Optimization of Automotive Bosch-140 Alternator to use as a Generator for Small Wind Turbine

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Abstract. The generator is one of the costly elements of a small wind turbine. This paper developed a suitable low-cost small wind turbine generator, which can be modified to be easily manufactured. The experiment was conducted in two parts, the first part involves monitoring the current, voltage, power, and temperature for the Bosch 140 alternator before re-winding (initial case), and the second part includes monitoring of parameters (current, voltage, power) with modifying the alternator (Bosch 140) by re-winding depending on the results of the JAMG program simulation (last case). The Bosch 140 alternator was modified consistently by reducing the wire diameter to half to double the windings to evaluate the maximum torque. A genetic algorithm was used to optimize the stator's design optimization to achieve a maximum torque of the magnet. The final result shows a good indication of the modified alternator's efficiency, where it is increased by about 30% from the initial case, and the generation of voltage started at a low rotation speed. It was observed that the new optimization of claw-pole alternator provides fairly the double torque with at least 16% reduction in rotation speed.

Keywords. Small wind turbine, Claw pole generator, Torque generator.

1. Introduction
Electrical energy has become of great importance in our lives in many fields and our daily use now. However, small wind turbines (SWT's) are still in their stage of development, particularly in many remote areas [1]. The wind turbine engine is one of the essential parts that should be monitored and maintained periodically. It is costly and is considered the heart of the turbine. Many researchers have worked in this field and have worked in the field of SWT under current research. In Reference [2], a Windpro2004 turbine was used. It could generate 163W wind velocities of around 9 m / s, and the selected gear ratio was 1:4. Reference [3] used an off-the-shelf recycled automotive alternator that is experimentally parameterized and modeled with an assumed small wind turbine. In [4], the viability of car alternators for wind power systems was discussed in many types of research. Pudji Irasari discussed the feasibility of using a car alternator as a wind turbine generator [5]. For use in remote areas, H. Fernández et al. implemented an AC electrical wind power generation system. A vertical axis wind turbine attached to a regular car alternator supplies mechanical energy.
References [6] and [7] evaluated the power produced by small wind turbines using an automotive alternator. This study aims to develop a suitable low-cost small wind turbine generator by some modifications in windings. To do this objective, it is important to suggest a low-cost solution that is simple to manufacture, assemble, and maintain. It exists in the market, especially the regional (Iraqi) market. The main research tasks are to analyze some commercially available small wind turbine systems to find a suitable generator for a small wind turbine used in the low wind speed areas as most Iraqi areas. Then, analyze and simulate a prototype generator. The manufacturability and low cost of the selected generator configuration will be observed. After that, verify the selected generator performance experimentally and monitoring measurement tests on-line, and investigates the possibility and benefits of an automotive alternator to be applied for a small wind turbine. This is important for low-cost solutions.

2. Small wind turbine (SWT)
This small wind turbine is suitable for working at a very low speed and can operate at a wind speed of 2 m/s. It can be built on rooftops and is easy to disassemble and install. It can be transported anywhere and can be built with smaller sizes and fewer capacities 1, 2, or 3 kilowatt-hours at a lower cost. Small-scale residential turbines are available; they typically have a rotor blade diameter of approximately 2.1–7.6 m and generate power at their rated wind speed at a rate of 300 to 10,000 watts. SWT is ideal for many uses, including homes on or off the grid, communication, remote monitoring, and other energy-intensive applications where the grid is unstable [8].

\[
P_w = \frac{1}{2} C_p(\lambda, \theta) \pi r^2 v^3 \rho
\]

Where; \( P_w \): Output power, \( C_p(\lambda, \theta) \): Performance coefficient, \( \lambda \): tip speed ratio, \( v \): wind speed (m/s), \( \rho \): air density, and \( \theta \): pitch angle of rotor blades.

Tip speed ratio can be calculated as in Equation 2:

\[
\lambda = \frac{r w_g}{v G}
\]

Where; \( G \) = gearbox ratio, \( \omega_g \) = generator rotor speed.
Therefore, it can determine wind speed according to Equation 3:

\[
v = \frac{r w_g}{\lambda G}
\]

In our study, SWT's cut-in wind speed is 3 m/s, and it is equal to 900 rpm shaft speed and a gear ratio of 10:1. This is equal to a 900 rpm shaft speed reduction at the alternator. The wind speed to be cut out is set at 25 m/s (8000rpm). Table 1 summarizes the supposed parameters of SWT.

| Parameters                              | Value       |
|-----------------------------------------|-------------|
| Rotor blade diameter (r)                | 2 m         |
| Wind speed(v)                           | 4 m/s       |
| Rated alternator speed                  | 2000 (rpm)  |
| Rated input power to the alternator     | 300 W       |
| The rated power output of an alternator | 200 W       |
| Tip speed ratio (\( \lambda \))        | 6.4         |
| Maximum aerodynamic coefficient (\( C_p,_{max} \)) | 39%        |
| Air density (\( \rho \))               | (1.225)kg/m3 |

3. Automotive alternator
The alternator consists of four parts, as shown in Figure 1.
The rotor is made up of iron poles and several fine turns, connected over the machine shaft; when a rotor shaft drives it, an electromagnetic field is generated. The alternator stator is composed of a three-phase winding that is typically connected based on the star configuration.

4. Experimental result

4.1. Alternator performance test

In this experiment, the claw pole alternator is coupling with a DC motor controlled through a variable frequency device. An AC/DC converter rectifies the variable-frequency voltage produced from the alternator. Figure 2 shows the test bench. The variable-frequency used to set the DC motor's shaft speed (300, 600, 900, 1200 and 1500 rpm) is connected by coupling. All of the output power is connected to the resistive load.

Figure 1. Claw pole alternator.

Figure 2. Test bench of experimental results.

4.1.1. No-load test. The alternator test was done with an alternator without any load, as shown in Figure 3. The power currents curves did not appear, and so the power curves equal zero because no-load was consumed, and the optimum value of generating voltage between 1200-1500 rpm.

Figure 3. Test values parameters without load.
4.1.2. One-load test (10A). The alternator test was done with a 10A load shown in Figure 4. At 800 rpm, the power is about 30 W, and the voltage generated is about 4 V. It seems that we need to operate the generator at relatively high rotational speeds, about 1500 rpm, to get a reasonable value of power.

![Figure 4. Load (10A) test.](image)

4.1.3. Two-load test (20A). The third step of the alternator test was done with a 20A load, as shown in Figure 5. Increasing the applied load on the generator leads to stating that voltage generation will be shifted to a higher rotation speed value. As seen from the above figure, the voltage generation started at 900 rpm. With increasing the power, the cogging torque increases directly proportional. At the maximum power and rotation speed, the maximum value of torque is equal to 0.13 N.m.

![Figure 5. Third test with 20A load.](image)

5. Re-winding Bosch Alternator
The alternator was re-winded with 28 turns in each coil and 0.7mm wire diameter. The initial spinning procedure was 13 rotations with a diameter of 1.2 mm, and the wire was shortened to 0.75 mm or half as long as the winding was doubled. In each stator slot, shown in Figure 6, 28 turns were fitted.
Figure 6. (a) Removing the old wire of winding, (b) Re-winding at 0.7mm, and (c) Stat connection of re-winding.

Figure 7 shows the results after re-winding the alternator; it is clear that the generating voltage reached 14V at much lower rpm. For a windmill that only has blades at 300 ~ 700 rpms, this is rather impractical. Final testing shows 14.6V and 11.2A, giving a power output of 164.5W max at 800 rpm, and the maximum torque is 2.2 N.m. This gives us a good indication that the modified alternator's efficiency was increased by about 30% from the initial alternator (before re-winding).

Figure 7. Third tests with a 20A load of the modified alternator.

6. Simulation bodel of Bosch 140 alternator
The Bosch 140 alternator comprises magnets, a rotor core, a stator core, and coils. The model is indicated below (Figure 8)

Figure 8. Rotor-Stator JMAG model Bosch140 alternator.
The Bosch140 alternator was used to run the cogging torque analysis, evaluating the cogging torque and induced voltage without a current flow. The step analysis can be summarized as in the algorithm of analysis, as illustrated in Figure 9.

![Figure 9. The algorithm of the analysis steps.](image01.png)

The analysis results can be shown clearly in Figure 10.

![Figure 10. Magnetic flux density quarter model.](image02.png)
The min magnetic flux density is 0, and the maximum value is 2.4 Tesla (volt second per square meter). The air region is included in the analysis, which is based on using the Finite Element Method. If the magnetic circuit is enclosed inside magnetic material, the air area's size does not influence the study result because the flux leakage will be negligible. However, if the leakage flux is intense or the magnetic circuit is not enclosed within a magnetic material, an appropriate size must be defined for the air area. For this analysis, the air area scale is set to ‘1.05’. Figure 11 shows the cogging torque versus phase angle. The maximum value of the torque is 0.17 N.m.

Figure 11. Torque and phase angle.

6.1. Modifying bosch140 alternator torque
If the current flows through the wire, then a Lorentz force is produced on that wire as described by

\[ F = NBIL \]

Where; \( N \): turns of wire on the coil, \( B \): flux density in the air gap, \( I \): current in the movable coil, and \( L \): vertical length of the coil.

The torque is a function of force. If the number of turns increases, the starting current and torque of the alternator are increased too. In this paper, the process used to study the stator winding turns can be presented in Figure 12.

Figure 12. Algorithm of maximizing the torque of Bosch 140.
The original windings of the Bosch140 alternator are 13 turns, which is 1.5 mm in diameter. To maximize its torque, the wire diameter was reduced to about half (0.75 mm) of its original diameter to double up the winding turns, which means increasing the torque. The new input number of turns was 30 turns in each stator slot. This is an attempt to increase the voltage, which has the benefit of generating 12V at the lowest rpm value. The analysis result of modified for steady torque is shown in Figure 13. The maximum torque value is 2.4Nm; this means that the torque was maximized by making the number of turns equals to 30; hence the power increases. The experimental results are identical to the simulation result.

![Figure 13. Torque and phase angle.](image)

7. Conclusion
In this paper, an analytical model of a claw pole alternator has been studied. The parameters such as the number of turns, winding wire resistance, the power factor, and the alternator efficiency were considered. A claw pole alternator was re-wound and tested. When the turbine is running at a wind speed rate, the claw pole alternator can generate electrical energy at its maximum at 8 m/s (800 rpm). Also, the numerical simulation by JMAG software results found satisfactory with the experimental outcomes. Therefore, the simulation environment was sufficiently accurate fitting with this work. The claw pole alternator's cost is reduced; therefore, the energy is produced with less cost than the energy produced from SWT, which is expensive. It was observed that the new optimization of claw-pole alternator provide fairly the double torque as the original machine with at least 16% reduction in rotation speed.

8. Reference
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Appendices

Appendix A

BOSCH Alternator 140A, Figure A1

Article number: 0 123 214 002

- Alternator Charge Current [A]: 140
- Rated Voltage [V]: 14
- Belt Pulley Ø [mm]: 45
- Pulleys: with multi-belt pulley
- Number of grooves: 7
- Rotation Direction: Clockwise rotation
- Alternator Type: excl. vacuum pump
- Fastening Type: Single pivoted lever
- Recommended additional repairs: V-Belt/V-Ribbed Belt
- Length [mm]: 178,2
- BOSCH: Alternator
- Item number: 0 123 214 002
- Manufacturer part number: 0 123 214 002
- Manufacturer: BOSCH
- EAN number: 3165142033082
- Usable in vehicles with alternator charge current [A]: This characteristic varies depending on the car model.
- Condition: New
- Use number: BOSCH NCR14V45140A
- EAN: BOSCH 3165142033082

Figure A1. Specification of Bosch 140 alternator
Appendix B
Steps of stator Re-winding, Figure A2

Figure A2. Steps of re-winding of Bosch 140 alternator
Appendix C  
Dimension (Unit: mm), Figure A3

Figure A3. Dimension of Bosch 140 alternator