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Design and Realization of a 300 W Human Power Energy Generator System on a Bicycle

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Abstract

In this study, we discuss a new type of human power energy generator (HPEG) system that has been designed to work with bicycles. To analyze the magnetic circuit, the finite element analysis was used to simulate the magnetic flux density in the axial flux permanent magnet（AFPM）generator. The performance of the designed HPEG was tested by mounting the E-bike in the training stand and pedaling at different speeds. Based on the experiments, the maximum output of current and voltage were 1.4 A and 215 V, respectively. The output power of the developed HPEG system had the maximum output power 300 W at the rotation speed of 790 rpm. On the road, the HPEG system is able to generate excess power to recharge the battery while pedaling, braking and coasting downhill, which turns the extra momentum into electricity to charge the battery. When the speed of the bike is above 25 km/hr, it is easy to generate approximately 100 watts of power by pedaling. It can provide a 10% increase in range. Furthermore, the developed HPEG system can also provide a method of generating electricity by means of a modified exercise bike for use in energy storage. Energy stored in battery form can act as a supplemental energy source for battery banks that may already be used for household appliances.

Keywords: planetary, axial-flux, permanent-magnet, power generator, HPEG

1. Introduction

Access to inexpensive energy in useful forms has been one of the most important issues for mankind throughout history. The fear of forthcoming energy shortages has even been the cause of wars. Recently, there has been the introduction of renewable energy, such as small hydro, wind, solar, geothermal, and biofuel energy. The most interesting of these energies are wind power and solar energy. However, the use of solar energy technologies has a shortcoming of very high cost. The limited life of solar panels is about 10-20 years and the production requires the use of a large amount of silicon, germanium, and boron, which may cause pollution in other areas (Nelson, 2003). On the other hand, the wind power energy has high installation cost, big noise, locations and wind farm requirements (Lei et al., 2005; Bansal et al., 2002). Due to various factors mentioned above, there is low interest in renewable energy investment in the private sector. Therefore, the use of renewable energy tends to be limited to government and education and is not prevalent in the public. When selecting a suitable renewable generator, consumers focus on low cost, easy installation, minimal limitation due to topography, height and size, realizable and low maintenance rather than the volume of electricity generated. Hence, bicycles become one of the best choices. Because of their mobility and convenience, bicycles turn out to be a useful tool for people traveling in the city. Moreover, bicycles do not require fossil fuel or generate any air pollution or noise. By combining bicycles and generators, the public would be able to recycle the long ignored human energy, significantly decreasing electricity bills and better protecting the environment. Therefore, it is generally recognized that there is a need for new methods of affordable, non-polluting personal generator. In this paper we provide the most primitive clean energy that has been used for thousands years – human power energy. Human power energy is also more abundant and less dependent on environmental conditions, such as climate, than solar energy and alternative sources of energy.

It is obvious that the bicycle is a well-understood and often used machine, but the electrical versions have had little commercial success over the past century. In the past, some types of bicycle generators have been developed, such as drum generators, sidewall generators, and hub generators. Sidewall generator is the most common type of the bicycle generator. It consists of a steel frame holding a permanent magnet direct current generator. The bicycle tire rubs against the drum of the generator that turns the generator shaft to create electrical power. Drum generator basically like sidewall generator, except that their roller is designed to rub against the top of the tire instead of the side (Heine & Oehler, 2005). Since all the friction drums of these generators have to make contact with the bicycle tire. This will lead the friction that occurs at the drum/tire interface and cause the energy loss. Hub generator is built into the hub of a bicycle wheel, thus make it more effective. However, it is less powerful than the other types due to the heavy weight and is difficult to install. Therefore, these generators can only produce 3-6 W of power. The efficiency of the bicycle generator has not yet reached the level that the public demands.

In this study, a new type of high power planetary axial flux permanent magnet（AFPM）generator is proposed for the construction of the human power energy generator (HPEG) system installed on a bicycle to generate electric power while the wheel in operation. The advantage of AFPM generator is that it performs efficient cooling and can be manufactured in slim styles. As the rotors of the AFPM generator are outer-rotors, they can be directly attached for direct drive without any gears (Gieras et al., 2004). High-energy permanent magnets using Nd-Fe-B structures allowed formation of relatively large airgaps to make the production of coreless types possible. The noted advantages of coreless type are the relatively high density in the volume of coil and less loss of energy from the cogging torque (Parlikar et al., 2012). Since the generator is non-contact with the wheel, the rotor does not rely on friction for the transfer of rotation, it can be easily employed for drive. The design, fabrication and the measurement of the HPEG are described in detail.

2. Method

The principle of power generation is very simple, that is Faraday's law. The law states that the induced electromotive force (EMF) in any closed circuit is proportional to the rate of change in the magnetic flux through the circuit (Sadiku, 2007). Design of permanent magnet machines, such as the permanent magnet axial flux generator, is a procedure involving iterative computations based on performance requirements and tradeoffs. Typically, empirical relations or simplified models are used in the early stages of the design, followed by finite element analysis (FEA) lately. The unique pancake profile of AFPM machines has made them ideal candidates for in-wheel generator applications as they inherently match vehicle rim aspect ratios of large diameter and thin width. Flux in an AFPM machine flows through the airgap axially. AFPM machines have discs for the rotor and the stator geometry. The proposed AFPM in-wheel machine configuration in this paper is shown in Figure 1.

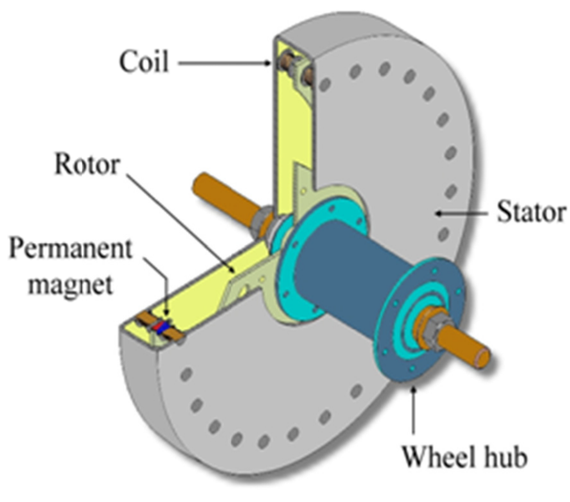

Figure 1. The scheme of the developed HPEG system

As illustrated in Figure 1, permanent magnets are glued to the surfaces of solid mild steel rotor discs. Particular care should be paid to the systems for jointing permanent magnets to the rotor. We used standard cylindrical axially flux magnetized Neodymium-Iron-Boron (NdFeB) permanent magnets for the field excitation in the rotor (Neji et al., 2006). The permanent magnets were encased in the rotor disc. The rotor has a diameter of 200 mm and 18 NdFeB permanent magnets were arranged in a N-S-N-S pattern around the circumference of the rotor.

The rotor disc was bolted to the rear wheel hub, and the stator was attached to the frame. Since the generator is non-contact with the wheel, the rotor do not rely on friction for the transfer of rotation, therefore, it can be easily employed for drive.

By using symmetry in electrical machines, most FE solutions can be obtained by 2D modeling, which is less computer processing intensive than 3D modeling. Even though 2D modeling is a somewhat approximation of the full model, it has been proved accurate. Figure 2 shows the magnetic flux lines of reaction field.

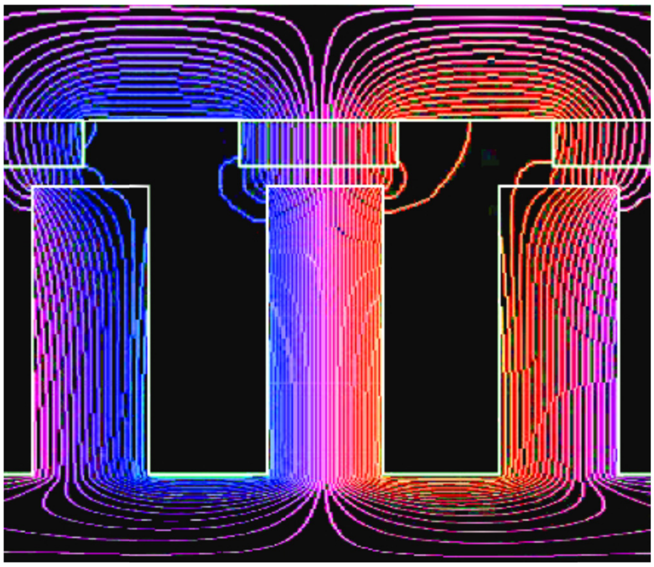

Figure 2. Magnetic flux lines in the machine

The attractive force between the stator and rotor in single-sided AFPM is a serious drawback for the topology. This force causes bending of the rotor and stator support structures and must be evaluated. The attractive forces can be determined analytically by Equation 1 (Patterson & Spée, 1995):

$$A_F = \frac{B_g^2 S_m \alpha_m}{2\mu_0} \tag{1}$$

Where A_F is the attraction force, B_g is the flux density in the airgap, S_m is the airgap surface area, α_m is the percentage of magnet to airgap area, and μ_0 is the permeability of free space. From the analysis, the attraction force of A_F = 6645 N was calculated for the rotor thickness to be such that the maximum deflection of the rotor disk is a fraction of the air gap length. Care must be taken in the resultant bending in the rotor back yoke (Δr) and the stator back support (Δb). Finite element analysis was once again used to determine the maximum deflection in the structure so as not to violate the mechanical clearance. The maximum combined reduction in clearance was calculated to be 0.08 mm which is within acceptable limits.

The prototype of the small power generation system is shown in Figure 3. Figure 3 shows the arrangement of magnet poles glued onto a rotor surface. The diameter and thickness of the NdFeB permanent magnet were 20 and 15 mm, respectively. The stator was ring shaped and consists of 18 induction coils with respect to the permanent magnets of the rotor. To reduce the cost, we inserted the screw into the coil as iron core instead of silicon steel. One important mechanical aspect with regard to AFPM machines pertains to the attraction forces between the stator and the rotor; in particular single-sided AFPM machines as they present the worst case. In order to counteract the attraction forces, non-ferromagnetic holders were designed and constructed. A set of paired bars was selected to handle the force.

Figure 3. The HPEG system has been installed on a commercial bicycle

In this research, the HPEG system was installed on a commercial bicycle and tested under different rotational speeds and wire configuration. Since the space between the hub and frame of the commercial bicycle is limited, only one stator was attached to the frame and the rotor plate was bolted to the rear wheel hub. Besides, without the contact between the generator and rear tire, the rotor, which does not rely on friction for the transfer of rotation, can be easily employed for drive without energy loss. Finally, the performance of the generator was obtained with experimental tests. It is expected that by driving the generator at high speeds, higher output power is obtained.

3. Results and Discussion

The system is not optimized in weight and dimension: it is only a first low cost prototype, useful to demonstrate the technology of HPEG system and to obtain direct information on operating tests. The experiments were conducted to observe the performance of the HPEG system. The HPEG system performance was tested by mounting the bike in the training stand and pedaling at different speeds. For the health-improving or energy-preserving activities applications, we are interested in the speed range from 20 km/hr to 100 km/hr. Figure 4 shows the output voltage and current as a function of speed. As shown in Figure 4, the maximum output current and voltage in parallel configuration were 0.7 A and 430 V.

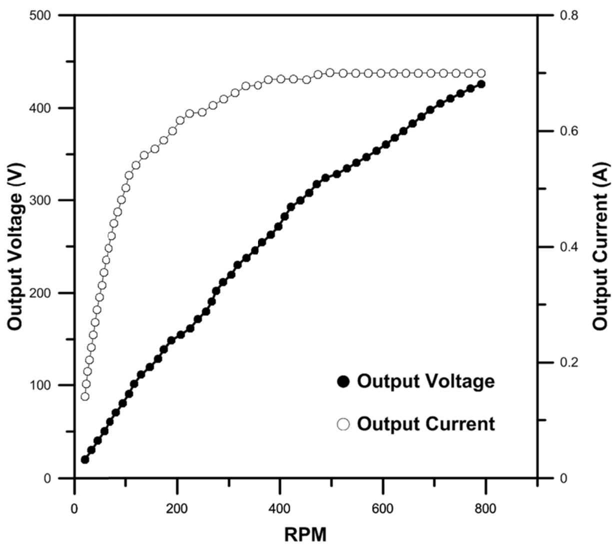

Figure 4. The output voltage and current as a function of speed in parallel

The output power of the developed HPEG in parallel configuration is illustrated in Figure 5. As shown in Figure 5, the developed HPEG had the maximum output power 300 W at the rotation speed of 790 rpm. We also found that at the normal speed 500 rpm (corresponds to downhill speed 60 km/hr) it is easy to achieve 215 W, even if in road travel at 200 rpm (about 25~30 km/hr), it can also achieve 100 W.

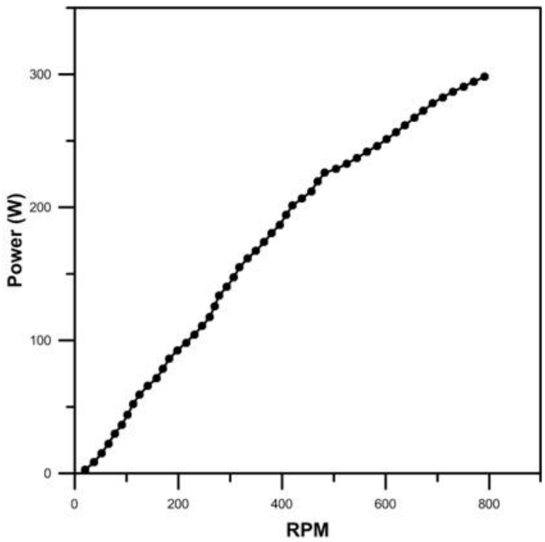

Figure 5. The output power of the developed HPEG

Furthermore, the developed HPEG system can also provide a method of generating electricity by means of a modified exercise bike for use in energy storage and running household appliances. The output alternating current (AC) is converted into a direct current (DC) by battery charger. The energy can be stored in various types of lead-acid batteries. Energy stored in battery form can act as a supplemental energy source for battery banks that may already be used for household appliances. If AC appliances are in place then an inverter must be used to transfer the 12 volts of DC current into the standard 110 volts of AC current for usage by these appliances. Appliances that could be powered include radios, televisions, lights, power tools and other appliances that pull relatively low amounts of energy for their usage.

In order to increase the driving range, we can install the HPEG system on the hub of the rear wheel of the electric bicycle, which can create excessive power to recharge the battery while pedaling, braking and coasting on a downhill. In this work, the Lithium battery was adopted for its light weight and long duration power. The power system consisted of a battery (36 V, 9 Ah) and an electric brushless DC motor (350 W). Figure 6 illustrates schematically the prototype of the electric bicycle with HPEG system. The system can transfer the kinetic energy to electric power and recharge the battery by use of a planetary AFPM generator, which can extend the range by 10-20 miles.

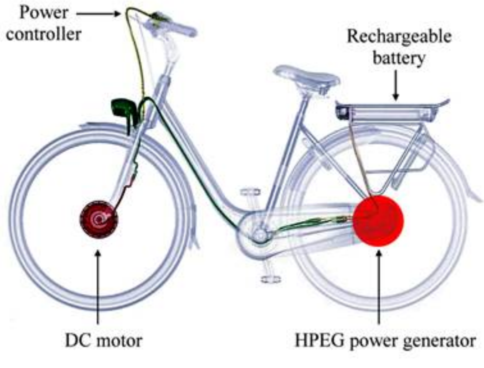

Figure 6. The prototype of the designed electric bicycle

The daily and hourly energy demand has been calculated. It is possible to calculate the rate of recharge that is needed to replenish the battery. We are examining the system with a 12 volt, 100 Ah battery. It would take 6 hours of pedaling to full charge the battery by mounting the bike in the training stand and pedaling at speed of 400 rpm. Though the time needed to generate electricity seems too long for one person to put out, it would probably be most appropriate for households with multiple people. Table 1 lists the appliances that the full charge battery could be powered. Currently the average installation cost is 10,000 US dollars for a 1,000 watt solar panel. Moreover, the amount of hours that the solar panel can generate electricity depends on the amount of sunlight received. The majority of small wind mills are installed by the government and education, not residential, due to unstable wind power, 6 meters distance requirement and limited space. Compared to solar panels or wind mills, HPEG is more convenient because it can be installed on bicycles. The cost of HPEG is approximately 300 US dollars and could be lower once it can be mass-produced. Therefore, HPEG is cheaper than other renewable energy devices.

Table 1. The appliances that the full charge battery could be powered

	Radio	Fluorescent lighting	37-inch LCD TV	Toaster	Air conditioner
Power(W)	20	20	150	600	2000
In use time(hr)	60	60	8	2	0.6

4. Summary

The purpose of the paper is to introduce an electric generator, which easily recycles kinetic energy, allowing the public to conserve energy and reduce carbon consumption. In this study, the prototype of the HPEG was designed, fabricated and tested under different rotational speeds and wire configuration. Human power is a readily available source of renewable energy. It is user-friendly, portable, and available whenever you need it. The power output of the designed HPEG was directly proportional to the effort of the person pedaling. Experiments showed that the maximum output power of the developed HPEG could achieve 300 W at the speed of 790 rpm and 100 W at the normal speed of 25~30 km/h during road test. It can be also employed as an emergency power generation and battery charging for household appliances and exercise systems that do useful work generating power while exercising. The prototyped generator is relatively small and cheap. The information gained with current experience can be employed as a useful guidance for further developments on this technology.

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