coil former. The wire should form an “S” bend as it winds onto the coil. The first turn lies against the cheek piece on the side where the tail comes out. The other turns lie against each other neatly, without crossing over. The coil is built up in even layers and the number of turns is counted carefully [8].

In this study, there are 80 turns per coil and totally 12 coils. When the coil is completed, a piece of sticky tape is passed under the coil on both sides and it is bind tightly. The coils are soldered together and then a copper crimp is crimped on to add better conductivity.

Then, the coils is closed the mould, and when it has cured, the stator comes out as one big disk with the coils encapsulated inside. All of the internal electrical connections were made in advance. Either they selected one particular 3-phase connection arrangement, or they have enough wires coming out to allow some external connection changes. A more elegant solution is to wire up the coils for 3-phase operation. The selection of size and gauge of wire (AWG#13gauge or SWG#15guage) are chosen, and then the voltage is clamped to a specific value, 48V, depending on the charging system. The selection of wire size allows the required current of AFPM design. The arrangement of the coils is a star-shaped pattern in the flat mould. The coils also have fiberglass Matt below them and small pieces of scrap fiberglass super glued to the coils, this is to prevent them, individual wires from vibrating against one another from moving when fiberglass resin is poured into the mould. C clamps are put on each sides of the mould to be tightened until the resin is hard. While it is a bit flexible, C clamps are removed then; the stator is removed from the mould. The casting stator is done the following steps as shown in Figure 2.

Figure 2. Stator coils casting from the mould

Assembly of Alternator

After finishing the magnet rotor and the stator, the alternator is assembled finally from all the finished parts. The front rotor is raised safely and back off the alternator if necessary. Each rotor also has a small mark (a divet made with a drill bit) so that the two rotors can be aligned properly. The nuts/washers are used between the magnet rotors are the same high. The back magnet rotor is taken and turned it so that the magnets face down on the beach. The back of the hub is taken and put into the hole in the magnet rotor, such that the ends of studs are poking into the 4 holes. The back magnet rotor is pickup by the studs and placed it onto the spindle, up against the back bearing, and then the front bearing is inserted. The washer is placed in front of the bearing, and then tightens the nut over the bearing. The length of the airgap is 4mm gap clearance between the magnets and the stator, on both sides. Next, the stator is mounted to the machine. Putting the assembly onto the wind turbine, the studs should be fitted through the holes in the stator bracket. The back nut can be adjusted with the fingers and set an approximately airgap between the stator and magnet rotor [8]. The front magnet rotor is picked up by the jacking screws and placed it over the studs sticking out the alternator. At this point, the alternator is assembled as shown in Figure 3.

Figure 3. Alternator apparatus

The performance of alternator can be got according to run and measured DC voltage. At around 140 rpm, this alternator will be produced 'average' battery voltage. By using the tachometer, v/rpm is tested to output through a rectifier and measured DC voltage at no load condition as shown in Figure 4.

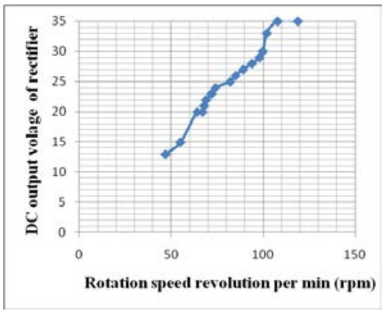

Figure 4. Relation between rpm and DC voltage of the alternator

The battery load is connected to rectifier output terminal. When the charging voltage will rise to a peak level (about 10% above the battery's standard voltage, 48V) about rated rpm, the current produced. In this test, higher wind speeds, the prop turns much faster and provides more energy to overcome the heavy load, upwards of 1.8 kW.

Blades

The blades are also one of the important parts in the wind turbine that drives the generator. The blades are made of wood because it's strong, lightweight, and reasonably inexpensive and resist rot. These wind turbine blades have a simple airfoil like airplane wings. The blades are twisted along their length this means that the blade pitch varies from shallow at the tips to steep at the roots to approximate the correct angle of attack to the wind because the tips of the blades are moving faster than the roots [7]. These blades are designed to run at the tips speed ratio (TSR) between 6 and 7, and matched to the alternator. According to the blade design, the diameter of blade is 15ft. The blade construction procedure is built and referred by Hugh Piggott Design. The blades are coated with a few thick coating of boiled linseed oil to protect the humid environments. The following Figure. 5 can be seen how to construct the blades of wind turbine.

Figure 5. Making of Blades

Tail

The tail consists of three pieces: The tail boom, the tail bracket and the wooden tail vane. The tail boom is a bit over 7.5 feet long, fabricated from steel pipe and steel stock. The tail vain is made from high quality 3/8 in thick birch plywood to be strong, light weight and resists fatigue cracking. Since it is wooden, it should be treated generously with linseed oil, paint or stain to protect it from the elements. The hardware is supplied, and consists of 6 × 5/16-18 bolts with washers, lock washers, and nuts use to attach the wooden tail vane to the tail bracket. The assembly of tail can be seen as shown in Figure 6. The machine will fold up and "furl" to reduce the effective swept area of the blades [7]. This protection system called a "furling tail" is very simple in that it works simply by the geometry of the machine's frame, requires no mechanical component like springs that can break, and simply allows gravity to return the wind turbine back to normal operating position when the wind drops back to normal levels (below 25m/s).

Figure 6. Tail vane bolted to the tail boom

Raise the Wind Turbine

In raising the tower, height of 33 fts and 6 in dia of cast iron pipe, the first step is to get the machine up on the tower. The tower top has a stub of 2 ½in pipe, with a thick flat 'washer' welded on the end. There is a plastic bushing on top of that, and then the machine simply slips over the top of the tower and rests on the plastic bushing. According to this turbine design to be available and flexible, the best standard wire grade (10 AWG) is selected for the tower wiring. The wire goes straight through the tower, up through a hole in the wind turbine, so as the machine turns the wire can twist. At the bottom of the tower there is a heavy 3 prong locking plug that can be unplugged to occasionally allow the wire to untwist if necessary. Then it is completely assembled and ready to go on the end of the tower.

In this position, the blades are balanced to be fitted to the alternator. To balance the blades the heavy part is turned to the bottom (6 O'clock). Then the heavy side is lifted to the 3 O'clock (or 9 O'clock) position and added weight opposite it, until it seems to be balance. These blades come out almost perfectly to add the hub [7]. There are two 6in diameter steel hubs included, and one has a hole in the centre so that it can fit over the grease cap on the alternator. The rotor will be clamped between these two hubs. The hub is mounted with the hole on the alternator. Then the rotor is fitted to the alternator. The last steel hub is put on over the blades. Each stud should get one lock washer and one nut to be tightened. These blades are fastened tightly to the alternator and balanced while on the tower stub in the lowered position. Before raise the tower up, the tail is fitted as a tilt up the tower. After finishing the checking of the apparatus wind turbine, the tower is raised slowly and gently adjusting the guy wires, turnbuckles, and etc. and tighten if needed. This test raising tower procedure is shown in Figure 7.

Figure 7. Preparation to raise the wind turbine

Test Result

The implementation process of small wind turbines is installed between Shwe Thar Layaung Mountain and Waibu Mountain, Kyaukse and tested within one week. This research work is tested at there in the winter so that the wind speed can get about below 5m/s. Therefore, this research time, the relationship between wind speed and charging current is shown in below the graph, Figure 8.

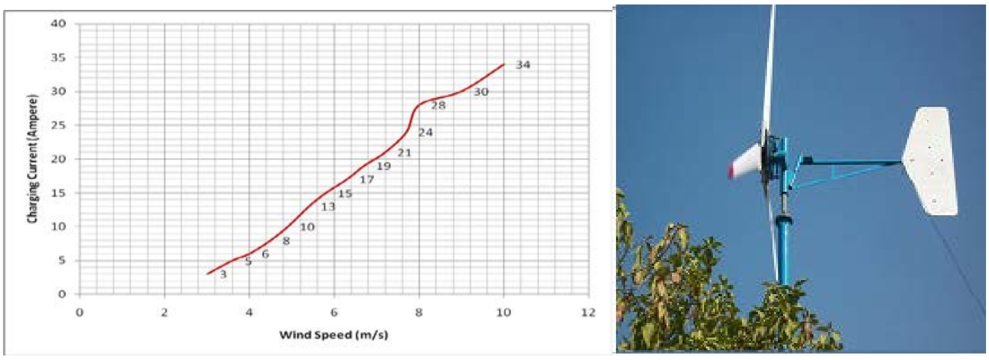

Figure 8. Relation between wind speed (m/s) and charging current (A)

In this research work, the cut in speed is needed about 10 m/s according to the design parameter of 1.8 kW wind turbine construction and the rated speed is needed at least 10 m/s to get the rated power. This system is designed to charge a bank of batteries. The inverter turns the battery voltage into AC that household appliances and lights can be used. When the wind starts to blow and turns the blades at 2 m/s, the battery starts to be charged with charging current, 2A. At the rated wind speed 10 m/s, the charging current is 30A to be charged the battery bank using with 200Ah battery connected to 4 series 3 parallel. As a result of this research work, the battery bank can be charged with 13.5A at 10m/s. If the battery is charged with the rate of charging current (13.5A), the no; of 20 fluorescents, four feet, is lighted about 4hr. On the other hand, if the location and the wind speed get better, the higher charging current can be stored to the more batteries attachment. Thus, if this research wind turbine can be installed at the place which is situated at the average wind speed is about 10 m/s, the charging current can be got the higher to the point at 30A to that the four feet fluorescents (40Watt) is lighted and used about 50nos: in a remote building with no power at all. The total power consuming power is 2 kW at the wind speed (10 m/s). The result detail data can be seen as shown in Figure.9.

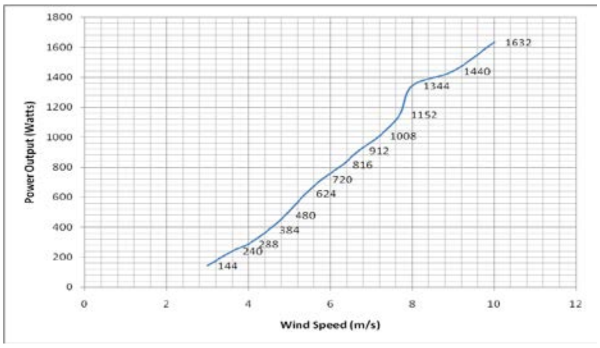

Figure 9. Relation between wind speed (m/s) and power (Watt)

In accordance with the performance graph in Figure 9, the output power of AFPM generator is 144W at the initial state (3m/s). When the wind speed gradually increases from 3m/s to 10m/s, the power also increase to about 1.62 kW. As these power data are measured at battery load side, the generator generates to power output more than the rated power, 1.62kW. If the cable loss is considered, the generator output can generate to 1.8kW approximately. On the other hand, the calculation of wind turbine output can produce 3kW according to the design at the rated wind speed 10m/s. In addition, when the output power of battery load (1.8kW) including cable loss is ratio to the input power of wind turbine (3kW) neglecting drive train losses, the overall efficiency is 60%. This type of wind turbine has not seen in Myanmar wind turbine market. The efficiency of other wind turbines can’t be also found out in the technical data. To describe efficiency test data is difficult in comparison to the existing commercially available wind turbines. Therefore, the performance research work can be analyzed in the generator output for home lighting system. The purpose of this construction of small-scale wind power system is not only to get electrification but also to use cheaply for rural people. Therefore, it can supply the energy requirements of Myanmar from one point.

Conclusions

In Myanmar, 70% of population lives in the rural areas. Therefore, this project work tends to the rural electrification system for promoting the living standard and improving the economy status of rural area by using wind energy. This research work of wind turbine design is inexpensive and easy to construct for rural area because of homemade design. However, the more output power mainly depends on the quality of the permanent magnet type if so the more expensive of generator construction cost. Therefore, if the price of the magnet can be got inexpensively in local area, Myanmar, this AFPM type of generator is most suitable and variable for using the home lighting system in remote area.

For the cost benefit, this type of wind turbine does not need many construction area and many labours cost to install it. To construct this wind turbine, all the equipments and peripheral can be easily bought within local market and also less maintenance. The blades made of wooden blades named Jameina which is easy to find, light, good strength and cheap instead of teak. Especially, this turbine is quite easy to construct, operate and maintain by users with a little technical experience. The whole cost for this type of wind turbine is about $ 1570 without battery bank. The price can be able to construct to use electricity cheaply for home lighting in rural area.

On the other hand, there are mainly two types of existing small scale wind turbine technology such as axial type and radial type. Comparing to radial type, the cost benefit per kW is not so different. The other comparing facts on advantage and disadvantage are many points. However, the main point of the selecting this type is direct driven at low wind speed. Direct driven operation is performed in order to minimize the mechanical losses in the system by eliminating the use of gearbox. By removing the gearbox from the system, the direct driven system can achieve higher performance with mass compared to a generator gearbox combination. Moreover, this small wind turbine is more economical than diesel engines for rural people in remote areas. By studying this research work, wind power system is one type of renewable energy and small wind power system is widely used as home-use system for rural electrification in low wind site, Myanmar.

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