Retrofitting a Car Alternator for Low-Speed Power Generation

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ABSTRACT

This report presents the analysis and methods taken to appropriately modify a car alternator to operate as a low speed generator for wind or hydro power generation. A Toyota car alternator taken from a junkyard is characterized via an Open-Circuit test to evaluate its operating specifications. The car alternator is also measured to determine its physical dimensions. The acquired values are used with the generated voltage equation to determine the machine's unknown rotor values— the product of the rotor winding factor and the number of rotor windings $\boldsymbol{k_f N_f}$. Using the generated voltage equation with the determined machine parameters, the number of stator windings required for the machine to generate power at low speeds is determined. The alternator's stator is then rewound and remounted to the body of the machine for testing. Inexpensive scrap materials are used to reduce the cost of the project and to simulate the experience of executing such a project in an environment where high-end tools are not accessible. The methods to disassemble the machine, rewind its stator and reassemble the alternator are noted and recorded to develop a guide that will be accessible to the public.

I. INTRODUCTION

In our modern world, electricity plays a pivotal role in driving industry and powering the systems used to meet our agricultural, health care, educational, and commercial needs. Developing countries across the world continue to lack access to electricity and the economic foundation needed to build and maintain the infrastructure necessary to harvest such energy. The severe impoverishment that these countries face inhibit communities from obtaining the energy needed to further their living stability and stimulate the growth of their economies. For instance, the gross national income (GNI) of countries like Indonesia and Guatemala falls below $2,800 annually, which signifies that on average, the bulk of their populations survive on less than 8 dollars a day [1]. Rural communities in these countries typically rely on wood and traditional biomass as sources of energy; however, the methods in which they harness and utilize their energy are inefficient (averaging 10%), environmentally unsound, and unhealthy [6]. Thus it is important to investigate better and inexpensive alternatives to power such communities; namely, methods that utilize the abundant renewable energy sources found in such communities.

The premise of this project is to develop an inexpensive method to modify a car alternator for power generation. The process taken to accomplish this feat will make use of scrap materials commonly found in junkyards. This would both reduce the starting cost of a small scale hydro or wind power-generation system and provide a sustainable solution to the energy problem faced by rural and impoverished communities. Furthermore, the methods taken to modify the alternator will be documented to develop an instructional guide that would be available to individuals across the globe via the internet. Ideally, the

information compiled through the extent of this project will provide the basic information needed to tackle similar energy projects.

II. BACKGROUND

2.1 The Car Alternator

The car alternator is an electro-mechanical device that is the central component of an automobile's charging system. The alternator's sole purpose is to charge the car's battery and work alongside the battery to power the electrical components of the vehicle. An alternator is able to produce power via the electromagnetic relationship of its rotor and stator. The rotor is the rotational component of the alternator that consists of a coil of wire wrapped around an iron core. The rotor is attached to a drive pulley through its shaft; thus the rotor rotates as the engine moves. DC current is run through the rotor's coil via a set of brushes and slip wrings; this current is referred as the "field current". The current is derived from the battery connected to the alternator. Furthermore, the field current serves to produce a magnetic field around the rotor's claw casings; the magnetic field essentially gives the rotor the characteristics of a magnet, containing north and south poles.

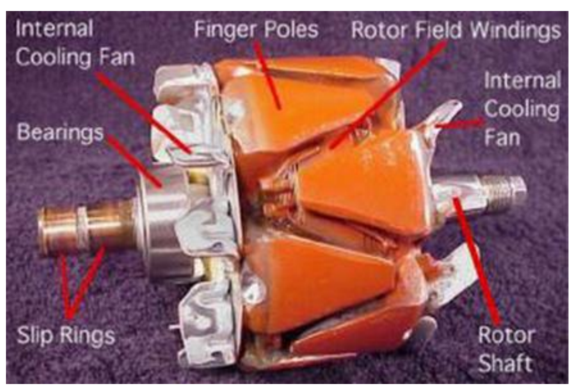


Figure 2-1: An Alternator's Rotor [3]

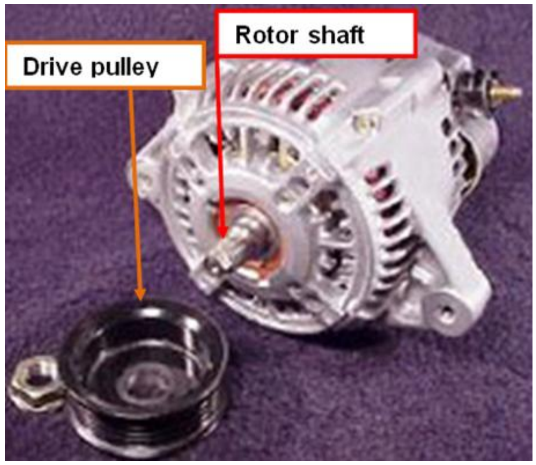


Figure 2-2: Drive Pulley and Rotor Shaft [3]

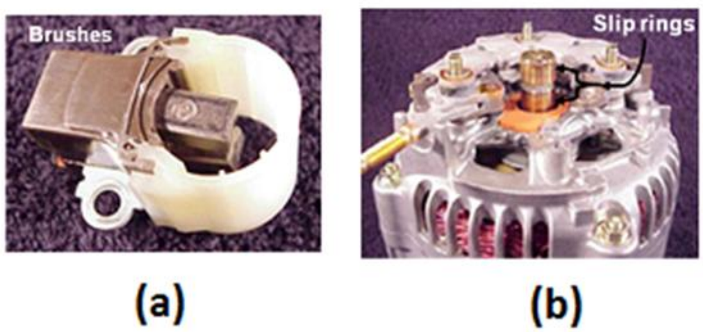


Figure 2-3: (a) Alternator Brushes; (b) Alternator Slip Rings [3]

The stator is the stationary component of the alternator composed of a set of three coils wrapped around an iron core. The coils are electrically separated 120° from each other and connected in either a Wye or Delta configuration to produce 3-phase AC voltage. The alternator used for this project contains Wye configured coils. Once the magnetized rotor commences to rotate, its magnetic field induces a voltage across the stator coils. Since the induced voltage is directly related to the rotor's magnetic field, the stronger the rotor's magnetic field is, the higher the induced voltage will be [3]. Conversely, the faster the rotor spins, the higher the voltage induced across the stator coils will be [3]. Typically, the lowest speed at which a car alternator is able to generate 12VDC is about 1,800 RPM.

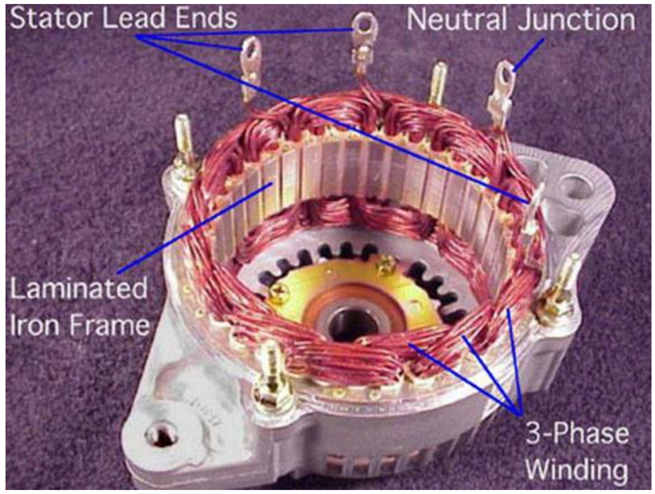


Figure 2-4: An Alternator's Stator [3]

Since the voltage induced across the stator coils is AC voltage, it must be converted to DC to appropriately charge the battery. Thus, the alternator contains a diode rectifier circuit to convert the AC voltage to DC. The diode circuit is configured to output the rectified superposition of the 3-phase voltages induced across the coils.

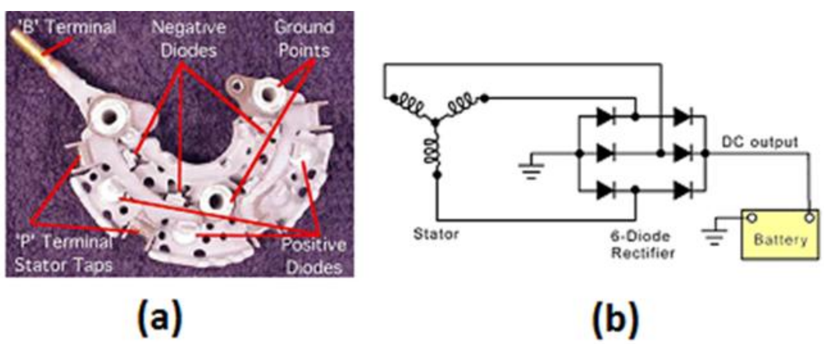


Figure 2-5: An Alternator's Diode-Rectifier Circuit for Wye-Configured Stator Coils [3]

The relationship between the induced voltage across the stator coils (in RMS), the number of windings of the stator coils, the rotational speed of the machine, and the flux exhibited by the rotating magnetic field of the rotor is given by the following equation:

$$E_{rms} \approx \left(\frac{1}{\sqrt{2}}\right)\omega_{me}k_w N_{ph}\varphi_p \qquad 2-1$$

E_{rms}
$\equiv$ ***line to neutral rms voltage produced by ac machine*** (V_{rms})
$\omega_{me} \equiv$ ***electrical frequancy*** (rad/sec)
$k_w \equiv$ ***stator widing factor***
$N_{ph} \equiv$ ***number of turn widings per phase on stator***
$\varphi_p \equiv$ ***air − gap flux per pole*** $[Wb]$

Equation 2-1 is valid for normal steady state conditions. Since the alternator in this project is tested under steady state conditions, Equation 2-1 is used to parameterize the original and modified alternator.

2.2 The Modified Generated Voltage Equation

Equation 2-1 was re-derived into a form that uses parameters that can be physically measured and calculated by Ervin Carrillo in the initial stages of this project [3]. The new form of Equation 2-1 is represented by the following equation:

$$E_{rms} \approx \left[\left(\frac{\sqrt{2}}{P}\right)\frac{\pi}{60}\frac{4\mu_0}{\pi g}2lr\right]\left[n_s k_w N_{ph} k_f N_f I_f\right] \qquad 2-2$$

E_{rms}
$\equiv$ ***line to neutral rms voltage produced by ac machine*** (V_{rms})
$P \equiv$ ***the number of poles of the machine***
$g \equiv$ ***air − gap length*** (m)
$l \equiv$ ***stator − core length*** (m)
$r \equiv$ ***rotor − radius to air − gap length*** (m)
$n_s \equiv$ ***machine speed*** (RPM)
$k_w \equiv$ ***stator − winding factor***
$N_{ph} \equiv$ ***number of stator winding turns***
$k_f \equiv$ ***rotor winding − factor***
$N_f \equiv$ ***number of rotor winding turns***
$I_f \equiv$ ***field winding current*** (A)

The orange values represent the constants and physical dimensions of the alternator [3]. The red value represents the operating speed of the machine. The purple values represent the stator parameters [3]. The green components represent the rotor values [3]. A summary of the parameters comprising Equation 2-2 is demonstrated by Table 1.

Table 2-1: Parameters of Equation 2-2 [3]

Output Phase-Voltage [V_{rms}]	Physical Dimensions	Rotational Input Speed [rpm]	Stator Parameters	Rotor Parameter
E_{rms}	$\left(\frac{\sqrt{2}}{poles}\right)\frac{\pi}{60}\frac{4\mu_0}{\pi g}2lr$	n_s	$k_w N_{ph}$	$k_f N_f I_f$

2.3 The Importance of Instructional Materials in the Third World

Without a doubt, the access to educational materials is vital in promoting change within communities. Education is essential to fostering the positive development of children, expanding ones horizons, inspiring innovation, and empowering individuals to explore their surroundings and search for the answers that will solve their immediate community needs. Thus, there is a strong educational undertone behind this project.

An exemplary example of how simple instructional materials impacted the lives of a rural community is demonstrated by the inspirational efforts of William Kamkwamba—the boy who harnessed the wind [4]. William was raised in an impoverished rural community located in Malawi, Africa. When he was approximately 14 years old, his village experienced a drought that caused a large famine, killing several of his neighbors and friends. At the time, William had dropped out of school because his family did not have the financial resources to support his education. Despite such a setback, William chose to search for

educational materials on his own and teach himself. One day, when he visited a village library, he stumbled upon a fifth grade science book titled *Using Energy* [4]. The book described how windmills are used to generate power and how they could also be used to pump water. After discovering this, William was inspired to build a windmill for his village to illuminate his community's homes and pump the water necessary to irrigate his drought stricken village [4].

William immediately went to work; using the materials he discovered at the library, he scavenged local scrap yards to gather the supplies he needed to develop his project [4]. After a couple months of searching, learning, and constructing, William fulfilled his hard-fought mission and completed his windmill. When presenting his creation to his village, as soon as the wind picked up, the car light he had connected to his system began to glow; the sign of a monumental success [4].

Inspired by Williams's story, this project carries the same approach; using scarp materials to fulfill the demands of the project. Furthermore, this project aims to equally encourage innovation by providing instructional materials to the public. It is incredible how such simple instructional guides could help change the lives of an entire community; and for that reason, we aim to continue the tradition by providing our knowledge to the world.

III. REQUIREMENTS AND SPECIFICATIONS

As previously mentioned, the primary objectives of this project are to retrofit a car alternator to generate power at low speeds and to develop a complementary tutorial that would be accessible via the internet. Since the project is intended for application in rural and impoverished communities, the objectives of this project must be accomplished using inexpensive materials in order to reduce the starting costs of implementing such a system. The average minimal cost of a low-speed generator is 100 dollars; however, the price of higher-quality low-speed generators may cost significantly higher, exceeding the budget that could be expended by a community in a developing country [3]. Thus, for the purposes of this project, a Toyota car alternator is purchased from a junkyard dealer. A Toyota car alternator is selected since the Toyota brand is one of the most commonly used brands across the world [5]. An Open-Circuit test is run on the purchased alternator to obtain its operating characteristics: its speed vs. induced voltage relationship. The Open-Circuit test is conducted in the Cal Poly SLO Power Electronics lab located in building 20, room 104.

After the machine is characterized, it is taken apart to measure the physical dimensions of its components: the stator's internal diameter (ID), the rotor's diameter, the stator's iron core length, the air-gap length, and the rotor's radius to air-gap length. The machine's stator is then taken apart to count its number of winding turns and measure its slot spacing, pole pitch, and the mechanical angle covered by a single stator coil; the stator values are computed to determine its winding factor and the amount of windings that may fit within its slots. The Open-Circuit test values and the measured physical dimensions are used with the modified generated voltage equation to

determine the unknown rotor parameters: the product of the rotor winding factor and the number of rotor windings $\boldsymbol{k_f N_f}$.

With all the determined machine parameters, the modified generated voltage equation is manipulated to determine the number of stator winding turns required for the machine to generate power at low speeds. The speed range desired is 200-350 RPM; such a range is suitable for wind or hydro power generation. Therefore, the machine should output an average of 12VDC at a speed falling within the specified range.

The stator is then wound to the number of turns computed in the previous step. To rewind the stator, 22-gauge wire rated at 7 amps is used; 22-gauge wire is used since it is the smallest sized wire that can handle at least 5 amps [2]. Amperage of 5 amps is selected since the alternator should produce at least 60 Watts at 12VDC. Once wound, the stator is remounted to the alternator for testing. An Open-Circuit test is run on the modified machine to verify its operating characteristics.

Every step of the process is documented to develop an instructional video that will be accessible online. The purpose of the video is intended to reach communities across the world seeking to investigate alternative low-cost methods to meet their power needs. The generator developed for this project may meet the minimal electrification needs of a rural home.

IV. DESIGN

In order to acquire the design parameters of the machine, the alternator must be characterized via an Open-Circuit test and then disassembled to measure its internal physical dimensions. The values determined by both processes are used to determine the number of stator windings required for the machine to generate 12VDC within a speed range of 200-350RPM.

4.1 The Open-Circuit Test

Figure 4-1 demonstrates the set-up diagram for the alternator Open-Circuit test. A Baldor DC Motor is coupled to the alternator to simulate the speed produced by the car's engine; the DC motor behaves as the prime mover of the machine. It must be noted that in order to couple the DC motor to the alternator, the alternator's pulley must be removed. Appendix A demonstrates the method used to remove the alternator's driver pulley. The Adjustable Speed Drive (ASD) controls the speed of the DC motor; the ASD is set to the alternator's rated speed of 1800rpm (60Hz). A potentiometer (rated at 100Ω, 3A) is connected to the field pins of the alternator to control its field current. A power supply set to 12VDC is connected across the ends of the potentiometer; the supply acts as the DC source needed to magnetize the rotor's field winding.

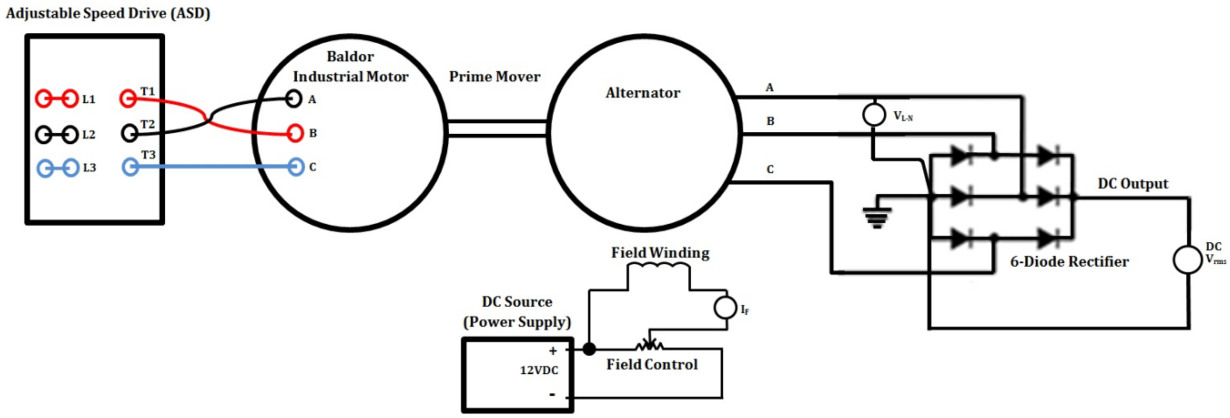


Figure 4-1 : Alternator Set-up Diagram for the Open-Circuit Test

To determine the Open-Circuit values, the rotor's field current is gradually increased until reaching the alternator's rated DC output voltage of 12 volts. The stator phase-voltage, stator line-voltage, machine's DC output voltage, and rotor's field current are all measured using digital multi-meters configured as shown in Figure 4-3.

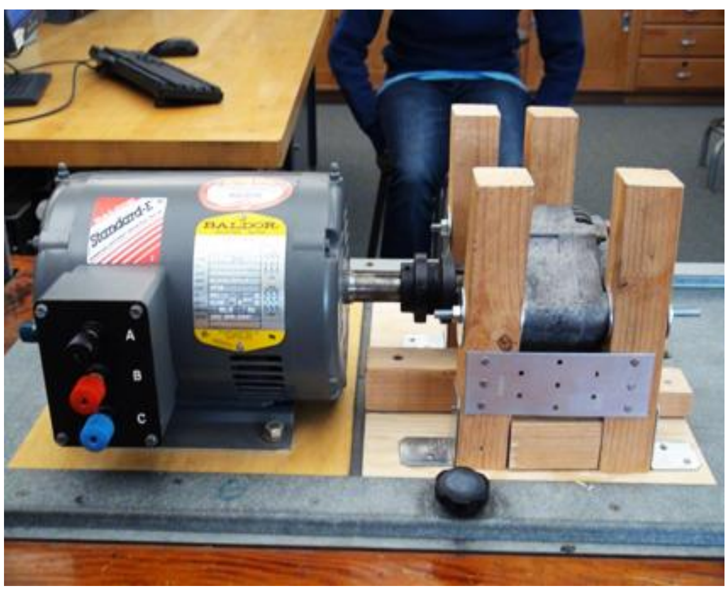


Figure 4-2: Baldor Motor coupled with Alternator

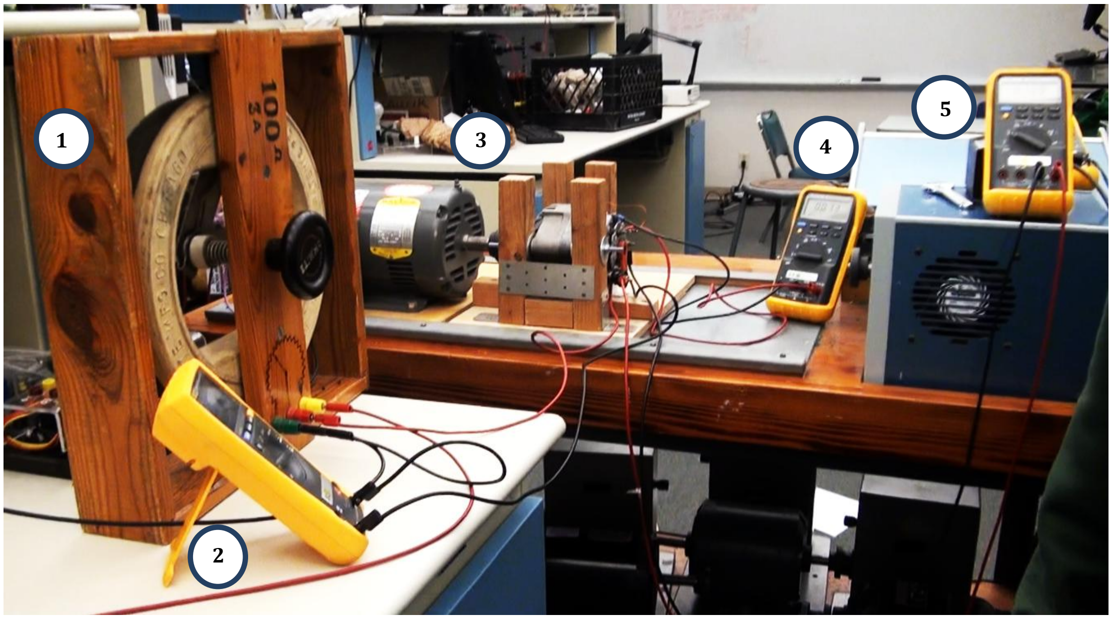


Figure 4-3: Open-Circuit Test Set-up: 1. field-current control Potentiometer; 2. DMM measuring field-current; 3. coupled Bolder-Motor with Alternator; 4; DMM measuring Phase-Voltage; 5. DMM measuring DC output voltage

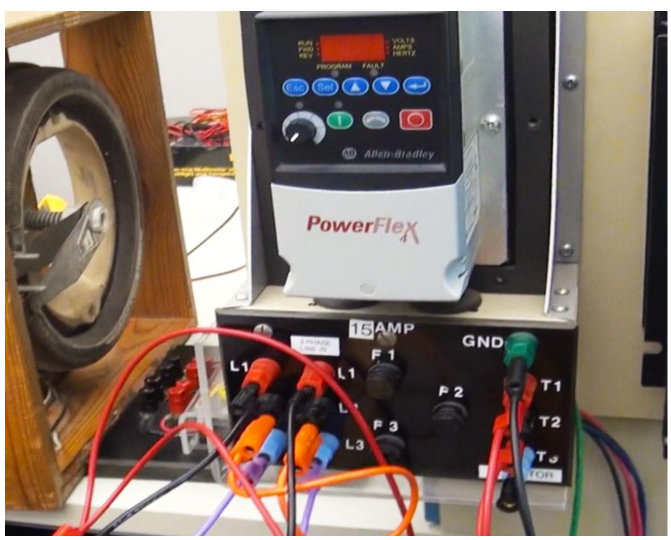


Figure 4-4: ASD Configuration

Table 4-1: Open-Circuit Test Results

I_f [A]	V_{L-L} [V]	V_{PH} [V]	$V_{out\ (DC)}$ [V]
0.123	0.921	0.53174	0.902
0.133	1.504	0.868335	1.718
0.17	1.952	1.126988	2.356
0.219	2.484	1.434138	3.12
0.263	2.952	1.704338	3.78
0.323	3.558	2.054212	4.66
0.374	4.23	2.442192	5.58
0.425	4.85	2.800149	6.42
0.473	5.38	3.106144	7.28
0.535	6.07	3.504516	8.22
0.641	7.16	4.133828	9.74
0.687	7.85	4.5322	10.71
0.745	8.44	4.872836	11.56
0.792	**8.82**	**5.092229**	**12.13**
0.862	9.56	5.519469	13.1
0.889	10.26	5.923614	13.93
0.955	10.62	6.13146	14.63
1.063	11.36	6.558699	15.67
1.332	13.7	7.909699	18.95

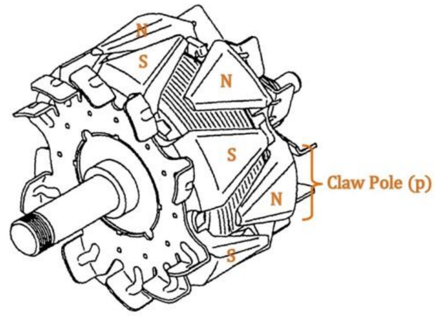
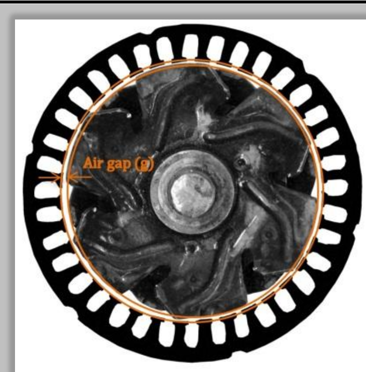
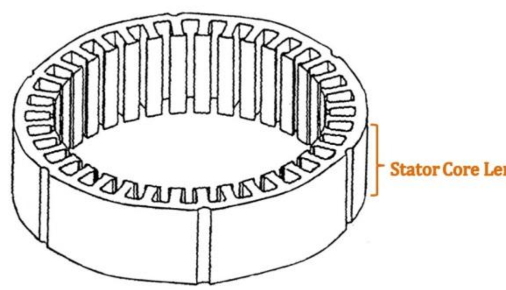
**Bolded values indicate results at rated field-current, 12VDC output.*

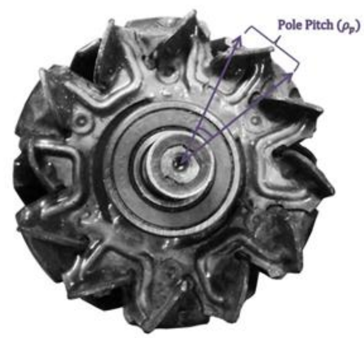
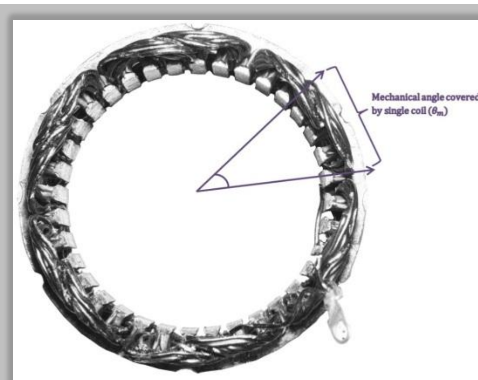
From the Open-Circuit Test, we determined that our rated field current (I_f) is approximately 0.792A; this is the current at which our machine outputs 12 volts DC.

4.2 Physical Dimensions of Alternator Components

Table 4-2 demonstrates the physical dimensions of the alternator components. Length measurements are conducted with a standard centimeter ruler and angular measurements are taken with a basic protractor. For an in-depth understanding of each parameter, please refer to *Equating a Car Alternator with the Generated Voltage Equation,* by Ervin Carrillo [3].

Table 4-2: Physical Dimensions of Alternator Components [3]

$Poles\ (P)$	12	
$Air - gap\ (g)$	$0.00125m$	
$Stator\ Length\ (l)$	$0.0258m$	

Rotor Radius to Air − Gap (r)	**0.0435*m***	
Pole Pitch (ρ_p)	**30°**	
angle of single coil (θ_m)	**20°**	

$\mathbf{4.3}$ Stator Parameters

Using the stator pole pitch and the mechanical angle spanned by a single stator coil (demonstrated in Table 4-2), the stator's winding factor is determined to be $\boldsymbol{k_w = k_p k_d \approx 0.866}$ [3].

To obtain the machine's number of stator windings per-phase, the windings are meticulously taken apart and counted one-by-one as they are removed from the stator slots. Appendix C demonstrates the method we used to remove the windings. We determined that our stator contained approximately 42 windings per phase [3].

4.4 Rotor Parameters

Having determined all the alternator's measurable parameters, Equation 2-2 is rearranged to solve for the $\boldsymbol{k_f N_f}$ product—the multiple of the rotor's winding factor and number of turns:

$$k_f N_f \approx \frac{E_{rms}}{\left[\left(\frac{\sqrt{2}}{poles}\right)\frac{\pi}{60}\frac{4\mu_0}{\pi g}2lr\right]\left[n_s k_w N_{ph} I_f\right]} \qquad \mathbf{4-1}$$

The $\boldsymbol{k_f N_f}$ product is evaluated for the different field current values acquired from the Open-Circuit test, as demonstrated in Table 4-3. The average of the $\boldsymbol{k_f N_f}$ product values are taken to determine the rotor constant.

$$k_f N_f \approx 5538$$

Table 4-3: $k_f N_f$ product computations using Open-Circuit Test [3]

I_f [A]	V_{L-L} [V]	E_{PH} [V]	$V_{out(DC)}$ [V]	$K_f N_f$
0.133	1.504	0.868335	1.718	5592.143
0.17	1.952	1.126988	2.356	5678.23
0.219	2.484	1.434138	3.12	5609.053
0.263	2.952	1.704338	3.78	5550.635
0.323	3.558	2.054212	4.66	5447.353
0.374	4.23	2.442192	5.58	5593.077
0.425	4.85	2.800149	6.42	5643.322
0.473	5.38	3.106144	7.28	5624.75
0.535	6.07	3.504516	8.22	5610.699
0.641	7.16	4.133828	9.74	5523.789
0.687	7.85	4.5322	10.71	5650.605
0.745	8.44	4.872836	11.56	5602.324
0.792	8.82	5.092229	12.13	5507.132
0.862	9.56	5.519469	13.1	5484.445
0.889	10.26	5.923614	13.93	5707.26
0.955	10.62	6.13146	14.63	5499.247
1.063	11.36	6.558699	15.67	5284.783

4.5 Design Parameters

The lower limit of the suitable speed range for wind or hydro power generation is selected to determine the new stator parameter; 200rpm. Equation 2-2 is rearranged to solve for the number of stator windings per-phase required for the new rpm condition:

$$N_{ph} \approx \frac{E_{rms}}{\left[\left(\frac{\sqrt{2}}{poles}\right)\frac{\pi}{60}\frac{4\mu_0}{\pi g}2lr\right]\left[n_s k_w k_f N_f I_f\right]} \quad 4-2$$

The phase-voltage and rated field-current at 12VDC output acquired from the Open-Circuit test are used to solve for the stator design parameter, as demonstrated in Table 4-4.

Table 4-4 : Phase-Voltage at 12VDC output [3]

E_{PH} [V]	I_F[A]	$V_{out(DC)}$ [V]
5.0922294	0.792	12.13

The following computation is taken to solve for N_{ph}:

$$N_{ph} \approx \frac{5.09\mathrm{V}}{\left[\left(\frac{\sqrt{2}}{12}\right)\frac{\pi}{60}\frac{4\mu_0}{\pi(0.00125m)}2(0.025832m)(0.0435m)\right][(200rpm)(0.87)(5538)(0.792A)]} \approx 376$$

Therefore, our stator requires 376 windings per-phase to output 12VDC at 200rpm.

The stator windings are to be distributed across the 36 slots of the stator, separated into 6-bundles of roughly 63 turns. The stator coils are wound to assure that the three phases are electrically $120°$ apart from each other. To assure this, the design is based on the original configuration of the stator windings, with the new windings entering from the same slots the original windings entered from, and exiting from the same slots the original windings exited from.

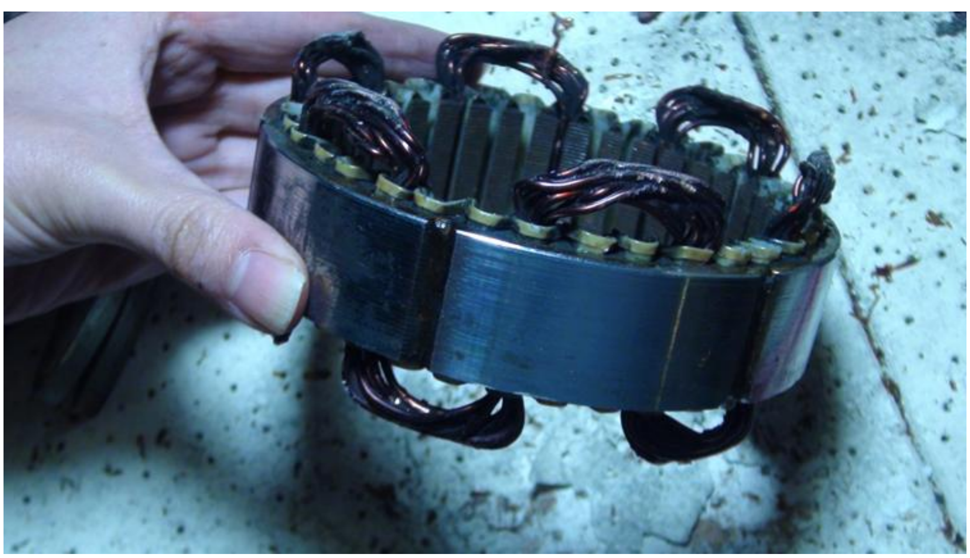


Figure 4-5 : Single-phase configuration of Stator Winding

V. CONSTRUCTION

5.1 Stator-Slot Dimension Constraints

Prior to winding the stator, the stator-slot dimensions are measured to approximate the number of windings that can physically fit within the slots; the computation is based on the gauge requirement discussed in Chapter III. The dimensions are measured using a standard centimeter ruler.

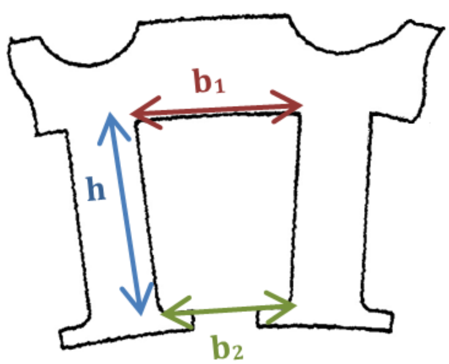


Figure 5-1: Single-Stator Slot; h-height, b_1-bottom base; b_2-top base

Table 5-1: Stator-Slot Dimensions

h (m)	b_1 (m)	b_2 (m)
0.009	0.004	0.001

Since the slots roughly exhibit a trapezoidal shape, the slot-area is computed using the area formula for a trapezoid:

$$A = \frac{1}{2}(b_1 + b_2) \cdot h \qquad 5-1$$

The following computation is taken to solve for the stator-slot area:

$$A = \frac{1}{2}(0.004m + 0.001m) \cdot 0.009m = 2.25 \times 10^{-5} m^2$$

Based on the American Wire Gauge Standards, the area of a 22-guage wire is $\mathbf{0.326mm^2}$ which is equivalent is to $\mathbf{3.26 \times 10^{-7}m^2}$ [2]. To determine the number of 22-gauge windings ($\boldsymbol{N}$) that can fit within the slot area, the slot area is divided by the wire area as follows:

$$\boldsymbol{N = \frac{A_{slot}}{A_{wire}} = \frac{2.25 \times 10^{-5}m^2}{3.26 \times 10^{-7}m^2} \approx 69\ turns} \quad \mathbf{5-2}$$

Accordingly, a 63-turn coil should theoretically fit within the stator's slots. Test coils are prepared to verify the computed assumption.

After attempting to wind the test coils on the stator using the design parameter, we realized that it was impossible to fit three sets of 63-turn bundles (one for each phase) within the stator slots without forcing the last 15 or so wires in and scratching the insulation of the wire. The error could be due to the approximation of the area of the slot. Furthermore, the additional spacing caused by the bundling of the wires was not considered in the calculation. After some trial and error, we determined that the best turn value for the distributed coils is 40 turns per bundle.

Figure 5-2 : Test-Bundle consisting of 40 turns

Due to the aforementioned discovery, our stator design parameter lowered to 240 turns per-phase. Given this change, Equation 2-2 is rearranged to solve for the operating speed correlating the new turn parameter:

$$n_s \approx \frac{E_{rms}}{\left[\left(\frac{\sqrt{2}}{poles}\right)\frac{\pi}{60}\frac{4\mu_0}{\pi g}2lr\right]\left[k_w N_{ph} k_f N_f I_f\right]} \qquad 5-3$$

$$n_s \approx \frac{5.09}{\left[\left(\frac{\sqrt{2}}{12}\right)\frac{\pi}{60}\frac{4\mu_0}{\pi(0.00125m)}2(0.0258m)(0.0453m)\right]\left[(0.87)(240)(5539)(0.792A)\right]} = 313.209rpm$$

Therefore, our alternator is physically constrained to generate 12VDC at speeds that are no lower than 313.2 rpm.

5.1 Stator-Winding Construction

To build the coil bundles for each phase, a coil-wrapping tool is constructed with electrical tape and scrap PVC pipes that were found within a pile of abandoned building materials. The circumference of the combined PVC pipes approximates the inner circumference of the test-coil (108 mm). The pipes are wrapped together with electrical tape, as shown in Figure 5-3.

Figure 5-3 : Combined PVC-pipe fixture

The combined pipes are marked with a permanent marker every 2 inches (50.8mm) for drilling.

Figure 5-4 : Drilling Holes into PVC-pipe fixture

Holes are drilled on each marking to insert nails into them; the nails are used as separators to assure that each bundle is appropriately separated and spaced. A battery powered drill is used to make the holes for sake of time; however, other non-electrically powered tools

could be used to create the necessary holes, such as a sharp carpenter's awl or a screw driver with a sheet metal screw.

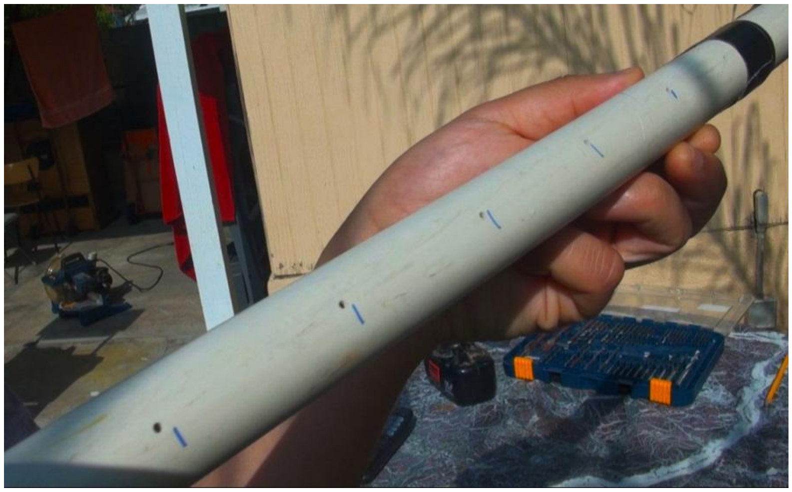


Figure 5-5 : PVC pipe-fixture with Drilled Holes

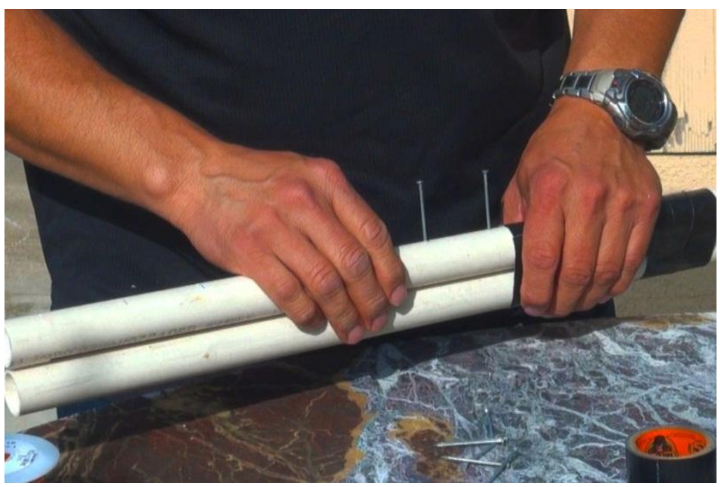


Figure 5-6 : Inserting Nails into PVC-pipe fixture

Once the pipe fixture is constructed, cooper coil is meticulously wrapped around the fixture to shape the bundles. The coils are wrapped tight enough to create a nice bundle shape, but loose enough to be able to slide the completed bundles off the pipe with ease. The coil-wrapping is conducted with two people; one person holds the copper-wire and assures that

the wire is slightly taut, while the second person twists the PVC-pipe. The person holding the copper-wire counts the turns as the spinner wraps. A pictorial demonstration of the wrapping technique is depicted in Figures 5-8 and 5-9.

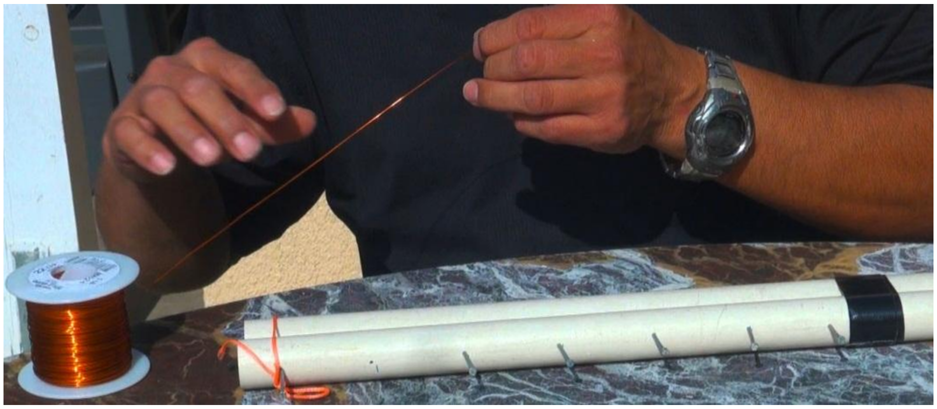


Figure 5-7 : Cooper Wire being prepared for Wrapping

Figure 5-8 : Wrapping Copper Coil around PVC-pipe fixture

Upon the completion of each bundle, about 1.5 inches (38.1mm) of wire is wrapped around the separator nails; this is the approximate length separation of each bundle.

Figure 5-9 : Two sets of Coil-bundles complete

Figure 5-10 : Single-Phase Coil Bundles (6 Bundles per-phase)

Once all the bundles are made, string is tied around each bundle to assure that they maintain their shape as they are slid off the pipe fixture. As demonstrated in Figures 5-12 and 5-13, the bundles are carefully pushed out of the pipe to prevent bundle overlapping and deformation.

Figure 5-11 : Tying string around Bundles

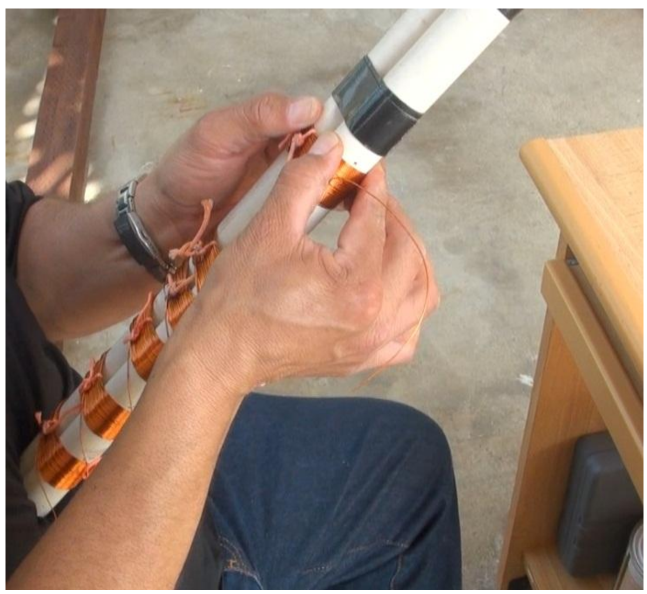


Figure 5-12 : Sliding Bundles off from PVC-pipe fixture (1)

Figure 5-13 : Sliding Bundles off from PVC-pipe fixture (2)

The bundles are carefully held and gently slid into the stator-slots as shown in Figures 5-14 and 5-15. It must be noted that—though not shown—chop-sticks are used to help guide the wires into the stator slots. Figure 5-16 shows the completed product developed from the aforementioned process.

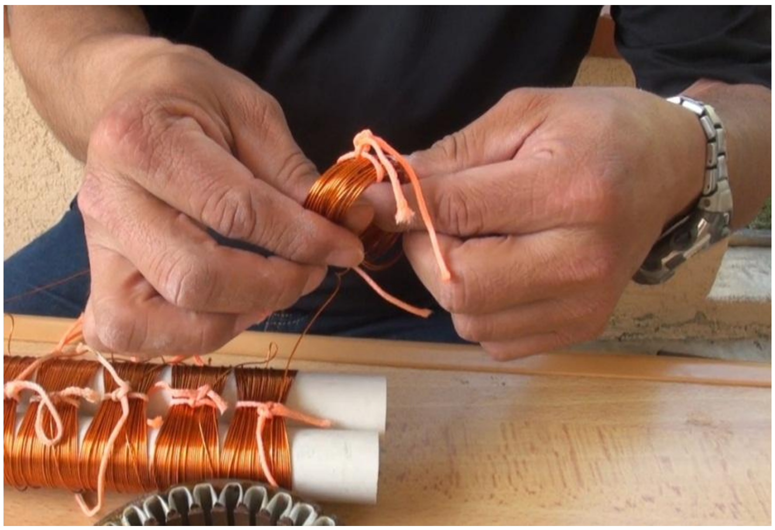


Figure 5-14 : Gently holding single Bundle

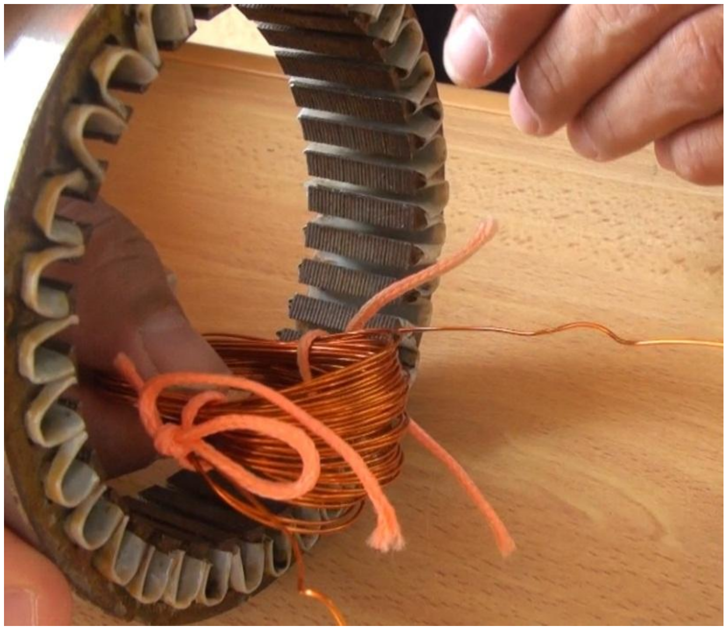


Figure 5-15 : Carefully inserting bundle into Stator-Slots

Figure 5-16 : Completed Re-Wound Stator

To add the finishing touches, a coat of varnish is applied to the coils in order to reinforce its insulation and essentially glue the windings together; this assures that the windings will not jut out off the slots.

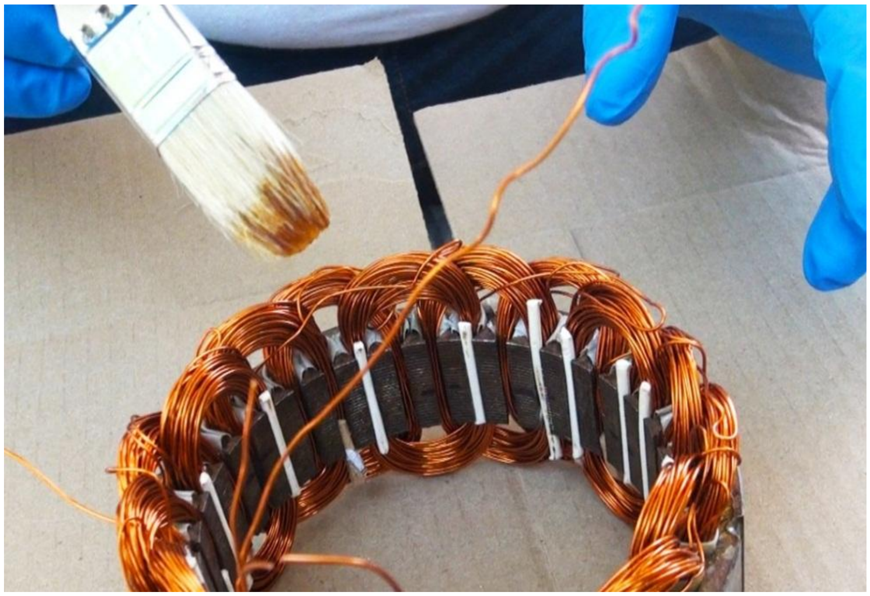


Figure 5-17 : Applying Varnish on Stator Coils

VI. TESTING

To test the alternator with the re-wound stator, an Open-Circuit test is conducted to determine its output characteristics at the determined speed of 313.2 rpms (10.2Hz). The same procedure and set-up used in the preliminary Open-Circuit Test (demonstrated in Chapter IV) is repeated to conduct the test. The results of the test are shown in Table 6-1. It must be noted that the machine was ran for a couple of minutes to allow for rotor-magnetization and stator voltage pick-up; values obtained prior to proper magnetization were unstable and thus not computed.

Table 6-1: Open-Circuit Test Values of Modified Alternator

If [A]	VL-L [V]	VPH [V]	Vout (DC) [V]
0	0.356976	0.2061	0.38
0.06	0.573309	0.331	0.53
0.103	0.732657	0.423	0.65
0.152	0.926647	0.535	0.9
0.2	1.087728	0.628	1.22
0.251	1.24188	0.717	1.38
0.301	1.389105	0.802	1.75
0.353	1.544989	0.892	1.92
0.402	1.687017	0.974	2.08
0.453	1.825582	1.054	2.27
0.502	1.962414	1.133	2.85
0.551	2.107906	1.217	3.12
0.602	2.223953	1.284	3.42
0.656	2.338269	1.35	3.64
0.708	2.462976	1.422	4.22
0.743	2.537454	1.465	4.84
0.796	**2.622325**	**1.514**	**5.79**
0.874	2.823243	1.63	6.07
0.926	2.915042	1.683	6.25
0.956	2.977395	1.719	6.66
1.009	3.008572	1.737	7.05

**Bolded Values indicate results at approximately rated field-current*

As indicated by the results, at approximately the rated field-current (I_F=0.796A), our induced open-circuit DC voltage is 5.79V. This is roughly half of the voltage that we desired to obtain (12VDC). Several reasons could be attributed to such error including, but not limited to: human-error during construction, approximations made when evaluating the machine parameters (primarily the $\boldsymbol{k_f N_f}$ product), the usage of an ideal equation that is also based on approximations, the usage of an old alternator, and the physical machine constraints.

To determine the speed at which the modified alternator produces 12VDC, the frequency on the ASD is adjusted until the volt-meter across the machine DC output read 12V. The field-current is maintained constant at its rated value (0.792A) during this procedure. It is determined that at a speed of 813.7 rpm (26.7Hz), the machine produced 12VDC. The Open-Circuit Characteristics of the machine are re-evaluated using this speed and shown in Table 6-2.

Table 6-2: Open-Circuit Test at a Speed of 813.7 rpm

If [A]	VL-L [V]	VPH [V]	Vout(DC) [V]
0	0.550792	0.318	0.51
0.062	0.914523	0.528	0.78
0.102	1.09812	0.634	1.16
1.51	1.330215	0.768	1.75
0.2	1.593487	0.92	2.28
0.254	1.827314	1.055	3.01
0.307	2.073265	1.197	3.67
0.353	2.417943	1.396	4.44
0.406	2.494153	1.44	5.41
0.452	2.78687	1.609	6.09
0.508	3.076122	1.776	7.5
0.551	3.186973	1.84	8.56
0.603	3.367107	1.944	9.34
0.655	3.557632	2.054	10.12
0.711	3.775871	2.18	11.19
0.774	4.08764	2.36	11.8
0.812	**4.264309**	**2.462**	**12.22**
0.863	4.486012	2.59	12.54
0.9	4.641896	2.68	13.11
0.95	4.896508	2.827	13.3
1.1	4.98311	2.877	13.58

**Bolded values indicate results at approximately rated field-current*

VII. CONCLUSIONS AND RECOMMENDATIONS

Despite the fact that our machine did not output 12VDC at the predetermined speed of 313.2 rpm, we did manage to reduce its operating rpm by a little more than half of its original operating speed; from 1800 rpm to 813.7 rpm. These results demonstrate that our methods to reduce the operating rpm of an alternator correlate with our assumptions; despite their accuracy. The issue behind the inaccuracy of our results may lie in the computed number of windings used for our design. The generated voltage equation is based on approximations and is only valid for ideal steady-state conditions. Such approximations might have contributed to our computational error. Human-error could also be a cause of our inaccurate results; we built and re-wound the machine by hand, leading to discrepancies in bundle sizes, our inability to fit the originally computed number of stator windings into the stator slots and other intermittent errors. Furthermore, perhaps our biggest source of error lies within our calculation of the unknown rotor values $\boldsymbol{k_f N_f}$. The constant used was an average of approximated values; thus its degree of inaccuracy may be higher than anticipated.

Though we only achieved an open-circuit voltage of 5.79VDC, this does not signify that our machine cannot be used for power generation. Due to time-constraints and a short-circuit fault, we were unable to run load, short circuit, and torque tests on our machine. The aforementioned tests are the key indicators of an operable machine and entail whether a machine is worthy to use for power generation. Thus, it is recommended to the person carrying on this project to conduct the listed tests to verify the operation of the machine. Further mathematical analysis is also recommended to achieve a more accurate mathematical model than that entailed by Equation 2-2. A correlation between the original

and modified machine's rotor constants should be determined to better compute the number of stator windings required for low-speed wind or hydro generation.

VIII. BIBLIOGRAPHY

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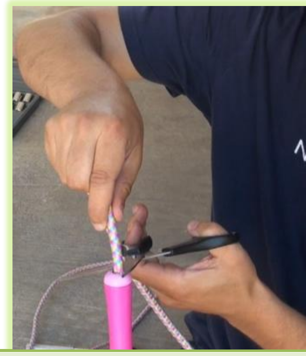
APPENDIX A

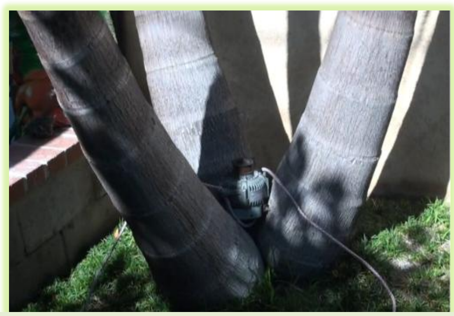
The following steps are taken to remove the alternator's drive pulley:

Step 1: Cut the handles of a jump-rope using a pair of scissors.



Step 2: Insert rope through the alternator's chassis holes.

Step 3: Rest the alternator between sturdy tree trunks.



Step 4: Tie the alternator around the tree trunks.

Step 5: Place socket wrench on the pulley nut. Place a Philips screw driver through the alternator chassis and stator to assure that stator does not move.

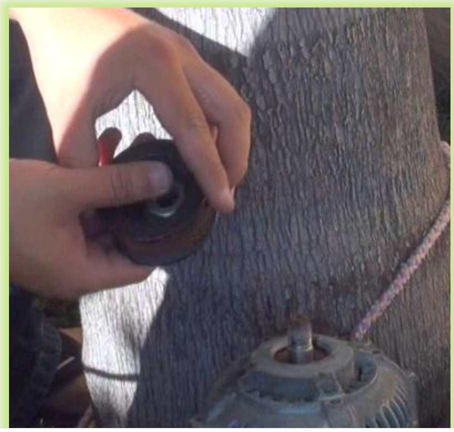
Step 6: Attach a long hollow scrap metal tube to the end of the wrench's handle to extend the lever arm of the wrench.

Step 7: Upon pulling the lever handle, place weight with your body on the alternator to assure it stays in place and to garner the strength to maneuver the lever handle.

Step 8: Loosen pulley nut by moving lever to the left.

Step 9: Once the nut is loos, remove the nut with your hands.

By following these steps, you may successfully detach the driver pulley from your alternator without the use of power tools.



Mission Accomplished!

APPENDIX B

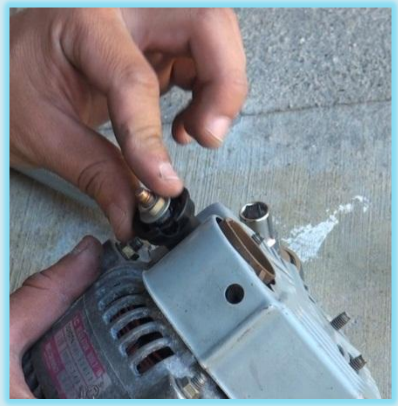
The following steps are taken to disassemble the car alternator:

Step 1: Using a socket-wrench, loosen the 3 nuts on the back panel of the alternator. These nuts attach the diode-rectifier circuit to the machine.

Step 2: Once back nuts are loose, remove nuts with hand.

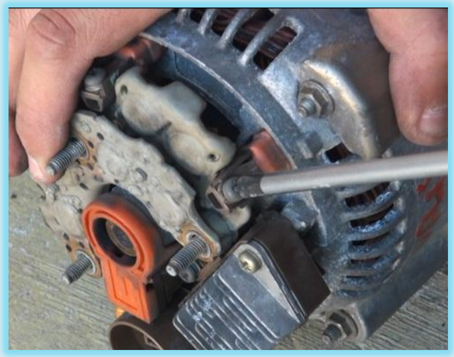
Step 3: Using socket wrench, loosen the nut of the DC-output terminal.

Step 4: Once the DC output nut is loose, remove nut with hand.



Step 5: Use a flat-head screw driver to pry out back panel casing of the machine.

Step 6: Unscrew the stator-winding screws using a Philips-head screw driver.



Step 7: With socket wrench, loosen the nuts holding the chassis plates in place.

Step 8: Once chassis nuts are loose, remove with hand.

Step 9: Pick up the alternator and gently tap on a hard surface to separate the top and bottom chassis plates.

Step 10: Separate top half of alternator from the bottom half.

Step 11: Using socket wrench, unscrew the bolts attaching the stator to the chassis plate.

Step 12: Use a chisel and a hammer to gently tap stator off from the chassis plate.

Step 13: Continue taping until stator comes out.

APPENDIX C

The following steps are taken to remove the stator windings from a stator:

Step 1: Rest stator on a cinder block.

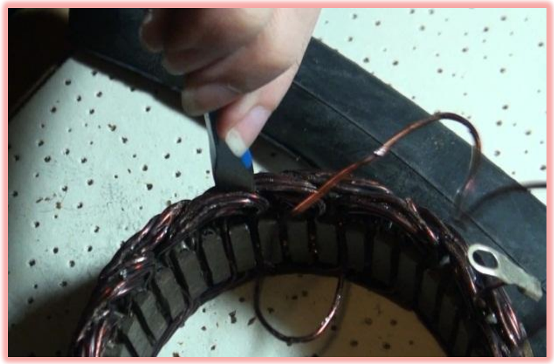
Step 2: Clamp the stator on the cinder block by wrapping old bicycle tubes around it. Make sure to tighten the tubes firmly to assure that the stator will stay in place.

Step 3: Using a chisel and a hammer, tap the stator pegs off the stator slots.

Step 3 *continued:* Continue hammering off the pegs until all 36 stator pegs are removed.

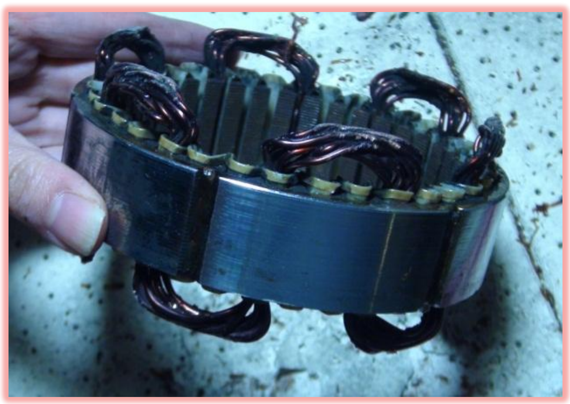
Step 4: Using a flat-head chisel and a hammer, separate adhesively bonded stator windings by hammering in between their grooves.

Step 4 *continued:* Continue hammering until breaking adhesive bonds.



Step 5: Once the stator windings are loose, use a plier to carefully pull out the wire from the stator slots. Make sure to keep track of the winding count for computational purposes.

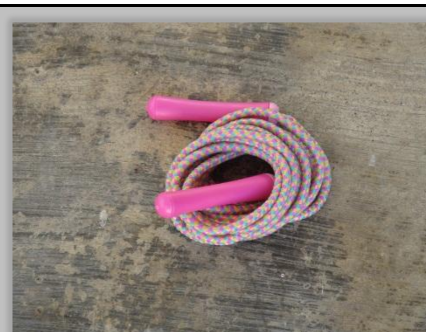
Step 6: Execute all the previous steps for each phase winding.



The end result.

APPENDIX D

Parts	Cost [$]
Car Alternator	**30**
22 gauge wire	24
Can of Varnish	10
Total	64

Materials Used (Scrap or Borrowed)	
Jump rope	
#2x4 Philips-head Screw Driver	

A pair of scissors

Socket-Wrench

- **Y-crV 22mm head**
- **10mm head**
- **5/16 head**
- **32T0 High Performance Adapter**

Hollow Metal Tube (39.625 in long)

Old Flat-head screw driver

Hammer	
Chisel	
2 PVC Pipes	