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A novel design of DC-AC electrical machine rotary converter for hybrid solar and wind energy applications

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Abstract. This paper proposes the design of a new bi-directional DC-AC rotary converter machine to convert a d.c. voltage to three-phase voltage and vice-versa using a two-stage energy conversion machine. The rotary converter consists of two main stages which are combined into single frame. These two stages are constructed from three main electromagnetic components. The first inner electromagnetic component represents the input stage that enables the DC power generated by solar energy from photo-voltaic cells to be transformed by the second and third components electro-magnetically to produce multi-phase voltages at the output stage. At the same time, extra kinetic energy from wind, which is sufficiently available, can be added to existing torque on the second electromagnetic component. Both of these input energies will add up to the final energy generated at the output terminals. Therefore, the machine will be able to convert solar and wind energies to the output terminals simultaneously. If the solar energy is low, the available wind energy will be able to provide energy to the output terminals and at the same time charges the batteries which are connected as backup system. At this moment, the machine behaves as wind turbine. The energy output from the machine benefits from two energy sources which are solar and wind. At night when the solar energy is not available and also the load is low, the wind energy is able to charge the batteries and at the same time provides output electrical power to the remaining the load. Therefore, the proposed system will have high usage of available renewable energy as compared to separated wind or solar systems. MATLAB codes are used to calculate the required dimensions, the magnetic and electrical circuits parameters to design of the new bi-directional rotary converter machine.

1. Introduction

Finding alternatives for fossil fuel to generate power has become the main motivation towards research on renewable energy in the last few decades. Out of the many renewable energy sources available, extensive research has been focused on harnessing solar energy using photo-voltaic cells [1] and wind energy using wind turbines [2] to generate electrical power.

Studies have shown that solar power is most suited to generate power during the day time whereas wind power is most suited during night time. Hence, extensive research has also been concluded to hybrid solar and wind energy systems for power generation [3]. These hybrid systems employ the use of power electronic converters to convert the dc voltage from solar PV cells and varying frequency ac voltage from the wind turbine into a constant frequency ac voltage to be supplied to the electrical grid system [4].

This paper aims to introduce a new design of electric machine rotary converter to convert dc to ac voltage and inversely which can be employed on solar and wind energy hybrid systems.



2. Components and Operation of the DC-AC Rotary Converter

The proposed direct current to multi-phase rotary converter machine contains two important stages. The first stage is made up of direct current motor. Naturally it consists of two main parts: stator and rotor. The stationary stator forms the inner fixed part which has wave or lapped windings. These windings are divided into two purposes: main winding, and improving windings. The D.C. motor's speed is determined by the number of main winding poles (2, 4, 6, etc.). The improving windings are devoted to provide a good starting and running performance of the motor.

Generally as in any design, it must be designed based on the demanded specifications of the suggested rotary converter rating, speed, rated input and output voltages. These will be utilized to calculate the engineering dimensions of the machine.

The d.c. stator may have tapered slots for small ratings or rectangular slots for higher ratings with the sizes for stator slots being dependent on the number of conductors per slot. The starting and running windings in the stator windings are always preferred to be wound in a wave or lap depending on the machine rated power. Figure 1 shows the inner d.c. stator of the rotary converters first stage. The rotor of the first stage consists of permanent magnet poles on the inside part of the middle section of the rotary converter as shown in figure 2. When d.c. voltage is applied to the inner d.c. stator of the rotary converters first stage.

The rotor of the first stage consists of permanent magnet poles placed on the inside part of the middle section of the rotary converter as shown in figure 2. When a d.c. voltage is applied to the inner d.c. stator of the first stage rotary converter, the magnetic field produced by the inner stator will interact with the permanent magnet poles on the inside part of the middle section causing the entire middle section to be rotated.

The second stage of the rotary converter is exactly the same as any conventional synchronous generator. The rotor of the second stage contains the excitation field windings placed on the outer part of the middle section of the rotary converter as shown in figure 2. The stator or armature of the second stage is shown in figure 3. The armature may be comprised of three, six, nine or twelve phases which is made up of a block of laminations mounted in a cast iron or die cast aluminum alloy frame. The armature has tapered slots for small rating machines or rectangular slots in higher rating machines. Armature windings are always preferred to be wound in lap or progressive coils, which gives a good value of winding factor, reaching more than ninety percent.

The rotor of conventional synchronous generator are driven by an exerted prime –mover. In the case of the second stage of the rotary converter, the excitation field windings are rated by the movement generated from the first stage. This rotation causes the excitation field to induce voltages on the multi-phase outer stator of the second stage to generate ac multi-phase voltages at the output terminals. The three components of the Dc-AC rotary converter are accumulated together as shown in figure 4.

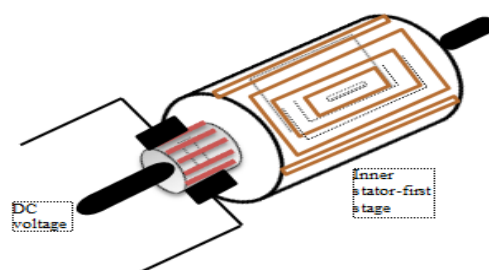


Figure 1. Inner D.C. Stator of the rotary converter's first stage.

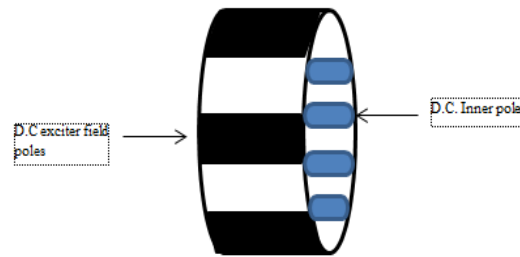


Figure 2. Middle rotating component of the rotary converter consisting of permanent magnet poles of the outer rotor d.c. motor. First stage on the inside part and excitation field windings of the second stage synchronous generator.

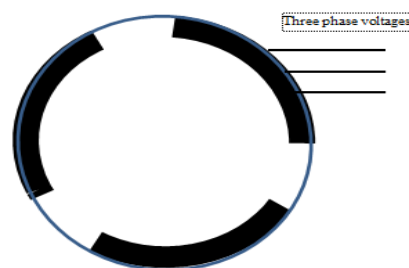


Figure 3. Three phase outer stator of the rotary converter's second stage.

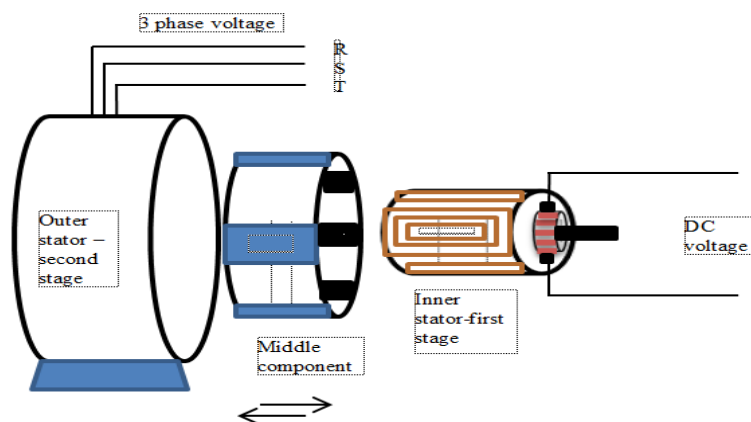


Figure 4. Components of the DC-AC rotary converter.

3. DC-AC Rotary Converter for Hybrid Wind- Solar Energy System

The designed DC-AC rotary converter is proposed in this paper can be employed to harness electrical power for a hybrid wind and solar energy system as shown in figure 6. The d.c. output voltage generated by photo-voltaic cells can be connected as the input to the inner d.c. stator of the rotary converter's first stage. This will then cause the middle rotating component of the rotary converter to rotate and hence generating three- phase output a.c. voltage at the outer stator of the rotary converter which can be connected directly to the grid.

The wind turbine can be coupled to the middle rotating component via gearbox. When the wind conditions are suitable, the wind turbine will be coupled to the middle rotating component causing it to rotate and generating three phase voltages to the grid via the outer stator of the second stage. The rotation by the wind turbine will also generate d.c. voltage at the inner d.c. stator which can be used to charge the back up batteries as shown in figure 5.

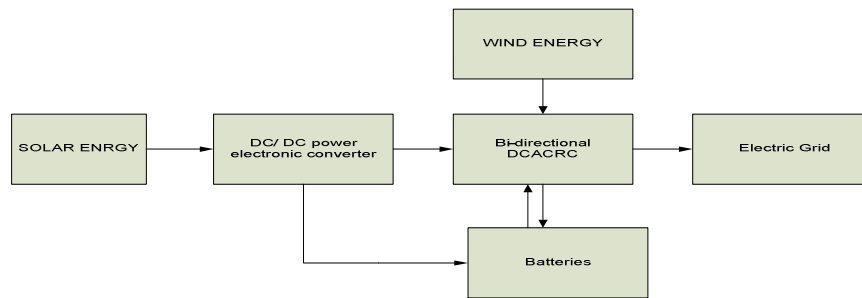


Figure 6. Basic configuration of the proposed hybrid renewable energy system employing the designed Dc-AC rotary converter.

4. Conclusions

The new rotary converter is proposed for hybrid power generation employing stator and wind energy. This can be used as a complement to the power electronic converters because the last type could not be able to violate the solar and wind energies at the same time without need for electric machine, the following merits are relevant to the proposed DC-Ac rotary converter machine:

- i. It can be used for generating three, six, or twelve phase.
- ii. The output voltages have a high efficiency of balanced multi-phase operation.
- iii. It is easy to maintain and re-wind.
- iv. It is capable of enduring high ambient temperatures.
- v. Its overall noise strength is expected to be similar to normal dc motor.
- vi. Its weight and size in within the acceptable range.

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