DEVELOPMENT AND ANALYSIS OF THE LOW TORQUE GENERATOR FOR HIGH EFFICIENCY APPLICATIONS

By

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This effort presents a novel design for a generator, named the low torque generator, as a device introduced for new applications. The main differences between the conventional generators and the low torque generator is the way the stator and rotor are intentionally aligned for producing different results. Also the materials used on the construction of both generators differ. Various prototypes where developed for testing the concept as an achievable product. One of the final prototypes was used to present all the details in this work and the concept of generation proposed on this work was recorded as experimentally achievable.

Resumen de Tesis Presentado a Escuela Graduada
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Requerimientos para el grado de Maestría en Ciencias

DESAROLLO Y ANALISIS DEL GENERADOR DE BAJO TORQUE PARA APLICACIONES DE ALTA EFICIENCIA

Por
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Julio 2016

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Este esfuerzo presenta un diseño novel de generador, llamado el generador de bajo torque, como un dispositivo introducido para aplicaciones nuevas. Entre las diferencias mayores entre el generador convencional y el de bajo torque se encuentran la manera en la cual el estator y el rotor están alineados intencionalmente para producir resultados diferentes y también los materiales utilizados en la construcción de los dos generadores. Varios prototipos fueron desarrollados para probar el concepto como un producto viable. Uno de los prototipos finales fue utilizado para presentar todos los detalles en este trabajo y el concepto de generación propuesto en este trabajo fue evidenciado como algo alcanzable experimentalmente.

To my wife Lorraine and daughter Victoria since they are the responsible for giving me the love, joy and energy to move forward.

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Table of Contents

Chapter 1: Introduction

Electric energy is an essential part of our modern society and the main device that is responsible for it's production is called the generator. Until now the main purpose of several systems that have been developed regarding this device has been to find new methods to put a conventional generator in movement by any type of mechanical energy sources. These sources include but are not limited to fossil fuels, nuclear energy, wind energy and hydroelectric energy. These four sources have in common that we make use of mechanical energy generated by them and they are connected on their specific outputs to a conventional generator for the electrical energy production [4]. The purpose of this work is to explore a new type of electric generator that seems to be a possible candidate to help our society in the current energy generation needs.

The Low Torque Generator (LTG) that is being presented on this work has the capacity of producing electrical energy without the same mechanical steady state torque reaction that characterizes the current conventional generators. On the following pages all the phases of development for this new technology are going to be addressed with the final experimental results up to this point. This work can be expanded to additional devices using the same principle that can lead us to newer electrical generation technologies.

1.1 Motivations

Vehicles are necessary artifacts to the proper functionality of our current society. One of my personal goals is to be able of doing an electric car that could be accessible and capable of performing the same or better than a conventional gasoline car. In order to have a practical and affordable car and thereby achieving this goal, new technologies regarding electric generation and storage need to be developed. One of the major challenges to achieve this goal is the power needed for a conventional car which is high to work properly. We can compare such need for power as high in a car as the same amount of energy needed to power various homes. Mechanical torque is fundamental for car operation in general and by making any significant change to it, it will cause an important impact to the overall car system. This Low Torque Generator work focus on the capacity of electric generation with minimum steady state torque and it could make a significant impact on existing electric car technology and the conventional electric power generation, since both applications have mechanical energy as the main input.

1.2 Thesis Organization

This thesis is organized the following way: Chapter 2 reviews the literature regarding conventional electric generators operation, and the proposed Low Torque Generator is introduced. Chapter 3 deals with the scientific theory and analysis regarding the Low Torque Generator operation. Chapter 4 shows the simulations and experimental results regarding the Low Torque Generator. Chapter 5 concludes the Low Torque Generator initial research and proposes future work that could take place as a result of the findings of this effort.

Chapter 2: Theory of Operation for Conventional Generators and the LTG

This chapter consists on a brief history of the conventional generator development and the technical aspects when it is operating. After the conventional generator has been addressed, the Low Torque Generator (LTG) will be introduced showing the main technical differences between both devices. The research findings are used to support theoretical aspects of its functionality and the beginning of additional bases that will serve as a foundation for additional study related to the area of electric generation.

2.1 Literature Review of Generator Technology

The foundations of an electric generator technology started by the initial work done by Faraday on August 1831 [5]. In terms of existing generator technologies, I will like to reference three different generators known from history as the Homopolar Generator, Dynamo and Alternating Current Generator. The first generator prototype was conceived by Faraday on 1831-1832 and was known as the Faraday Disc [6]. What makes a generator different from other devices that generate electricity is that they work on the principle of a change in magnetic flux inducing a voltage that once loaded induces a current thru the load that becomes electric power.

Years after the Faraday Disc was discovered; the Dynamo started to be developed. The Dynamo is also known as the first Direct Current generator invented for large scale electric generation [7][11]. Around 1880's, Thomas Edison was able of designing a new dynamo that was capable of achieving efficiencies in excess of 90 percent [11]. His first successful dynamos produced about five kilowatts [11]. In 1881, the "Jumbo" dynamo, which he shipped to the Paris electric exhibition, produced approximately 120 kilowatts [11].

After the development of the dynamo, Nikola Tesla invented a practical induction motor in the late 1880's [11]. Alternating current could be simply transformed from low to high voltage and from high to low, and at high voltage it could be transmitted over long distance with lower loss than DC systems [11]. Westinghouse built ten two-phase, 25-Hz alternating current dynamos based on several Tesla patents for the initial Niagara power station; two were installed in 1895, the final one in 1900 [11]. Each one was rated at 5000 horsepower. Electricity was transmitted at the generated 2200 volts to local industrial plants and at 11,000 volts (converted to three phase) to Buffalo [11]. An interesting fact is that all of these technologies of generators are still being used by our modern society.

The basis of operation for the conventional generator is due to the change in magnetic flux effect on the induction of an electromotive force that is capable of generating an electric current when connected to an electrical load. The physics law that explains this phenomenon is called the Faraday's Law and the statement concept is as follows: "the induced electromotive force (emf), V_{emf} (in volts), in any closed circuit is equal to the time rate of change of the magnetic flux linkage by the circuit. The equation that describes this phenomenon is,

$$V_{emf} = -N\frac{d\Phi}{dt}$$

$\lambda = d\Phi$ is the flux linkage, N is the number of turns in the circuit, and Φ is the flux through each turn [1][2]. The negative sign shows that the induced voltage acts in such a way as to oppose the flux producing it [1][2]. This is known as Lenz's law, and it emphasizes that the direction of current flow in the circuit is such that the induced magnetic field produced by the induced voltage will oppose the change in original magnetic field [1][2]." Conventional generators and the LTG both work on same laws expressed above; the main difference occurs when we consider the Lorentz equation that still governs the actual operation of conventional generators. The definition of the Lorentz equation is the following: if a particle of charge q moves with velocity **v** in the presence of both magnetic field **B** and an electric field **E**, it will feel a force,

$$\mathbf{F} = q(\mathbf{E} + \mathbf{v} \times \mathbf{B})$$

and it is considered as one of the basic equations in physics [2]. The equation above shows the relations between force and magnetic fields that eventually relates to torque when we generate electric currents from magnetic fields. In other words, conventional generators have no issues regarding the induction of an electromotive force; the problem begins when you produce a current as a result of the electromotive force generated which in consequence creates an opposing torque to the rotor of the conventional generator. To deal with this phenomenon, additional mechanical energy is needed in order to overcome this steady state opposing torque and to keep the conventional generator in rotational movement. The LTG work shows a new machine that is capable of reducing this steady state opposing torque so significantly that the experimental results regarding this opposing torque are negligible. The theory that supports the LTG experimental results will be explained in the following chapter.

2.2 Hypothesis of the LTG Device

The LTG is a novel device that could ignite a new approach of thinking regarding to electric generators. An Internet article regarding conventional generators technology expresses the following: "The majority of electrical machines (motors and generators) sold today are still based on the Lorentz force and their principle of operation [3]". The device that is being proposed is an electrical machine that has a new design approach since the way it produces electric energy reduces significantly the interaction of the magnetic fields always present in electrical machines. This machine can generate electricity from low power mechanical sources since the power on a mechanical system is related to the following equation:

$$P = T \cdot \omega$$

In which, T means the developed torque and the ω means rotational speed of the mechanical system. The proposed machine seems to have more benefit when we increase the rotational speed without needing to increase the mechanical torque because of the design configuration. This design has been intentionally developed to be a generator with less opposing steady state torque as a result of electric generation. To expand this concept, the following details should be pointed out: an ideal electrical motor should be capable of converting all the electric energy at the input to a full mechanical energy by its output that is related to torque and speed; the ideal generator known until now should be capable of completely producing electrical energy at its output from the mechanical energy source at its input [4]. The device that is being presented on this work is novel since it is considering a field of study that is relatively unexplored on books since it considers the generation of electric energy mostly from magnetic energy itself instead of mechanical energy as it has been commonly done on most of the electrical generators commercially available until now. The law of conservation of energy states that the total energy of an isolated system remains constant - it is said to be conserved over time [12]. Energy can neither be created nor destroyed; rather, it transforms from one form to another [12]. Consequently, any additional energy available from systems as the one presented is related to the magnetic energy that until now has been mostly ignored in most analysis even when it is a form of energy as common as electrical or mechanical energy. This statement is what explains that the generation of electricity based on Faraday's Law is only dependent on the change of magnetic energy and not on the mechanical energy. The mechanical energy is mostly a consequence of existing electric generation methods; the main form of energy necessary to generate electric energy is magnetic energy and not mechanical energy since is the change in magnetic flux what induces an electromotive force which when connected to a load produces an electric current. The product of these two physical quantities with time is commonly defined has electric energy. The following equation relates what is being expressed on this work:

$$\mathbf{E_{ele} + E_{mec} + E_{mag} + E_{loss} = 0}$$

In which E_{ele} means the electrical energy, E_{mec} means the mechanical energy, E_{mag} means the magnetic energy and E_{loss} means energy losses of the system and the sum of all this energy is zero since it cannot be either created or destroyed. For the ideal case the value of E_{loss} can be assumed to be zero and any energy that exceeds the mechanical energy input to the generator should be the result of the E_{mag} present on the system. This final statement regarding E_{mag} still is a hypothesis and further investigation is needed in order to find experimental and theoretical proof for it.

Chapter 3: Scientific Formulation of LTG Operation

The LTG is a new machine that has been specially designed to produce electric energy with less steady state opposing torque when it is compare to conventional generators. The concept was born with an initial study on magnetic energy interactions and how it behaves. First, a neodymium magnet was being considered since a strong magnetic force results from this device when compare to other materials. Then another idea came up regarding what the magnet wanted to do as a natural process, to be in equilibrium. After putting the neodymium magnet closer to a U shape ferrite core, which is a ferromagnetic material, then it was clear that the magnet wanted to put both poles aligned with the core closer to it. In other words, if the magnet had the capability it will stretch and connect both the north pole and south pole together. As a result of these findings, it was initially established that if the magnet was placed in the center of a ferromagnetic material then it will be in a mechanical equilibrium point and in a maximum magnetic energy configuration. Figure 1 shows a block diagram of the written formulation that is going to be presented on the next paragraph.

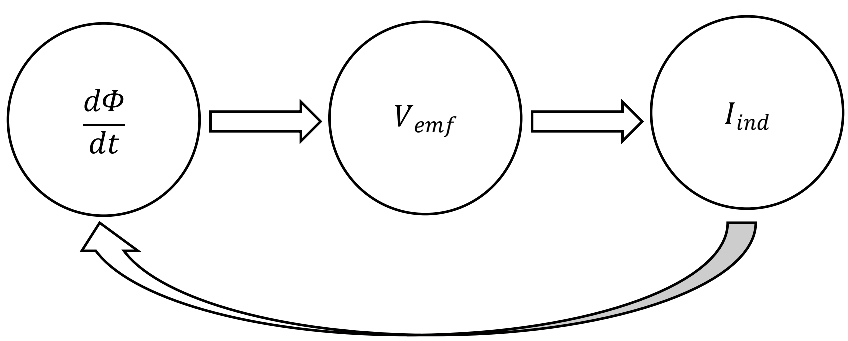

Figure 1: Depiction of the Relationship Between Change in Magnetic Flux, Electromotive Force and Induced Current

After this initial assumption then the possibilities of this device to create electric energy were analyzed and lead to the following formulation: "If a change in the magnetic flux is the responsible for the generation of an electromotive force, and the electromotive force is the responsible the generation of an electric current, and at the same time electric current is the responsible for the generation of a magnetic flux; now we can make a change in magnetic flux at the center of a toroidal core which in consequence will generate an electromotive force on the windings of the toroid that will result in an electric current, once connected to a load. Such current will produce a magnetic flux that will stay within the toroidal core and will not interfere with the initial change in magnetic flux produced at the center of the toroid". After this formulation was established, the other step left was to create a small prototype to find an experimental proof to the formulation above. When it was tested, it showed that if a neodymium magnet was rotated at the center of a toroidal ferrite core then it did generate an electromotive force, or a voltage in a sinusoidal waveform.

The next step was to start a journey to get more experimental proof of the hypothesis that is already presented. Then a better prototype was built. The original served as the basis of proof for the last portion of the formulation. When it was constructed, it started to show that indeed, if an electric current was generated at the winding terminal with this machine, it did not oppose to the steady state mechanical movement that was already taking place at the center of the toroid. After this the ferrite U shape core became the stator and the neodymium magnet rotating at the center of the toroid became the rotor of the LTG.

In order to explain the working characteristics of the LTG the following concepts gives a theory that works as a basis of operation for the machine. First, we consider the concept of the Ampere's circuit law that states: "the line integral of $\boldsymbol{H}$ around a closed path is the same as the net current I_{enc} enclosed by the path [1][2]." The Ampere's Law follows,

$$\oint \boldsymbol{H} \cdot d\boldsymbol{l} = I_{enc}$$

where $\boldsymbol{H}$ is the magnetic field intensity and $d\boldsymbol{l}$ is the line differential of the Amperian path [1][2]. For the following analysis $\boldsymbol{H_1}$ is the magnetic field intensity due to the permanent magnet and $\boldsymbol{H_2}$ is the magnetic field intensity due to the windings at the toroidal core. The mentioning of this concept is useful when we consider typical winded toroidal core case. The solutions for magnetic field intensity on different locations with respect the toroid are the following: for a point that is located inside of the toroidal core the current enclosed by the Amperian path is NI which in consequence creates a magnetic field intensity [1][2] that can be called $\boldsymbol{H_2}$ for this analysis and is maximum inside the core.

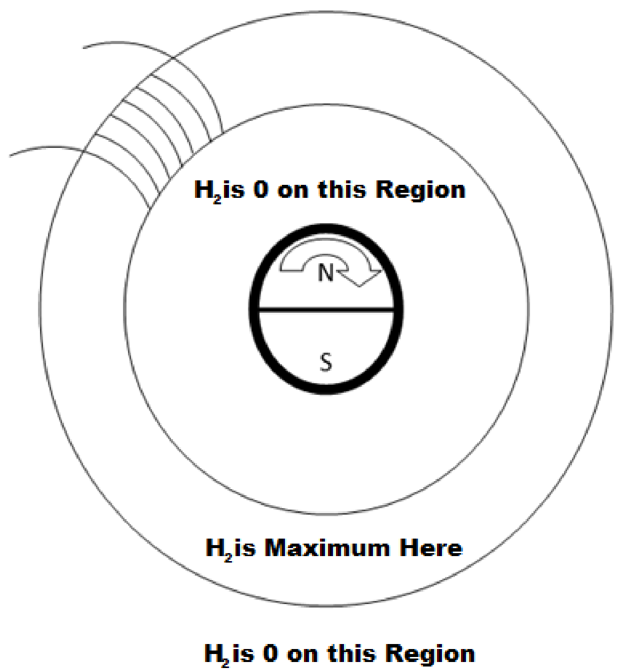

Figure 2: Magnetic Field Intensity $\boldsymbol{H_2}$ per Region of the LTG

The concept that is being emphasized on this work is the solution for a point near the center of the toroid and outside of the core, since the current enclosed by the Amperian path in relation to $\boldsymbol{H_2}$ for this case is zero; therefore, no currents are enclosed and the magnetic field intensity $\boldsymbol{H_2}$ for it is also zero [1][2]. Because of this the magnetic flux density which is defined as $\boldsymbol{B_2} = \mu_0 \boldsymbol{H_2}$ is also zero and the torque exerted to an external point near the center by the current generated around the toroid is defined as $\boldsymbol{T} = \boldsymbol{m} \times \boldsymbol{B_2}$ is also zero because of the magnetic flux density being zero for this case [1][2]. The net result is no torque is actuating on the permanent magnet by the current that is flowing thru the toroidal core winding since the magnetic field intensity $\boldsymbol{H_2}$ is zero outside the toroidal core. The steady state opposing torque is defined as a direct interaction between the magnetic field intensities $\boldsymbol{H_1}$ and $\boldsymbol{H_2}$ which is not present on the LTG design.

Chapter 4: LTG Experimental Data and Analysis of Results

4.1 LTG Experimental Setup

In this work, three different configurations of the LTG are being tested and analyzed. Since this is a novel concept, the development of the LTG has occur at first from an empirical approach. Later on, analysis of the different effects seen on laboratory results have being explained. The prime mover for all this work is a small DC motor because of the convenience of measuring input power on the device.

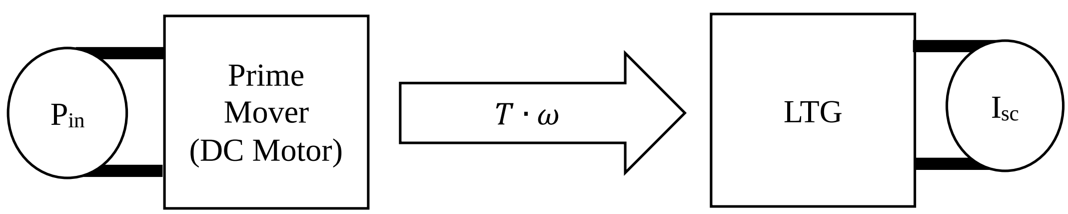

Figure 3: Diagram of Measurements performed to the LTG

Figure 3 shows a general diagram of the experimental setting, where we use the DC motor as the prime mover of LTG. Because of this we can make a comparison with the output current of the LTG against the input current of the DC motor, with the input power. This allows us to compare the effect of the steady state opposing torque in the following ways: changing the electric load at the LTG, if there was some reaction torque then P_{in} needs to change. At the contrary, if the steady state opposing torque does not change with the change at the load, it means that changes at the load does not produce changes in the steady state opposing torque.

A drawing of the Ferrite U Shape Core used as the stator is presented on Figure 4. Two of the same one are what are named the stator in all this work. The ferrite core stator dimensions are specified by the manufacturer on the table present at appendix Figure 28. The Neodymium magnet used on the LTG characteristics are the following: cylindrical shape, axially magnetized, 15mm diameter and 22mm of height. A visual representation of the permanent magnet is shown on Figure 5.

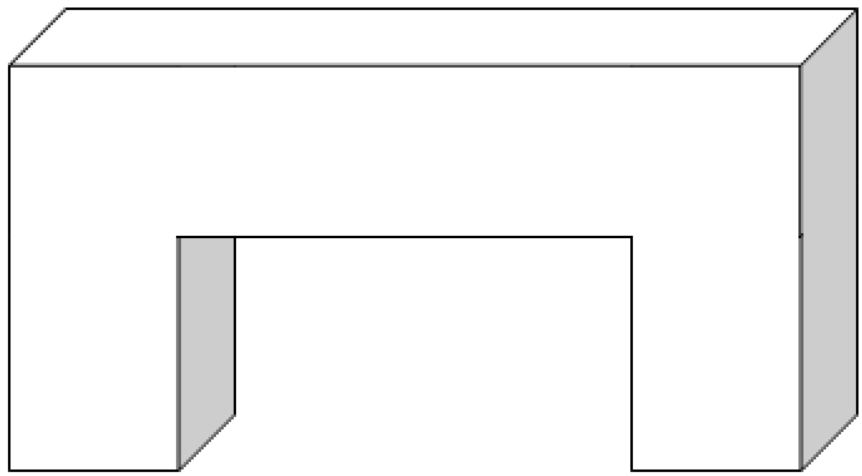

Figure 4: Ferrite U Shape Core Stator Drawing

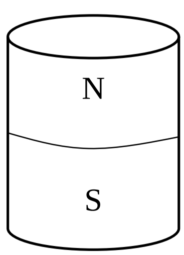

Figure 5: Rotor Neodymium Magnet Illustration

4.2 LTG First Configuration

The first configuration of the LTG considers a stator and rotor as depicted on Figure 6 in which the stator is of ferrite material and has only one winding. The rotor is a permanent neodymium magnet. On Table 1, the stator named U1 was used to generate the results, which consists of a coil of approximately 23 turns of an 18 AWG normal insulated wire. The other three tables were generated with another stator named U3 with around 50 turns and one layer of windings of magnet wire.

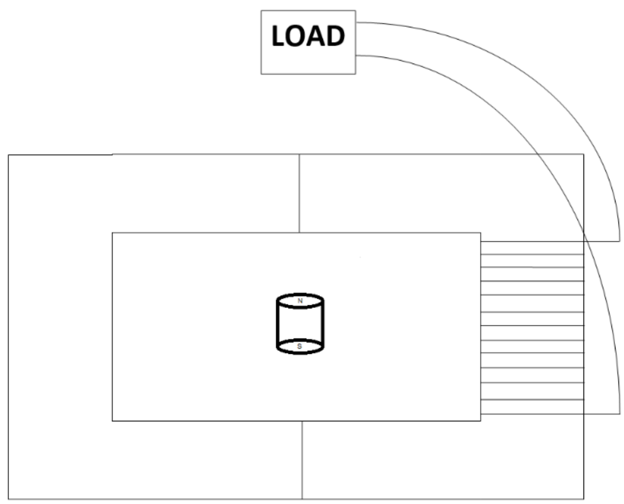

Figure 6: LTG First Configuration

Tests of the stator on open circuit voltage and short circuit current where done for this configuration and the results shows important observations. First, we can see on Table 1 that the open circuit voltage is directly proportional to the rotational speed of the rotor as it is commonly seen on a conventional generator. The short circuit current was observed while considering the input power, in order to compare how much I_{sc} is changing with the input power with respect to the placement of the short circuit on the stator. Short circuit current is the worst possible current for this generator, which in consequence would produce the worst steady state opposing torque. This is due to their direct proportionality (relation between current and torque).

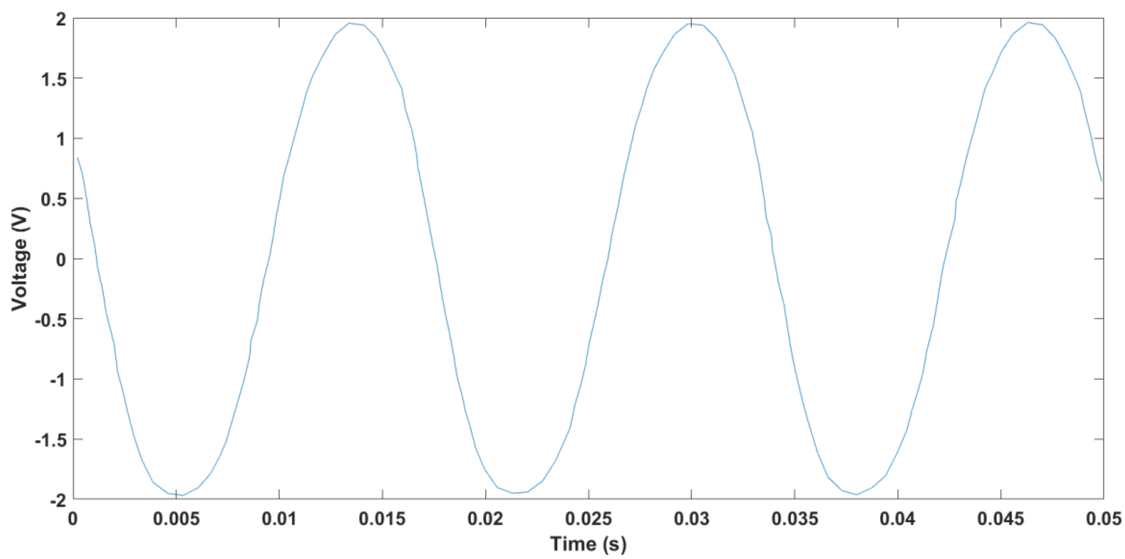

Figure 7: No Load Output Voltage using LTG First Configuration

As seen on the Figure 7 we can easily identify the output voltage as a sinusoidal waveform. The magnitude is around $2V_{peak}$ and the frequency of rotation for this waveform is close to 60Hz.

Input Power	Short Circuit Current	Open Circuit Voltage
V_{in} = 1.13V I_{in} = 4.02A P_{in} = 4.45W	I_{sc} = 123mA	V_{out} = 186mV
V_{in} = 1.75V I_{in} = 4.5A P_{in} = 7.88W	I_{sc} = 136mA	V_{out} = 300mV
V_{in} = 2V I_{in} = 4.75A P_{in} = 9.5W	I_{sc} = 134mA	V_{out} = 335mV

Table 1: Prime Mover Input Power for LTG First Configuration on Open and Short Circuit Conditions

The prime mover input power refers to the measurements of voltage, current and power that are being performed at the DC motor input that is being used to create the rotation at the generator rotor. Table 1 is arranged by experiment and must be read by row, and so, it shows one of the most significant arguments of this work; for LTG first configuration Pin does not change for between Open Circuit or Short Circuit conditions which covers all the spectrum of loading possibilities for no gap case. The opposing torque at the prime mover is negligible for this experiment and is evidenced both visually and measured for the zero gap case. The following Tables shows a comparison on how the output power for the LTG first configuration changes with the addition of a core gap.

Without Core Gap	
DC Motor	**Stator (U3)**
V_{in} = 1.41V	Open Circuit Voltage = 383mV
I_{in} = 5.27A	Short Circuit Current = 100mA
P_{in} = 7.43W	Estimated Output Power = 38.3mW

Table 2: DC Motor Input Power and Estimated Output Power for LTG First Configuration without Gap

Core Gap of One Tape Width (Estimated 7mil)	
DC Motor	**Stator (U3)**
V_{in} = 1.35V	Open Circuit Voltage = 484mV
I_{in} = 5.27A	Short Circuit Current = 256mA
P_{in} = 7.11W	Estimated Output Power = 124mW

Table 3: Input Power and Estimated Output Power for One Tape Core Gap on the LTG

Core Gap of Two Tapes Width (Estimated 14mil)	
DC Motor	**Stator (U3)**
V_{in} = 1.30V	Open Circuit Voltage = 547mV
I_{in} = 5.27A	Short Circuit Current = 426mA
P_{in} = 6.85W	Estimated Output Power = 233mW

Table 4: Input Power and Estimated Output Power for Two Tapes Core Gap on the LTG

After looking at Tables 2 thru 4, adding a core gap to this configuration results in higher output power and this has been demonstrated by placing a bulb as a load and being able of turning on with the core gap but results on reducing the rotational speed at the prime mover and it is evidenced by the voltage drop at the input. It is important to note that the current magnitude at the prime mover stay the same and torque should be related to current on a DC motor.

4.3 LTG Second Configuration

The second configuration of the LTG considers a stator and rotor as shown below in which the stator is of ferrite and has two windings and the rotor is a permanent neodymium magnet. Stator core named U2 is being used as the output for all the rest of this work. The main detail of this new configuration is that one of the windings, stator core named U1 is intentionally shorted during normal operation as shown in Figure 8.

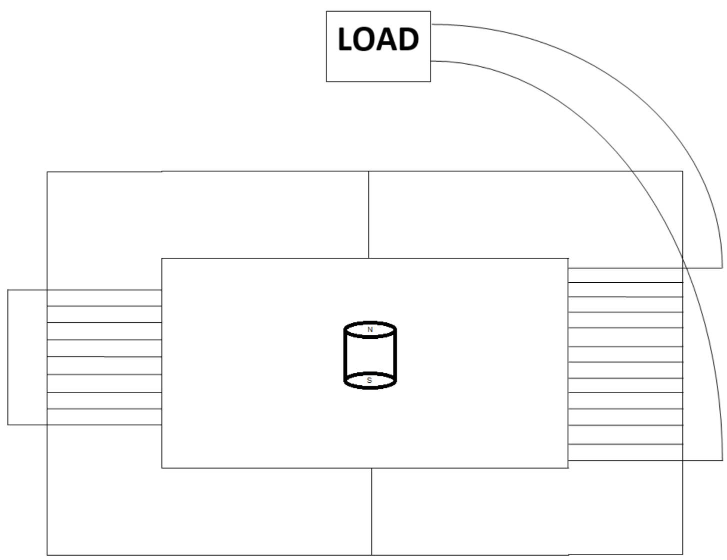

Figure 8: LTG Second Configuration

This LTG second configuration results in higher output voltage than the first configuration by almost a factor of two as shown in Figure 9 for the same rotational speed than Figure 7. This configuration for now has been the one that has produced more output power at the laboratory experiments but at the same time has the higher effect on rotational speed that for now has been considered as steady state opposing torque presence. Figures 10 thru 15 shows how the output voltage at no load condition changes for the

LTG second configuration with the increase of rotational speed from the prime mover.

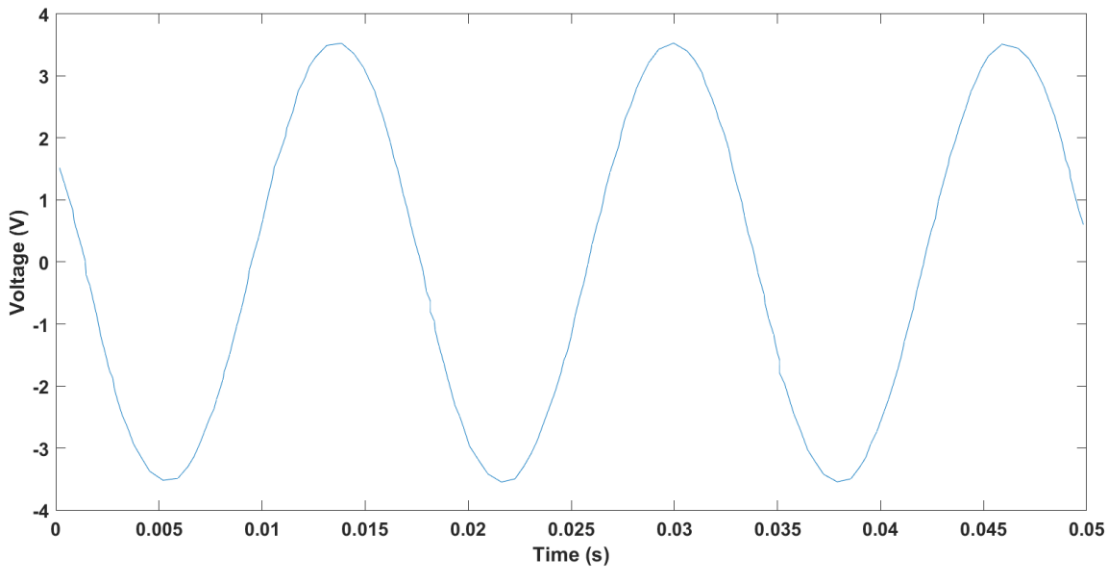

Figure 9: No Load Output Voltage using LTG Second Configuration

Figure 9 shows the output voltage as a sinusoidal waveform. The magnitude is around $3.6V_{peak}$ and the frequency of rotation for this waveform is close to 60Hz.

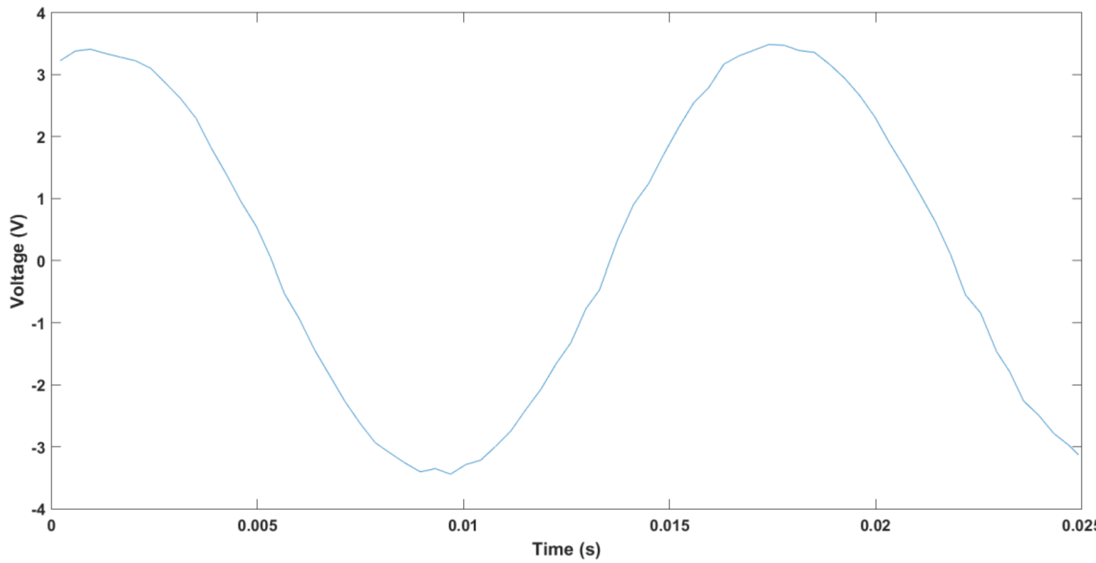

Figure 10: No Load Output Voltage using LTG Second Configuration at 60Hz

Figure 10 shows the output voltage of the LTG second configuration at 60Hz. The waveform is sinusoidal for all the LTG second configuration plots.

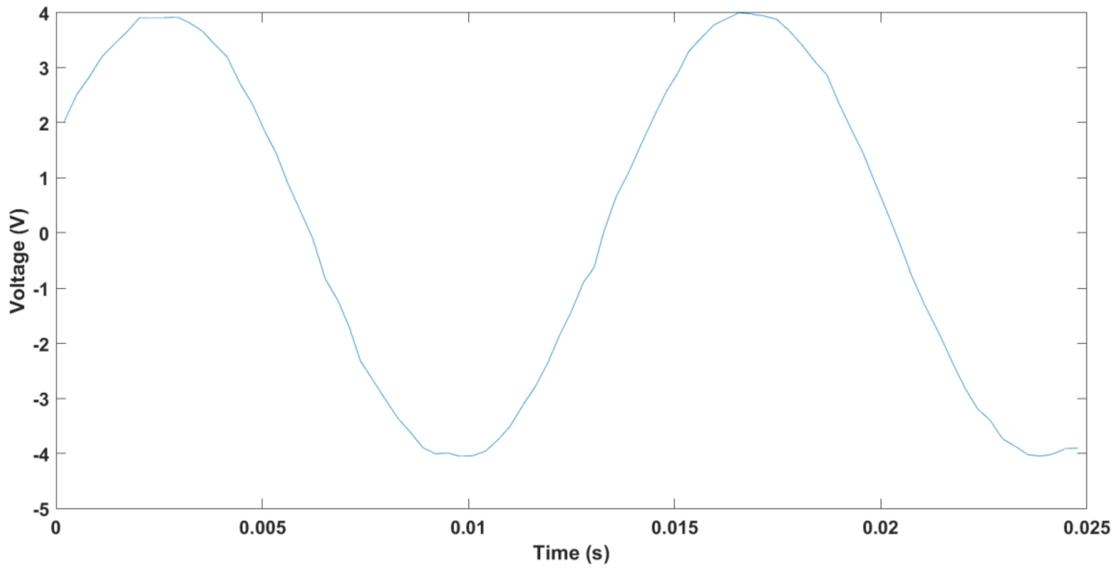

Figure 11: No Load Output Voltage using LTG Second Configuration at 70Hz

Figure 11 shows the output voltage of the LTG second configuration at 70Hz. The peak output voltage is around $4V_{peak}$ at the specified rotation frequency of the permanent magnet.

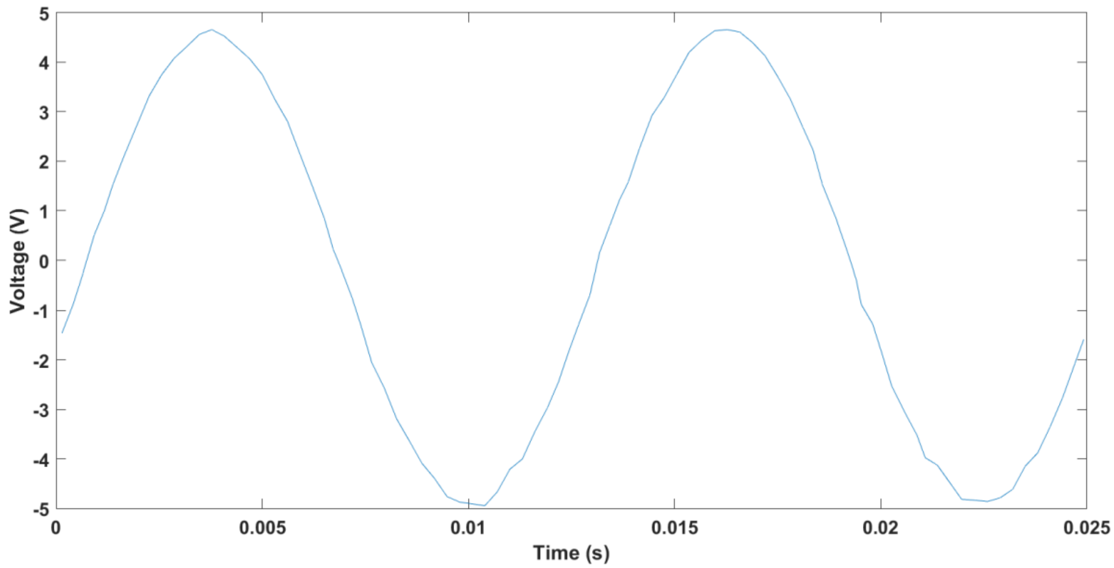

Figure 12: No Load Output Voltage using LTG Second Configuration at 80Hz

Figure 12 shows the output voltage of the LTG second configuration at 80Hz. The peak output voltage is around 4.8V_{peak} at the specified rotation frequency of the permanent magnet.

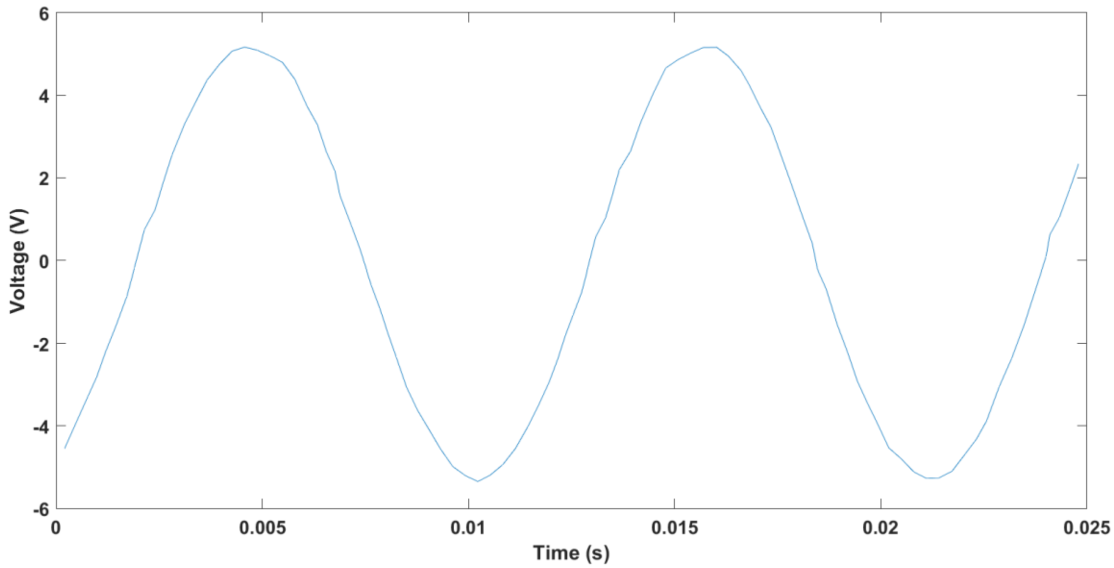

Figure 13: No Load Output Voltage using LTG Second Configuration at 90Hz

Figure 13 shows the output voltage of the LTG second configuration at 90Hz. The peak output voltage is around $5.5V_{peak}$ at the specified rotation frequency of the permanent magnet.

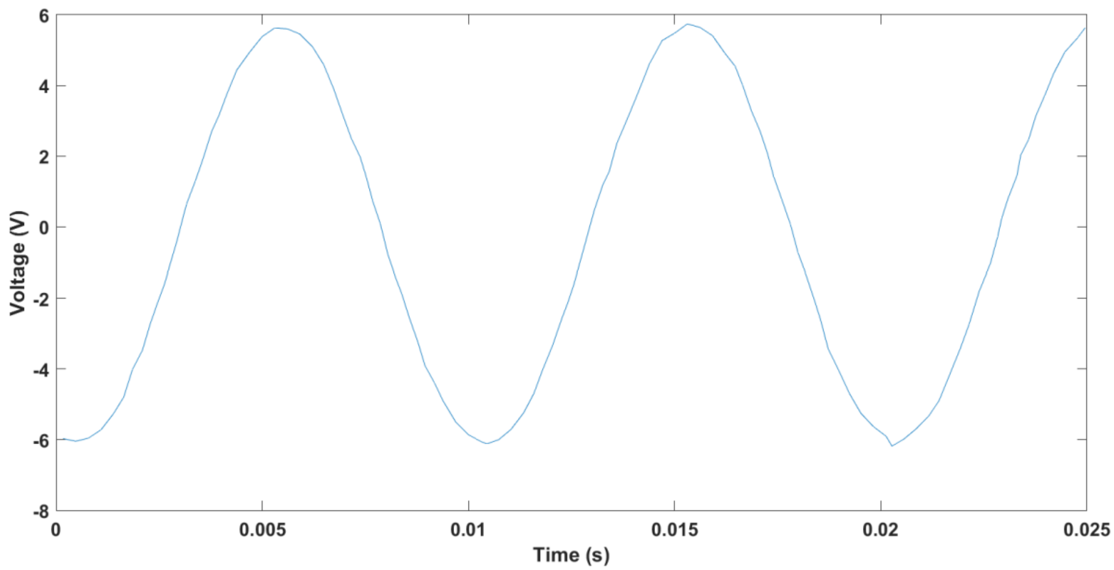

Figure 14: No Load Output Voltage using LTG Second Configuration at 100Hz

Figure 14 shows the output voltage of the LTG second configuration at 100Hz. The peak output voltage is around 6V_{peak} at the specified rotation frequency of the permanent magnet.

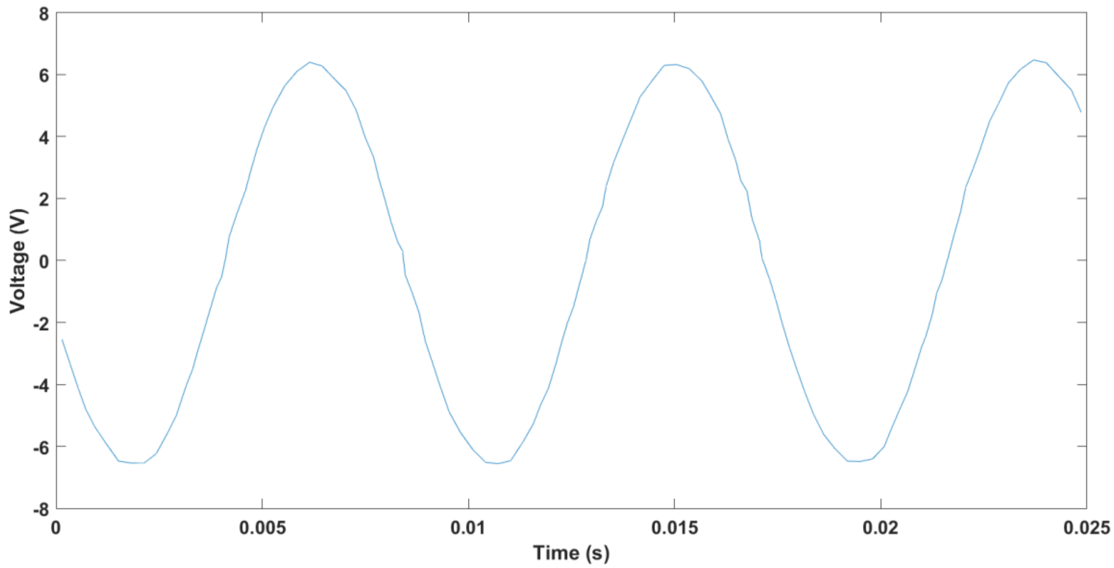

Figure 15: No Load Output Voltage using LTG Second Configuration at 114Hz

Figure 15 shows the output voltage of the LTG second configuration at 114Hz. The peak output voltage is around 6.5V_{peak} at the specified rotation frequency of the permanent magnet.

For the LTG second configuration a bridge rectifier was added in order to test for the capacity of the generator to power a DC rectifier circuit. Results were satisfactory and are shown on Figure 16 as the bridge rectifier output and on Table 5 when powering a lamp.

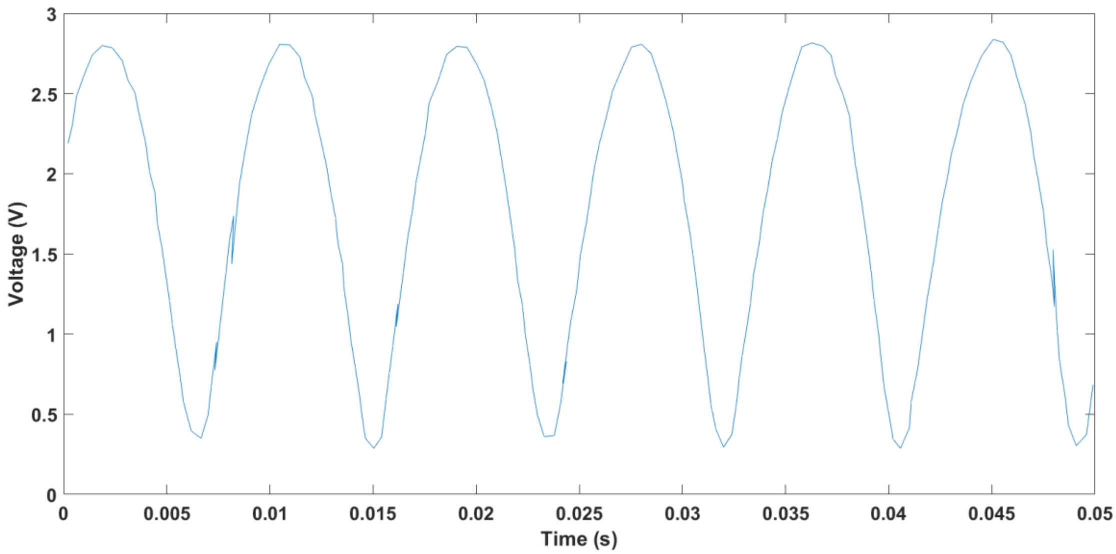

Figure 16: Output Voltage of Bridge Rectifier for LTG Second Configuration

Figure 16 shows the output voltage of the LTG second configuration with a bridge rectifier. The peak output voltage is around $2.8V_{peak}$ and is DC since it is not alternating.

Parameters	**Measurement**
Voltage	4.69V
Current	388mA
Power	1.82W

Table 5: Output Power at the Load after Bridge Rectifier Circuit

Table 5 shows the higher measured power at the load from the LTG second configuration. This power was being applied to a lamp and that was evidenced since the intensity of brightness was the highest achieve for this experiment. The important detail regarding this LTG second configuration is that it does affect the rotational speed at the rotor in comparison with the LTG first configuration that does not shows this effect.

4.4 LTG Third Configuration

The third configuration of the LTG considers two windings as the second configuration with the addition of resonance to improve the output voltage of the generator as represented in Figure 17. Stator core named U2 is being used as the output and stator core named U3 is being used connected to external capacitors to produce the resonance.

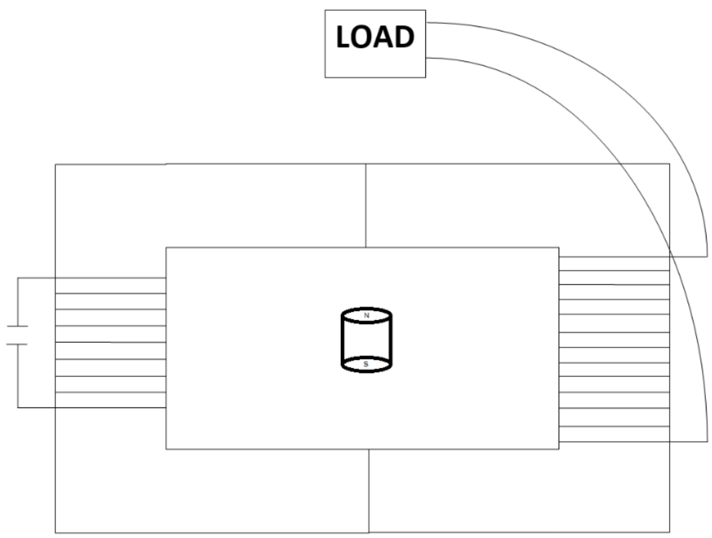

Figure 17: LTG Third Configuration

The resonance is being achieve by using the inductance from the core and capacitors externally connected to the windings. The rotor is tuned in such a way that its rotation matches the resonant frequency. Figures 18 thru 22 shows output voltage at no load for the LTG third configuration and it is evident from them that the output is almost double than the LTG second configuration for the same rotational speed.

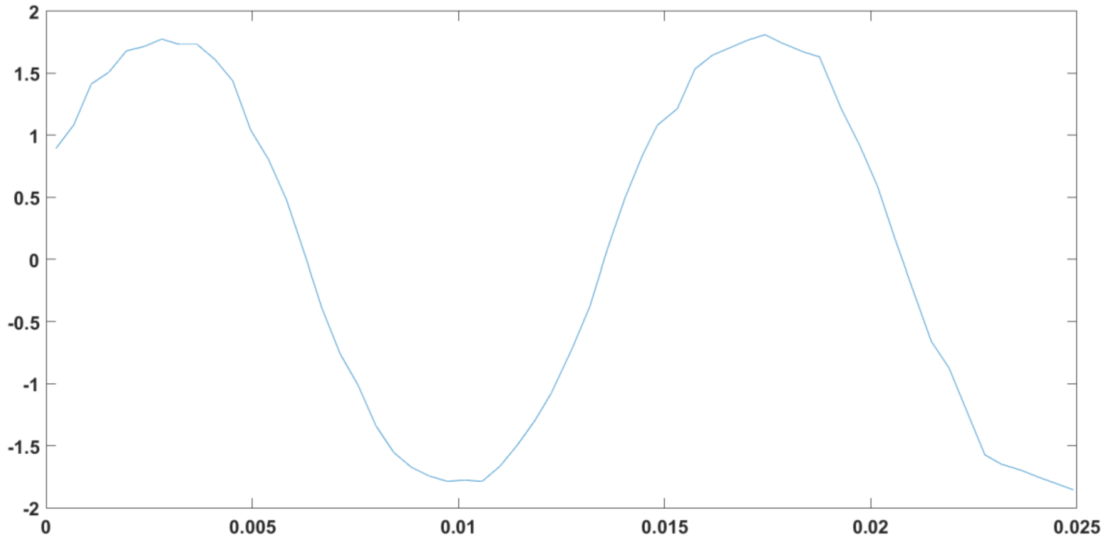

Figure 18: No Load Output Voltage using LTG Third Configuration at approximately 70Hz

Figure 18 shows the output voltage of the LTG third configuration at 70Hz. The peak output voltage is around 1.8V_{peak} at the specified rotation frequency of the permanent magnet.

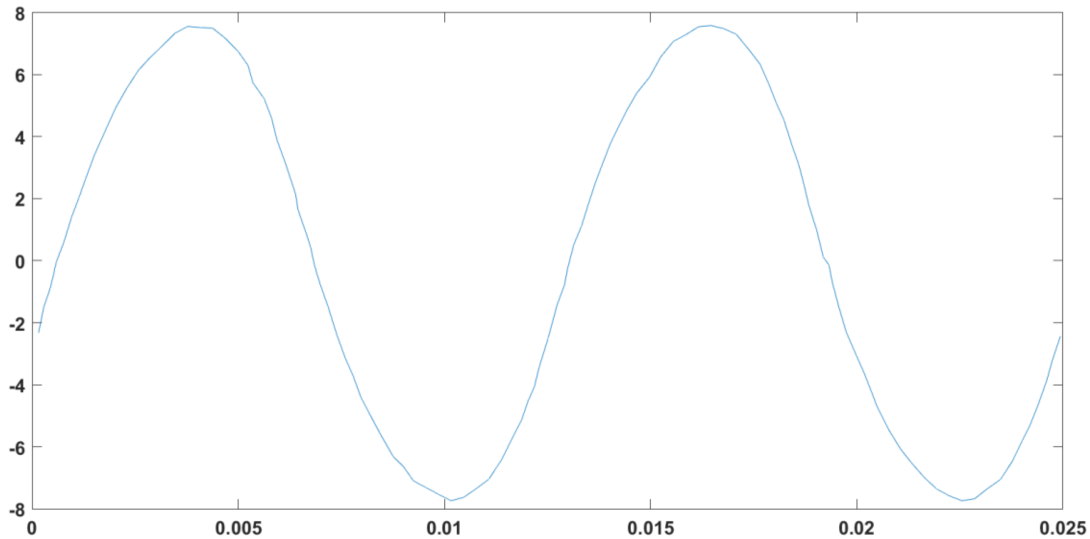

Figure 19: No Load Output Voltage using LTG Third Configuration at 80Hz

Figure 19 shows the output voltage of the LTG third configuration at 80Hz. The peak output voltage is around 7.8V_{peak} at the specified rotation frequency of the permanent magnet.

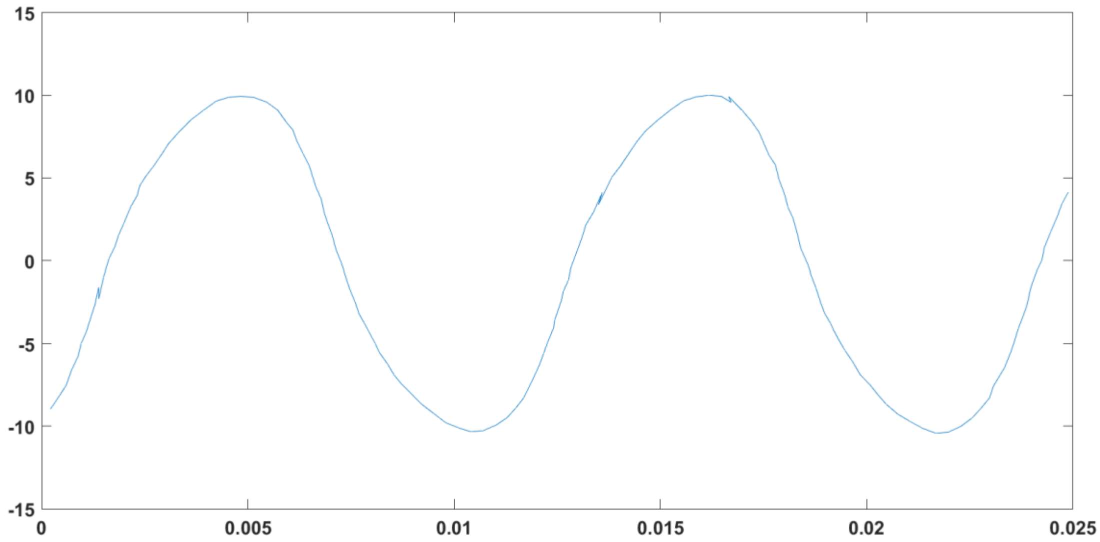

Figure 20: No Load Output Voltage using LTG Third Configuration at approximately 90Hz

Figure 20 shows the output voltage of the LTG third configuration at 90Hz. The peak output voltage is around $10V_{peak}$ at the specified rotation frequency of the permanent magnet. Some waveform distortion is being observed at the plot.

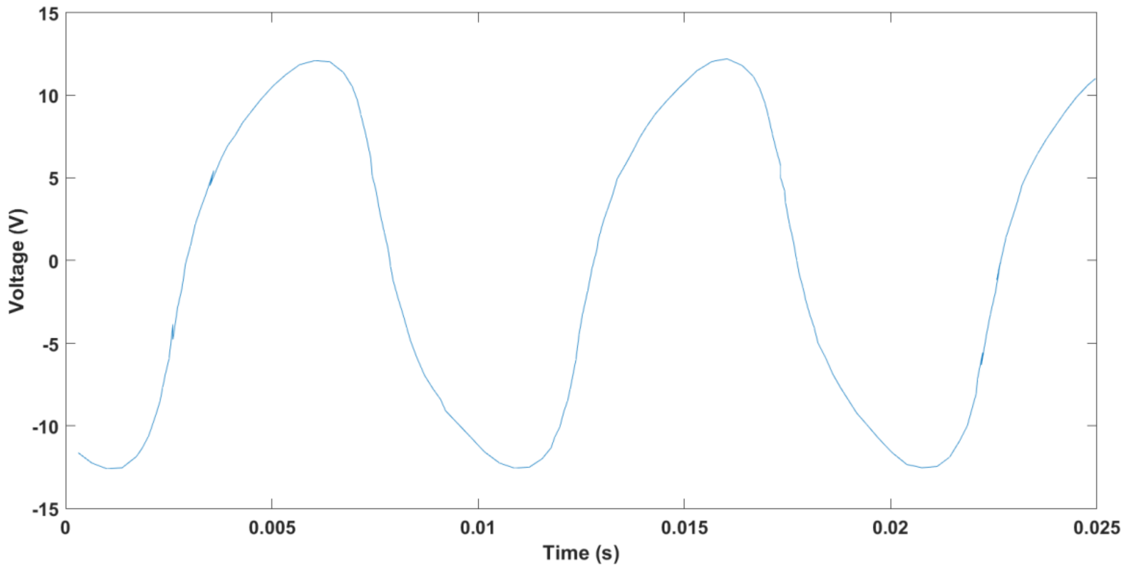

Figure 21: No Load Output Voltage using LTG Third Configuration at approximately 100Hz

Figure 21 shows the output voltage of the LTG third configuration at 100Hz. The peak output voltage is around $12V_{peak}$ at the specified rotation frequency of the permanent magnet. Some waveform distortion is being observed at the plot.

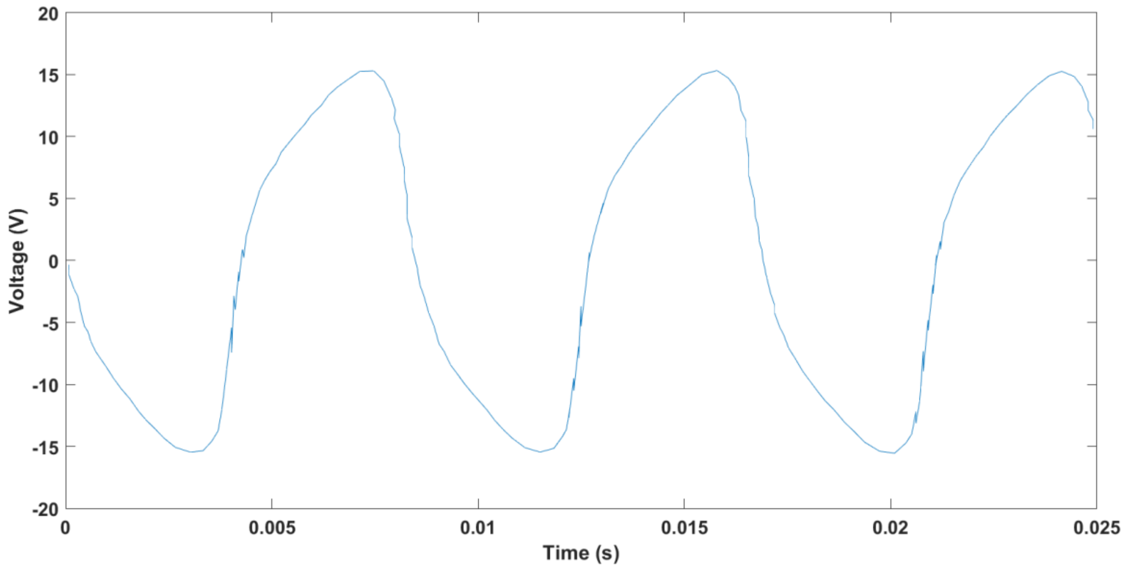

Figure 22: No Load Output Voltage using LTG Third Configuration at 119Hz

Figure 22 shows the output voltage of the LTG third configuration at 119Hz. The peak output voltage is around 15V_{peak} at the specified rotation frequency of the permanent magnet. Some waveform distortion is being observed at the plot.

Output voltage waveform still sinusoidal even that some distortion has been observed which has been considered as experimental setup error for being able of correct it with another setup as shown on appendix Figure 45. Even that the output voltage is more than double for some frequencies in comparison to the second configuration, current at the output for this configuration is not increased which is typical for some resonant circuits. This configuration has just been introduced in this work and still needs more development as a future work.

4.5 Torque Analysis

In order to analyze the torque characteristics of the generator the following experiments were added to this work. A DC motor has been used as a prime mover in all this work as originally presented on Figure 3. Since current is the parameter related to torque for a DC motor as shown in the following equation $T=k\Phi I$, we use the current measurements to evaluate torque characteristics of the generators [13].

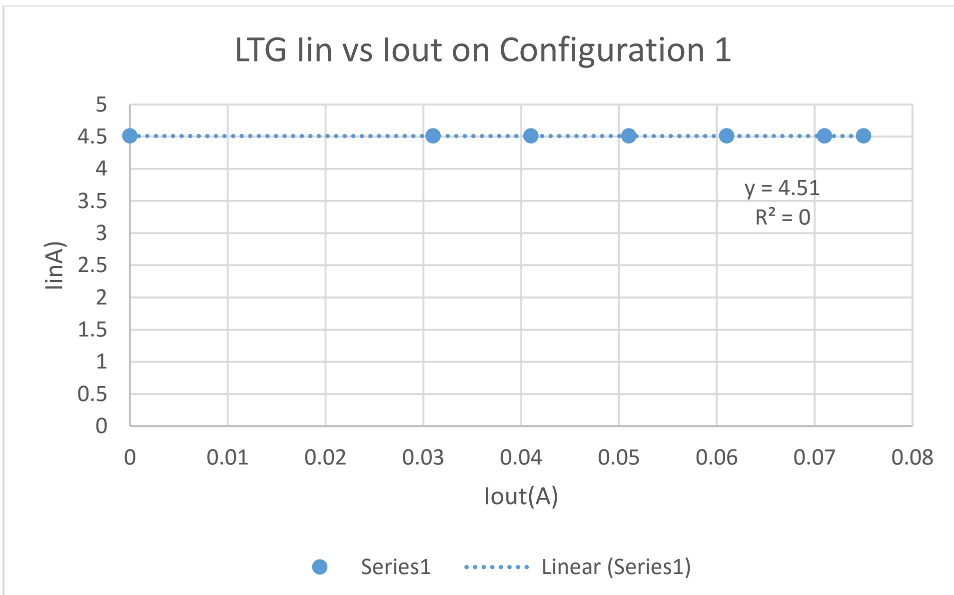

Figure 23: LTG First Configuration Prime Mover Input Current versus Output Current

First, we gather the data of input torque and output voltage and current for the LTG first configuration from short circuit condition to open circuit condition and it can be seen on Figure 23. Then a similar data was recorded for the LTG second configuration and it is shown on Figure 24.

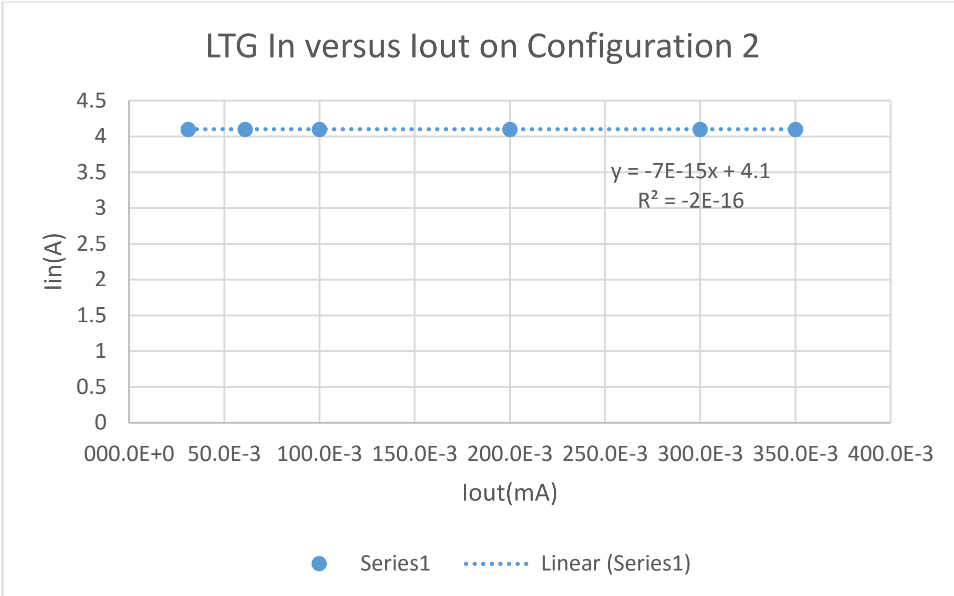

Figure 24: LTG First Configuration Prime Mover Input Current versus Output Current

Finally, a comparison between the LTG second configuration and a conventional generator was performed to evaluate the torque characteristics of both. This final step was based on the assumption that the lowest input power to the DC motor will be necessary to create the same short circuit current on both the conventional generator and the LTG and it can be seen on Figure 25.

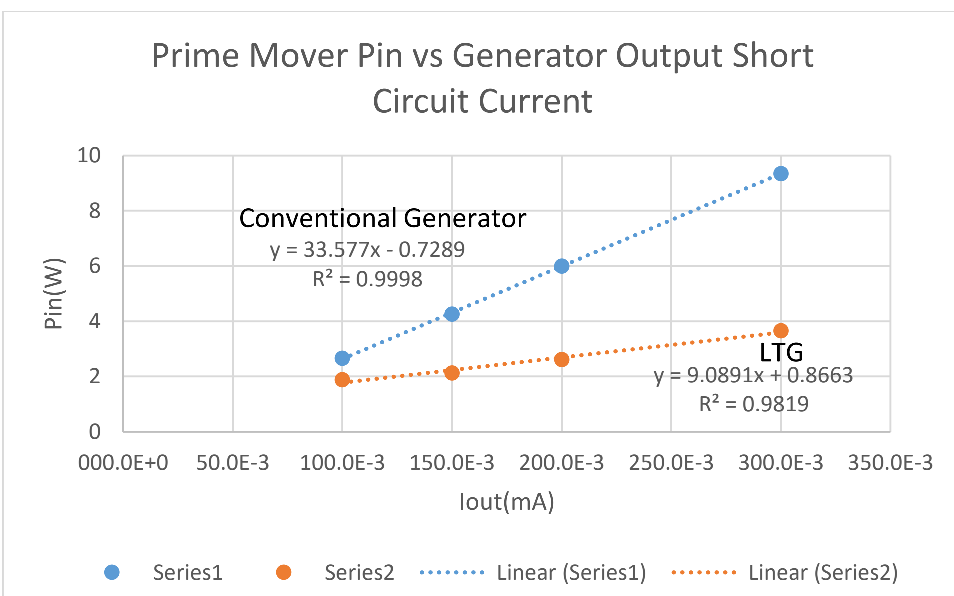

Figure 25: LTG Second Configuration Prime Mover Input Current versus Short Circuit Output Current

It is significant to note that current at the input is constant for both the LTG first and second configuration. There is an important difference between the LTG first and second configuration and it is that the voltage and the speed of the prime mover stays constant on the first configuration and both reduce on the second configuration. The comparison between the conventional generator and the LTG second configuration shows that the LTG is capable of producing the same current at short circuit with less input power at the prime mover and current is the only responsible for the steady state opposing torque as explained before by ampere's law. The LTG second configuration is showing to generate less steady state opposing torque for the same loading conditions as the conventional generator, therefore it is generating less mechanical opposition to the prime mover as expected from this work.

Chapter 5: Conclusions of the LTG Research and Future Development

There are four important conclusions that have been found regarding the investigation of the low torque generator. One of them consist on the concept that it is possible to transform the magnetic energy to electric energy generating a minimum torque since the electric generation is due to the change in magnetic flux and not to the torque itself. The proof of this principle that was discovered by the initial work done by myself and Orama can be explained by the following magnetic circuit shown below,

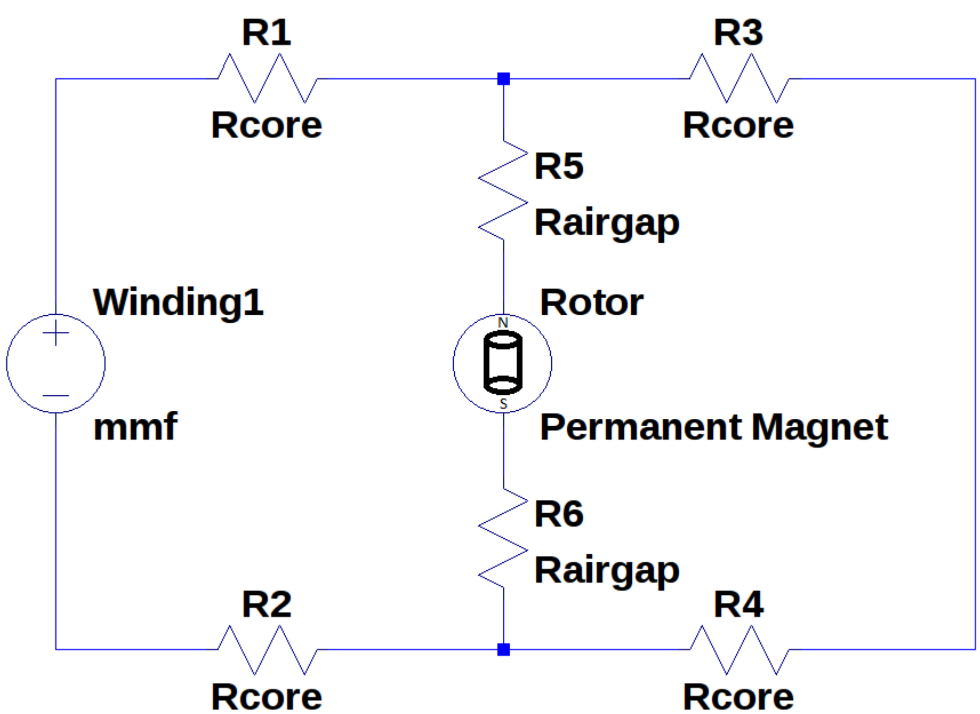

Figure 26: Magnetic Circuit of the Low Torque Generator for One Winding on the Stator

When the reluctance of the air gap is considerable bigger than the reluctance of the core for the magnetic circuit shown on the circuit in Figure 26, it can be demonstrated that the magnetic flux that is produced by the magnetomotive force (mmf) source can flow a lot easier thru the core instead of the air gap path thru the permanent magnet rotor. At the same time the mmf that is being produced by the current generated when the output of the generator is connected to an electrical load; it has been recorded that it produces negligible effects on the rotor even with the worst possible load. On the experiments done so far, the highest torque configuration has been considered with positive results of negligible effects on the movement of the rotor.

The second conclusion that has been found from this work is that if we consider a magnetic circuit with two windings on the stator when we short circuit one of them, the other output increases in magnitude almost by a factor of two which has been experimentally recorded on an oscilloscope. An effect that can be properly named as magnetic superposition has been observed when both of the outputs of the generator are loaded with a short circuit. The effect shown is a considerable reduction on the rotor speed which evidences that the magnetic flux is now passing thru the rotor with this configuration and therefore it reduces the magnetic energy available from the rotation of the magnet. Figure 27 explains magnetically speaking the effect that we are talking in this second conclusion,

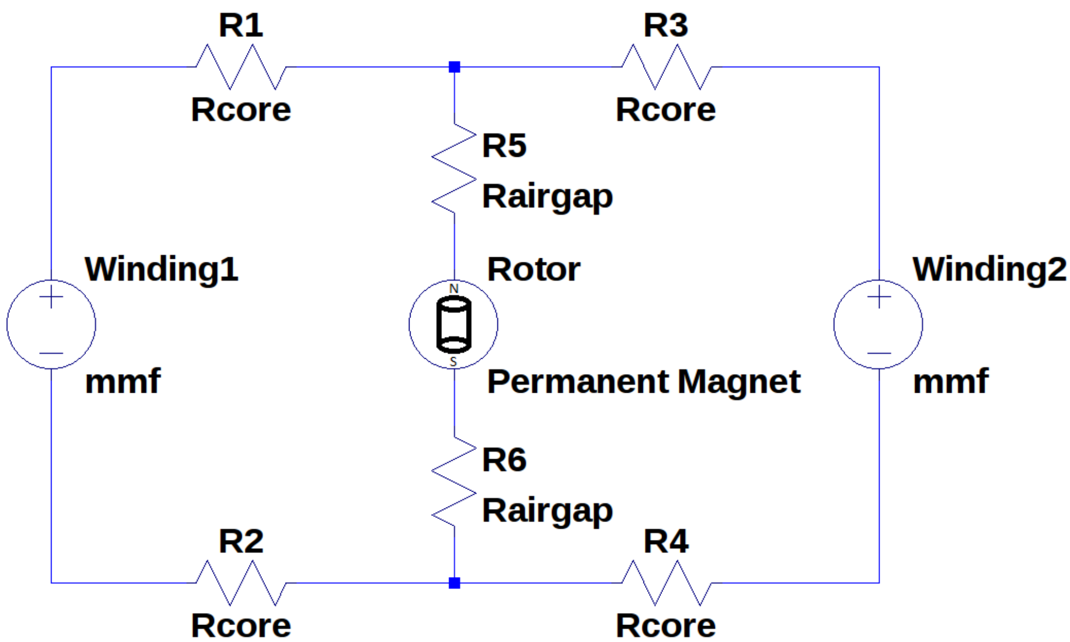

Figure 27: Magnetic Circuit of the Low Torque Generator for Two Windings on the Stator

Two possible solutions that could be considered regarding this issue are the following: one is to create a phase shift for the output current on the second output of the generator two eliminate the superposition effect that causes the magnetic flux to go against the rotor configuration, or to place both of the outputs from the generator on the same leg of the magnetic circuit to possibly mitigate the superposition effect on the rotor.

The third conclusion that arises from this work is that it has been prove that with resonance the LTG produces a higher output voltage than with other configurations. This section is basically just being introduced on this work since additional effort and time will be required to explore more deeply this phenomenon. Several advantages can be easily seen by this operation since this can result in a more efficient way to extract at least the same power from the generator with less input energy because of a possible reduction of speed because of resonance.

The final conclusion regarding this work is that when we add an air gap on the core (core gap), it has been recorder than it produces better results in terms of current extraction thru the output of the generator. This effect shows that there are some magnetic effects that we still do not have enough understanding with the current literature since the reality based on the current magnetic theory is that if we add an additional reluctance to a magnetic circuit; it should decrease the output current but instead we are recording the opposite on the experimental results. The only drawback of considering this condition is that the rotor speed starts decreasing showing that the magnetic flux is now flowing thru the rotor to some degree that it reduces its mechanical energy. The system needs to be optimized since it is possible that the maximum power extraction for any configuration of this generator be dependent of the following parameters: mechanical system optimization, core and core gap materials, reluctance ratio between the core and the rotor gap, stator windings optimization and the core gap effect.

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Appendix

Part Name	Material	Dimensions	Notes
Core	Ferrite	Specified on Figure 28	U Shape
Magnet	Neodymium	15mm dia, 22mm height	Cylindrical, Axially Magnetized
Stator (U1) Coil 1	Copper	23 Turns	18AWG Normal Insulated Wire, One Layer
Stator (U2) Coil 2	Copper	Estimated 100 Turns	22AWG Magnet Wire, Two Layers
Stator (U3) Coil 3	Copper	50 Turns	18AWG Magnet Wire, One Layer

Table 6: Dimensions of the Prototype Fundamental Materials

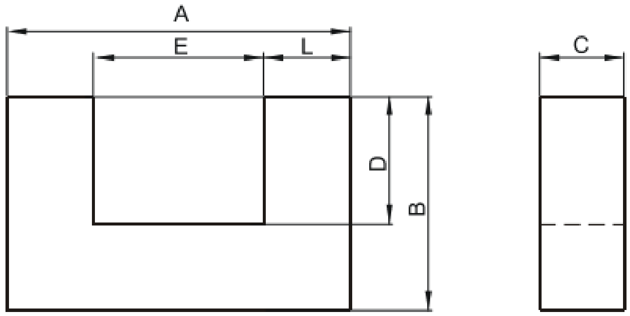
MAGNETICS®
A Division of Spang & Company

Specification for:

0P49925UC

110 Delta Drive
Pittsburgh, PA 15238
Phone: 412/696-1333
Fax: 412/696-0333
Email:magnetics@spang.com

DIMENSIONS



(mm)	Nominal:	Tol. min.:	Tol. max.:
A	101.6	-1.5	+ 1.5
B	57.1	-0.4	+ 0.4
C	25.4	-0.6	+ 0.6
D	31.7	-0.75	+ 0.75
E	50.8	-1.0	+ 1.0
L	25.4	-0.8	+ 0.8
Eff. Parameters			
Ae mm ^{2}	**Amin mm ^{2}**	**le mm**	**Ve mm ^{3}**
645.0	645.0	308.0	199000

INDUCTANCE

AL value (nH/T²)	Test conditions
Nom: 5500±25% :	10 kHz, < 0.5 mT, 25 ℃

MARKING

0P49925UC PXXXXX

CORE LOSSES

P_l max	Test conditions
< 32 W/set (< 161 mW/cm³)	100 kHz, 100 mT, 100 °C

NOTE

Spec. modifications	Previous	Revised
2005-11-21	B=56.8 Min. D=31.1 Min. Losses: General P material	B=56.7 Min. D=30.95 Min. Losses: Detail as indicated
2010-09-27	Al.4920 Nom Al.3650 Min.	Al.5500±25%

Figure 28: Ferrite U Shape Core Manufacturer Datasheet

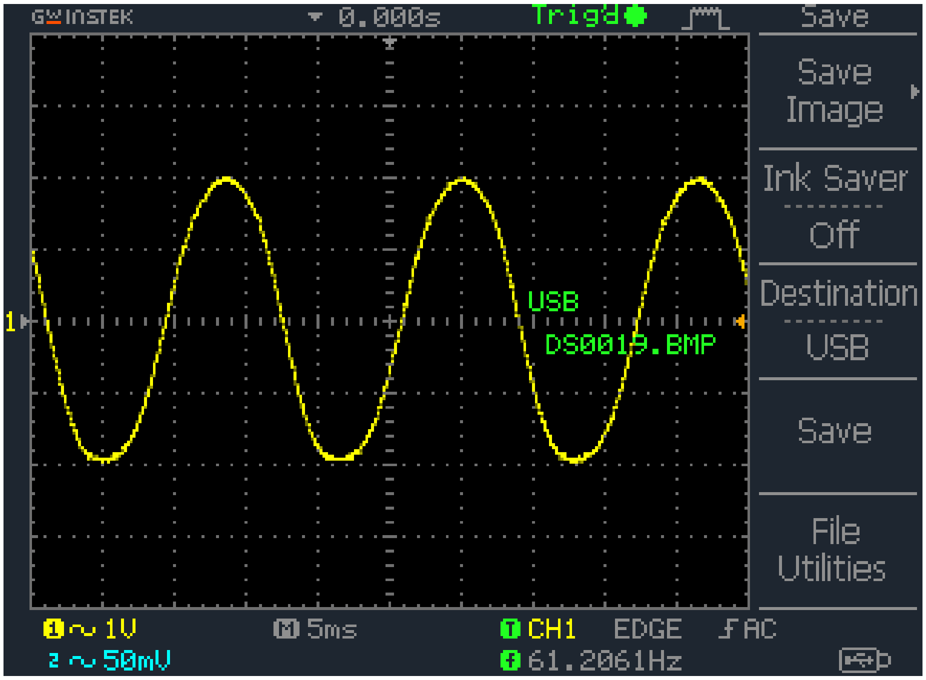


Figure 29: No Load Output Voltage using LTG First Configuration

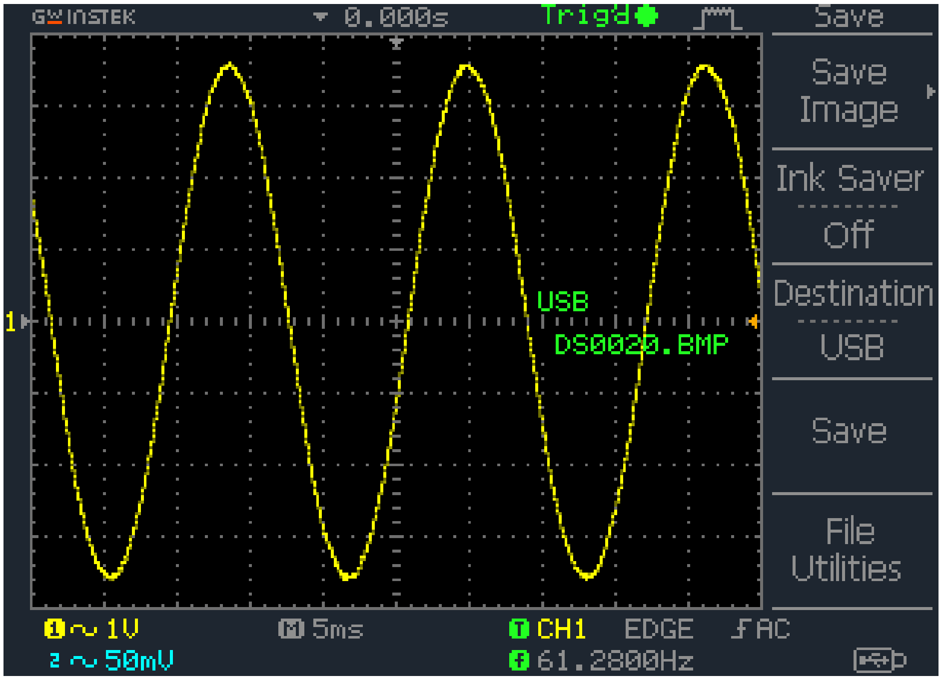


Figure 30: No Load Output Voltage using LTG Second Configuration

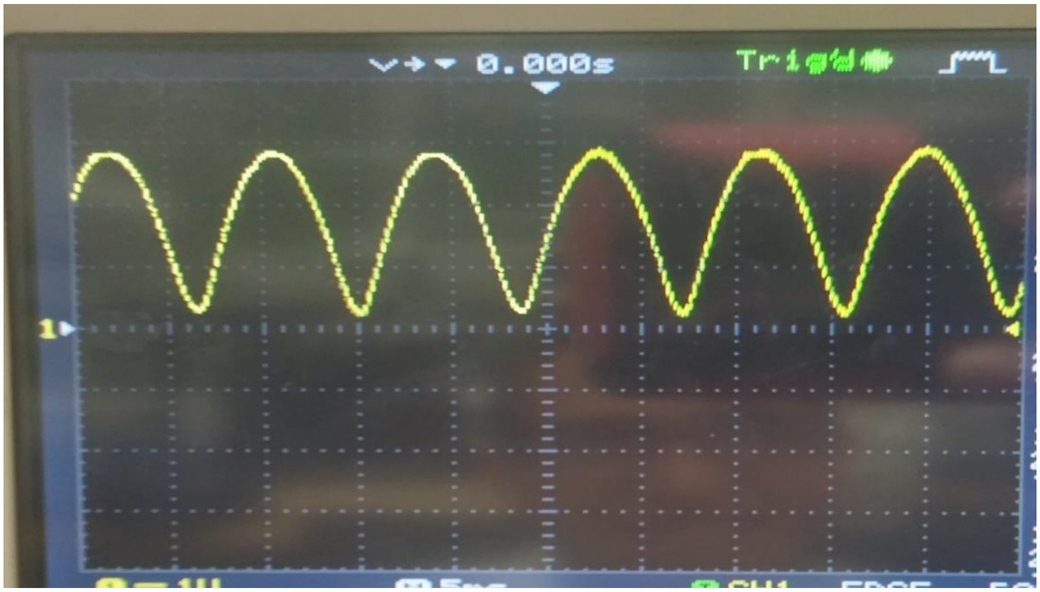


Figure 31: Bridge Rectification of the LTG Second Configuration

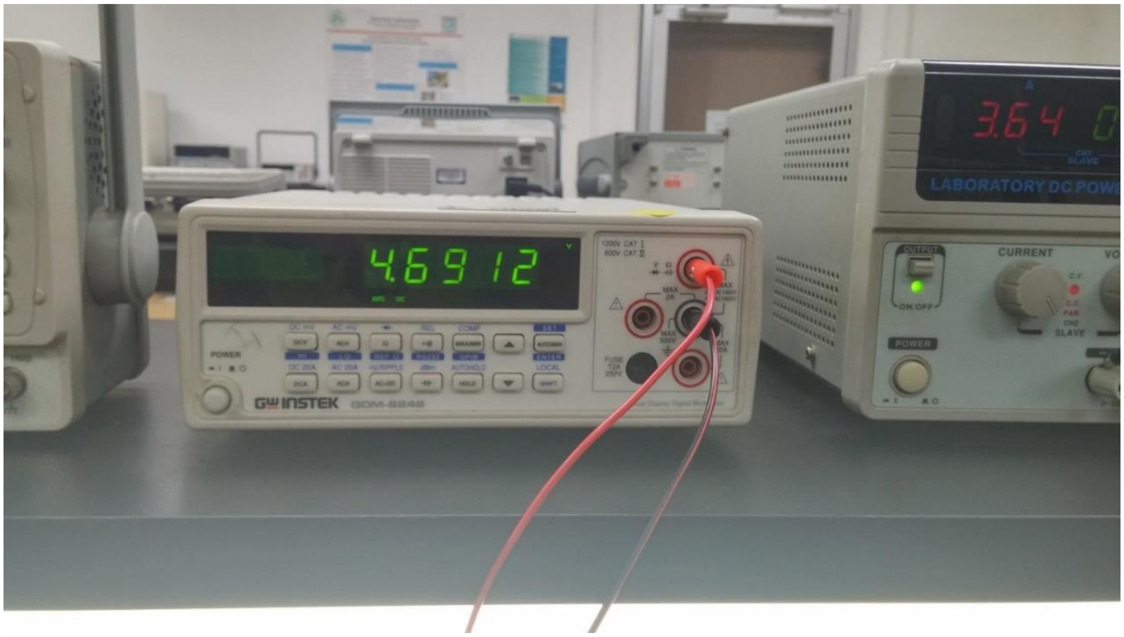


Figure 32: Lamp Voltage of the LTG Second Configuration using the Bridge Rectifier Circuit

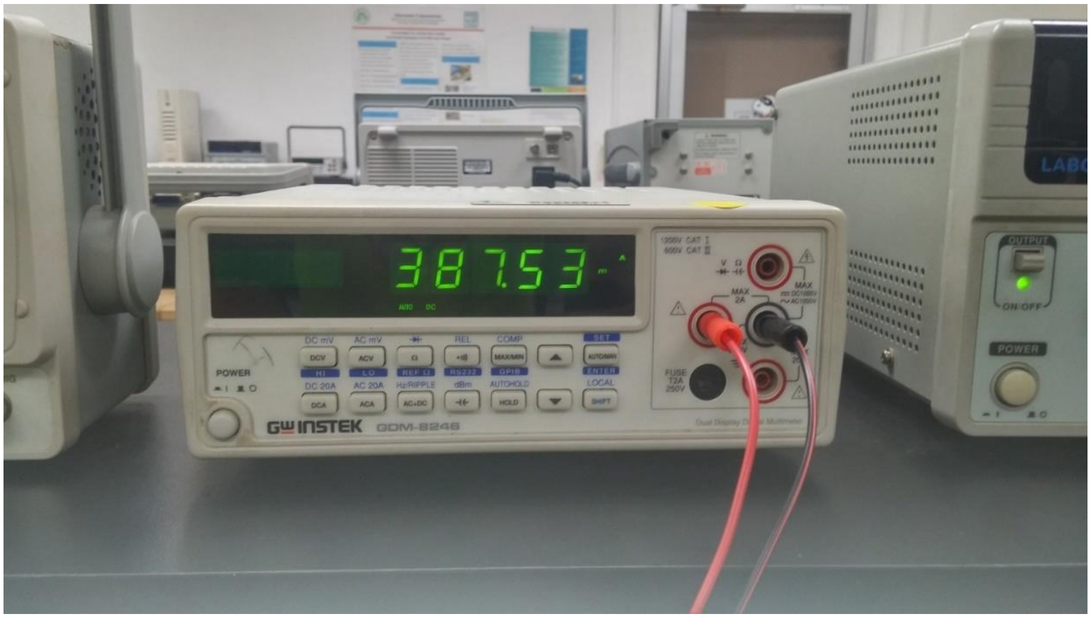


Figure 33: Lamp Current of the LTG Second Configuration using the Bridge Rectifier Circuit

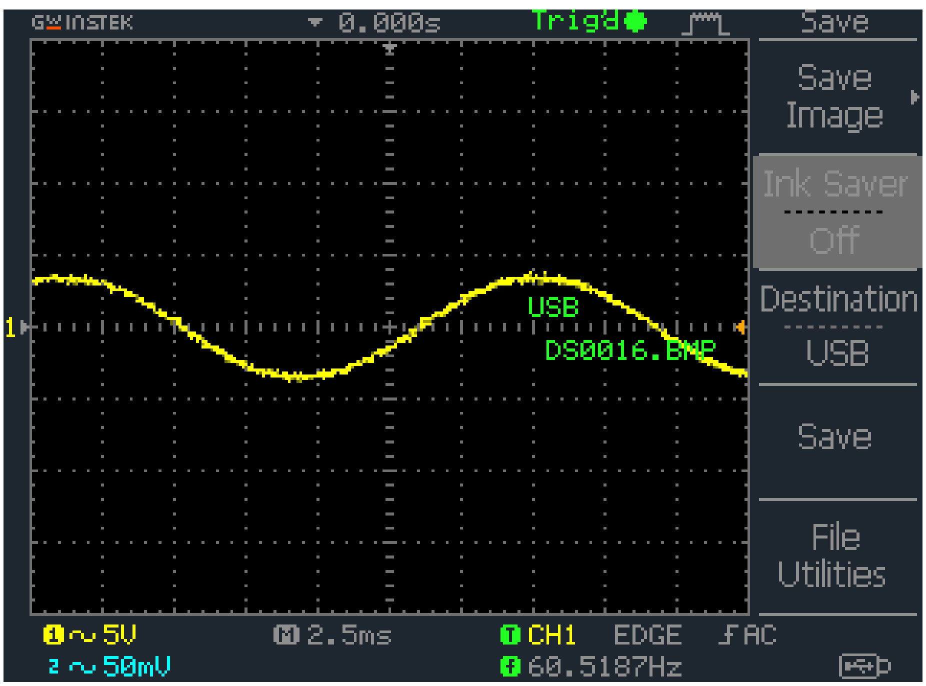


Figure 34: No Load Output Voltage using LTG Second Configuration at 60Hz

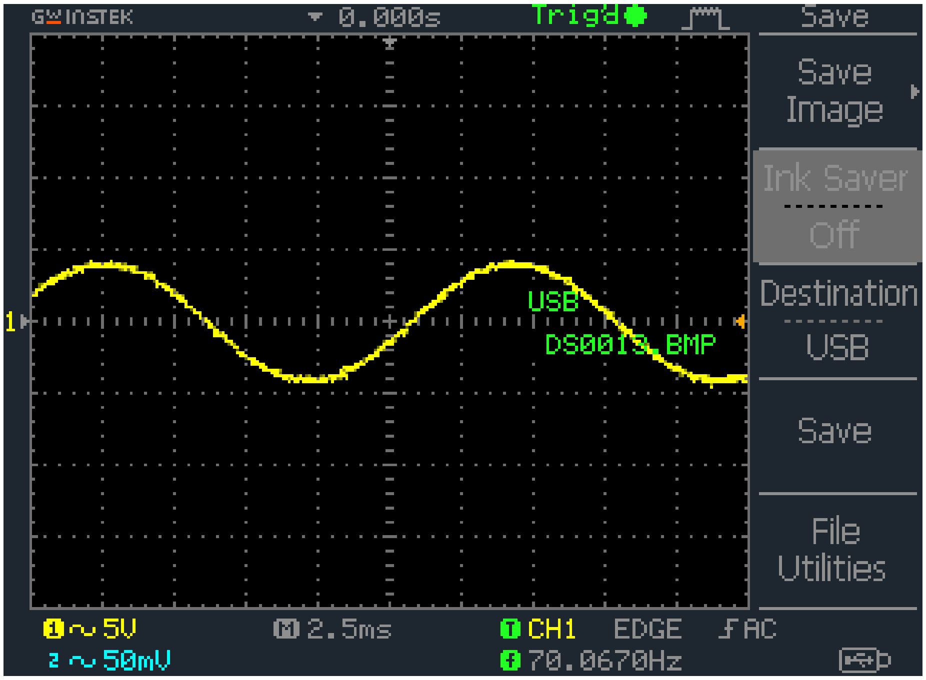


Figure 35: No Load Output Voltage using LTG Second Configuration at 70Hz

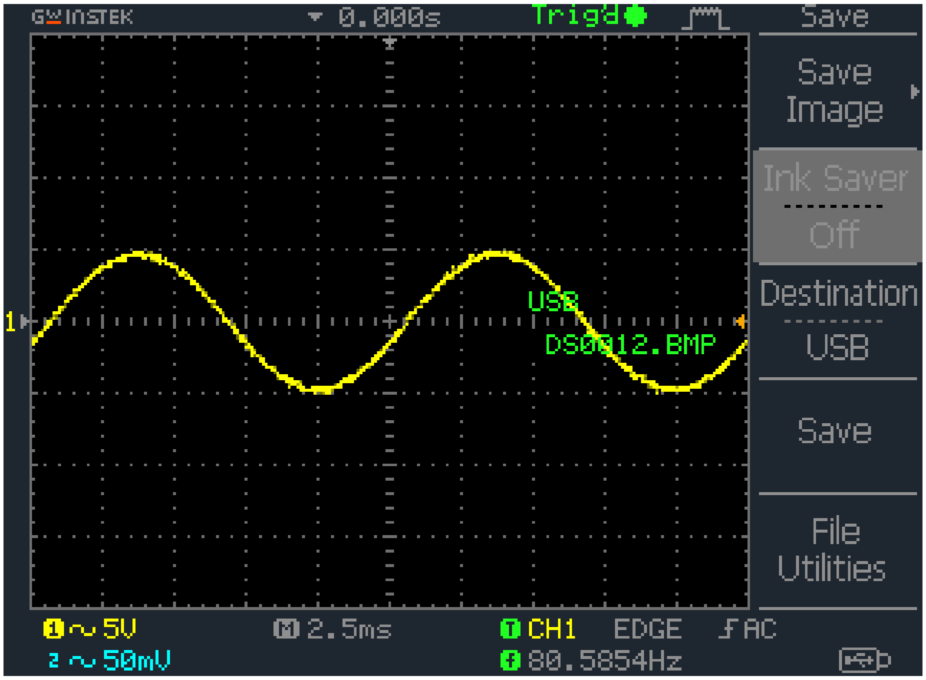


Figure 36: No Load Output Voltage using LTG Second Configuration at 80Hz

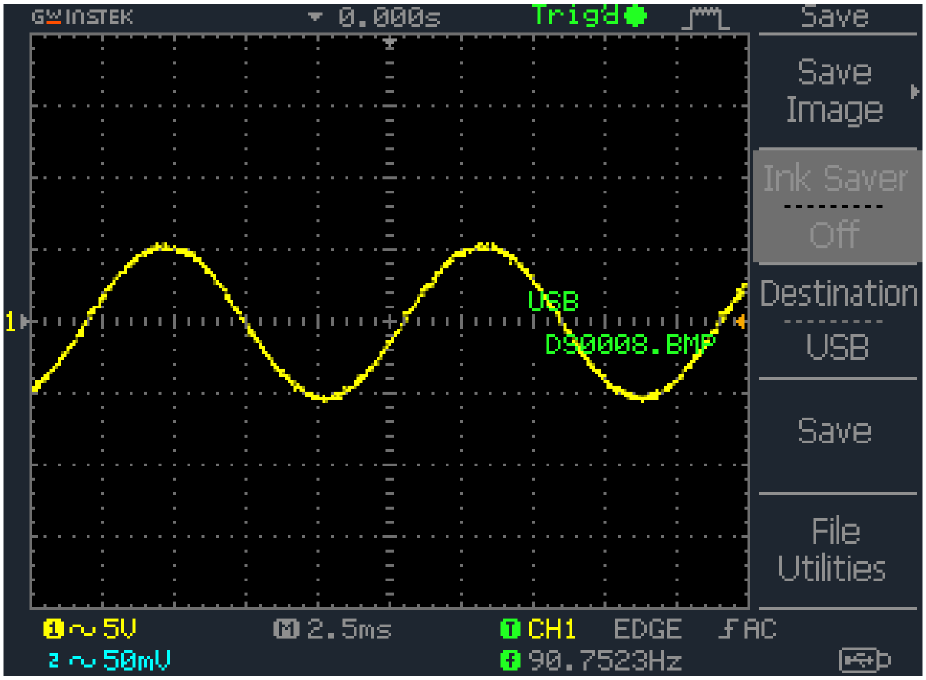


Figure 37: No Load Output Voltage using LTG Second Configuration at 90Hz

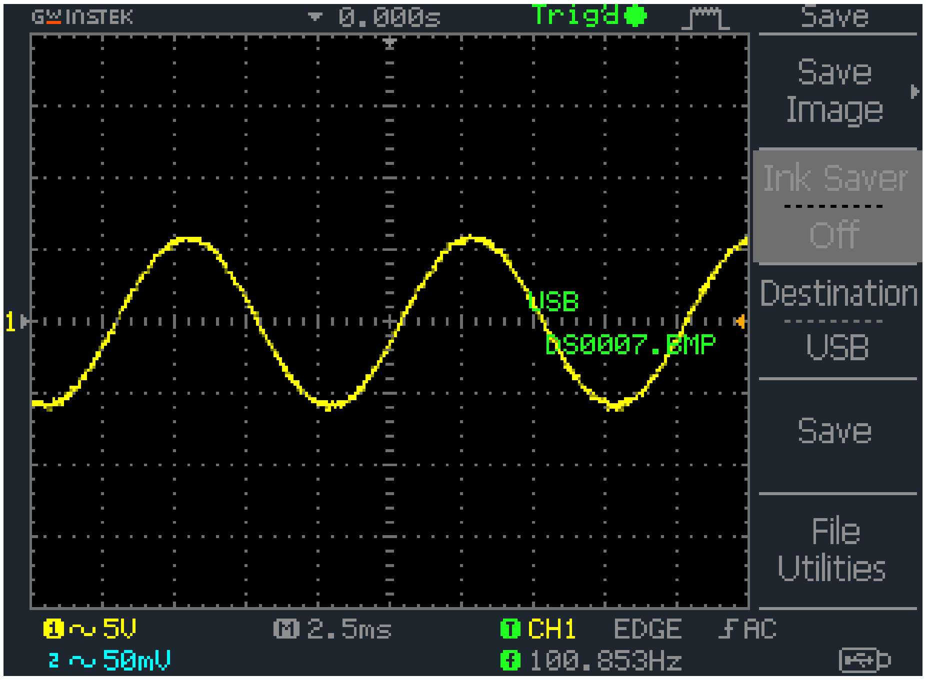


Figure 38: No Load Output Voltage using LTG Second Configuration at 100Hz

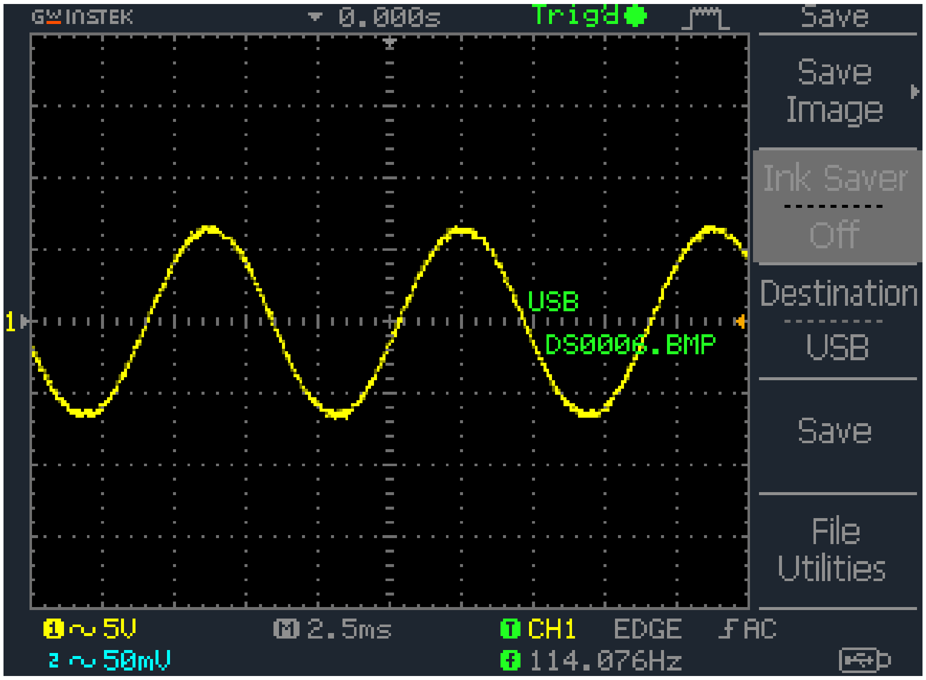


Figure 39: No Load Output Voltage using LTG Second Configuration at 114Hz

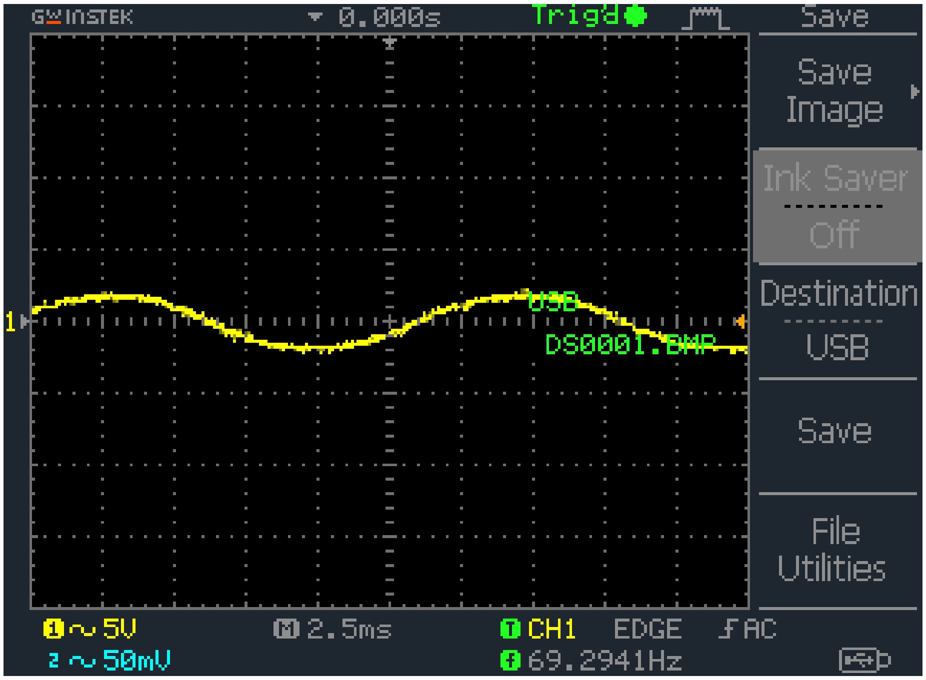


Figure 40: No Load Output Voltage using LTG Third Configuration at approximately 70Hz

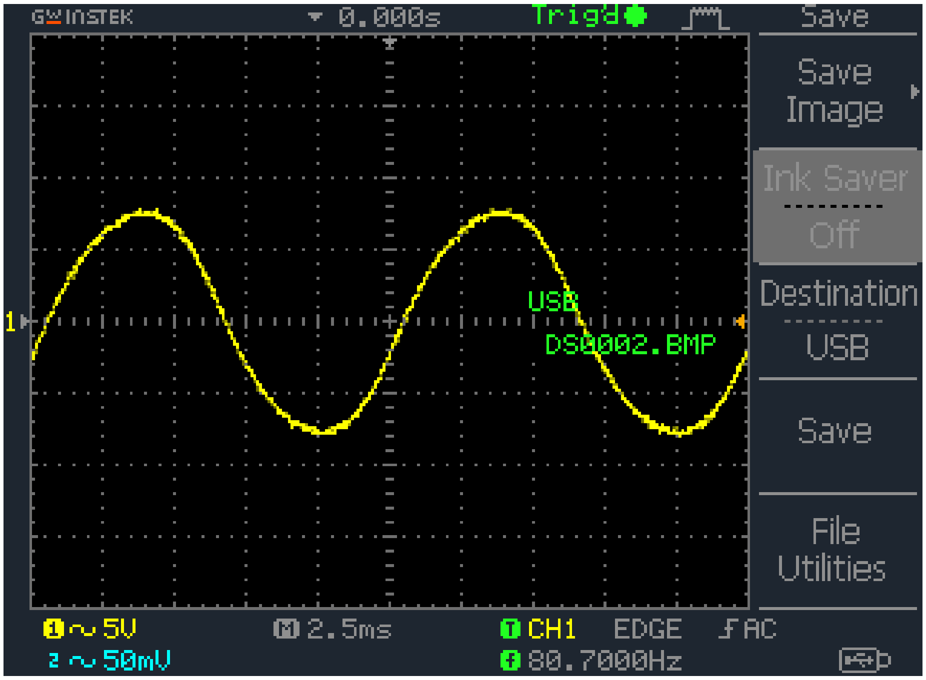


Figure 41: No Load Output Voltage using LTG Third Configuration at 80Hz

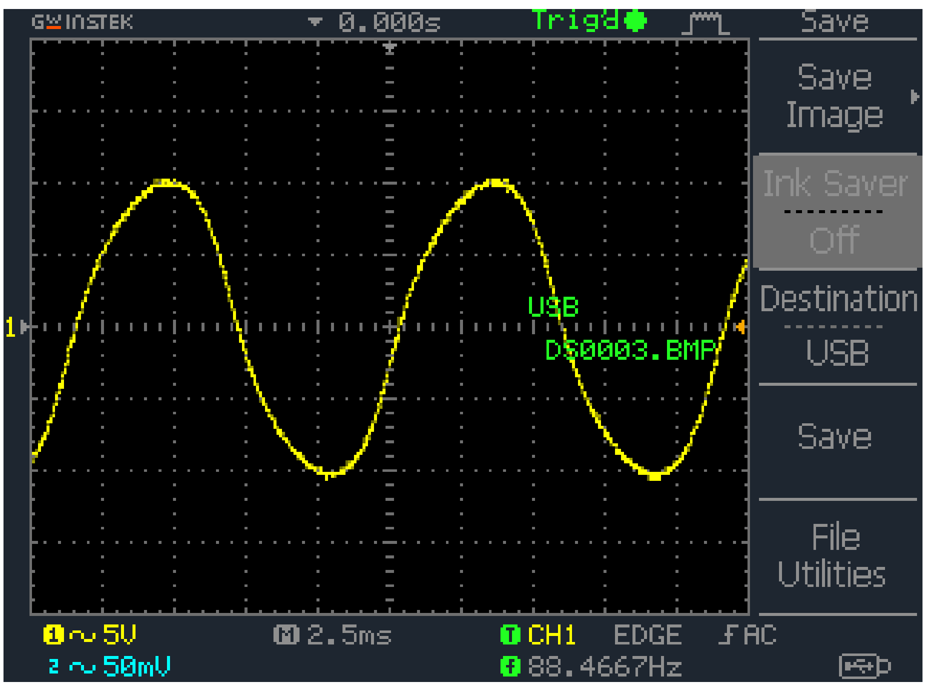


Figure 42: No Load Output Voltage using LTG Third Configuration at approximately 90Hz

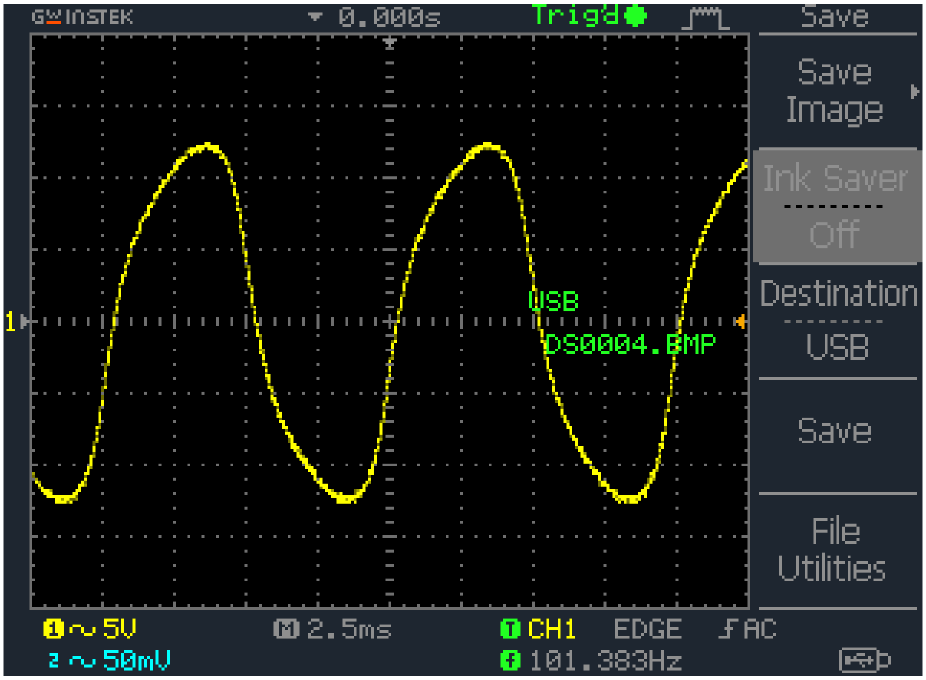


Figure 43: No Load Output Voltage using LTG Third Configuration at approximately 100Hz

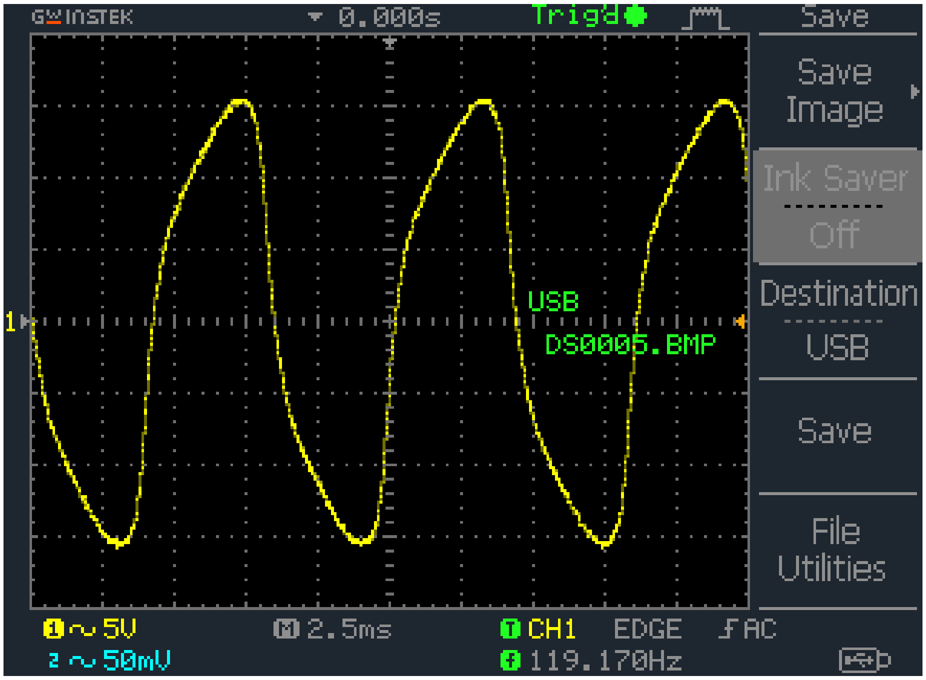


Figure 44: No Load Output Voltage using LTG Third Configuration at approximately 120Hz

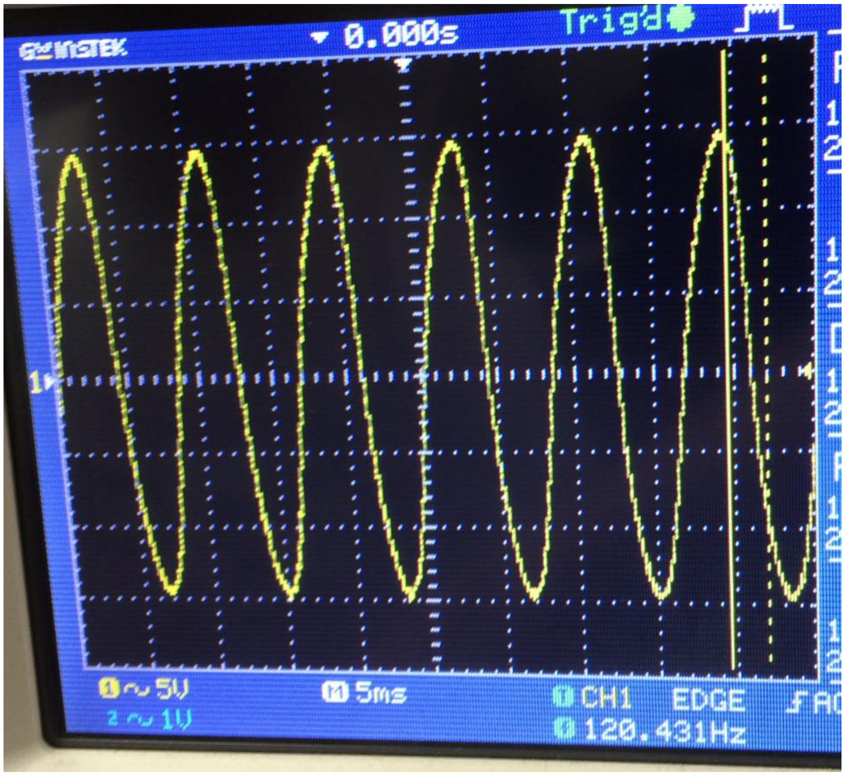


Figure 45: No Load Output Voltage using LTG Third Configuration at 120Hz with Less Waveform Distortion