***ELECTRIC POWER GENERATION UTILIZING KINETIC***

***ENERGY OF VEHICLES OVER SPEED BREAKER***

*By*

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# ABSTRACT

*Electrical energy is essentially required for industrial as well as all-round development of any country. The growing demand of electrical power for different activities has forced scientists and researchers to develop alternate sources of power generation from different sources of renewable energy. Nowadays the renewable energy sources have become more popular due to their sustainability, renewability and easy availability. One of the economical and environment friendly sources of electrical power generation is the utilization of kinetic energy of vehicles passing over speed breakers.*

*This thesis focused towards the studies on design, modeling and simulation of an electromechanical system for producing electrical power from kinetic energy of vehicles passing over speed breakers. The Speed breaker power generation unit is driven by a vehicle on the road which acts as a prime mover for power generation. The system is described in terms of the dimensions of the rack and ratchet. The pulley structure combined with a flywheel is geared to DC generators for inducing EMF which leads to power generation.*

*To facilitate simulation studies, mathematical model of the electromechanical system is developed under MATLAB 13B Simulink environment as well as a mutism 14 for power electronic modeling and simulation. Simulation results for power generation from kinetic energy of vehicles are obtained considering four units of rotational induction generators and two units of translational induction generators.*

*From the simulation results it is observed that for 2000 N vehicular load and for angular speed of the generator gear ranging between 0.8-0.806 rev/sec, the generated output voltage ranges from 11.91-12 V DC. A DC to DC converter is used to enhance the generated voltage level from 11.91-12 Volts to 24 V DC and finally an inverter is incorporated to convert 24 V DC to a single phase 220V, 50 Hz AC.*

*It is observed that the generated voltage is directly proportional to the angular speed of the generator gear. Further, it is found that the total power generated from the rotational induction generators is 691 kW while that from the translational induction generators is 8.2922 kW per day on 12-hour basis.*

*Electrical power generation from kinetic energy of vehicles passing over speed breakers has got many advantages because it does not require any type of fuel, no pollution at any stage of the power generation process. Therefore, it is recommended that EEPCo should come forward to create prototype of the proposed system and test it for implementation on the highways for considerable power generation alternative.*

***Keywords: Speed Breaker, Kinetic Energy, Translational Induction, Rotational induction, Boost converter, Inverter.***

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Last, but not least, I would like to express my deepest gratitude to my family and friends, who always believed in me and supported me. I would have achieved for less without their constrictive and continuous support. They have been my greatest mentors, and I owe all my success to them.

Finally, *I would like to dedicate this thesis work for those, who always struggle to come up with an efficient and green energy production alternative for our planet Earth.*

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# LIST OF VARIABLES

- $\omega_{ratchet}$ - *Angular speed of the ratchet gear*
- $\omega_{pinion}$ - *Angular speed of the pinion gear*
- $N_{ratchet}$ - *No. of tooth on ratchet gear*
- $N_{pinion}$ - *No. of tooth on pinion gear*
- $\delta$- Deflection of a spring
- $d$ – Diameter of a wire
- n – Number of springs
- $G$ – Modulus of rigidity
- $R$ – Mean diameter of a spring coil
- $W$- Effective designed load
- $n_a$- Number of active spring turns
- $n_t$- Total number of spring turns
- $p$- Pitch of a spring
- $l$- Actual length of a spring
- $n_t$- Total number of spring turns
- $p$ – Developed power
- K- Spring constant
- g- Acceleration due to gravity
- $x$- Spring deflection length

- Φ - Flux per pole
- Z - Total number of armature conductors
- $E_g$ – Induced emf in any parallel path in armature
- $\mu_0$ - Permeability of a free space
- z - Relative axial distance from the center of the coil to the magnet
- r - Average coil radial distance from the center of the magnet,
- $B_\rho$ - The radial component of the magnetic flux density
- $l_w$ - Total length of the coil wire inside the magnetic field.
- $\mu_0$ - Permeability ($4\pi\times10-7$ N/A$^2$) of a vacuum,
- $\mu$ - Magnetic dipole moment
- $\sigma$ – Electric conductivity
- $v$ – Velocity of a magnet
- $N$ - Number of turns wrung on the cylindrical pipe external part
- $V_i$ – Input Voltage
- $V_0$ – Average output voltage
- $t_{on}$ – "ON" state duration
- $t_{off}$ – OFF" state duration
- Ts - Switching period
- D - Duty cycle

- $I_i - A$verage input current
- $I_0 - A$verage output current
- $f_s$ – Swiching frequency
- $R$ – Equivalent load resistance
- A - Voltage gain
- $K_s$ – Packing coefficient
- $K_r$ – Filling coefficient
- $L_p$ – Net thickness of the iron package
- $K_u$ - Utilization factor
- ∅ - Flux per column
- $L_{gross} - G$ross thickness
- $\varepsilon_i$ - Induced emf per turns
- $I_1$ – Primary winding current
- $I_2$ – Secondary winding current
- $A_{copper}$ – wire diameter
- $B_P$ – Number of batteries wired in parallel
- $V_{sin}$ – Sinusoidal voltage peak magnitude
- $V_{tri}$ – Triangular carrier peak magnitude

# LIST OF ABBREVIATIONS AND ACRONYMS

FES - Flywheel Energy Storage System

FESS - Flywheel Energy Storage System

ESR - Equivalent Series Resistance

E.M.F - Electromotive Force

RMS - Root Mean Square

R.P.M - Revolution Per Minute

DC - Direct Current

CCM - Continuous Conduction Mode

DCM - Discontinuous Conduction Mode

PWM - Pulse Width Modulation

Op-Amp - Operational Amplifier

AGM - Absorbed Glass Mat

RPS - Revolution Per Second

AH - Ampere Hour

EEPCo- Ethiopian Electric Power Corporation

DG - Distributed Generation.

# CHAPTER 1
# INTRODUCTION

## 1.1 BACKGROUND

The growing demand of power for a variety of human activities cannot be answered without continuous efforts of exploring better options and application of sustainable energy sources. Today power has become one of the major needs of human life however, one of the fear of the generation is whether the current energy sources continue to generate the required amount which has a progressive trend across generation. Hence, dreaming future days with insufficient or no electricity makes the generations' future very difficult or impossible. Therefore, such conditions call an integrated research approach on power generation and it is our responsibility to work and come up with a possible means of sustainable and green energy production for satisfying our day to day progressive energy requirements and makes the planet earth a better place to live in.

The rapid industrialization, growing technology and expansions have demanded very high power of electricity that is increasing day by day and thereby the world is facing energy crisis due to limited power resources. The electricity generation greatly depends on conventional sources, which is limited in amount and some are harmful for the environment. Therefore, it is critical to explore an environmental friendly and sustainable energy source. In order to reduce the greenhouse gas emission, the renewable energy sources are now widely utilized for electricity generation. Among different renewable energy production technologies, solar and wind technologies are widely used for large scale electricity generation. Though still a small percentage of renewable resources are exerted for electricity generation, the researchers are trying to improve technologies so that the green electricity can be economically feasible, environmentally friendly and sustainable in the electric production industry.

The day-to-day increasing population and decreasing quantity trend of conventional sources for power generation, provides a need to think on other energy resources. States are working toward the development of non-conventional sources for power generation. Due to the reasons that conventional sources of power are releasing live risking byproducts which are causing huge problems to humans and all living things on the planet earth. They are getting scarcer due to continuous exploitation of high amount. Energy harvesting is related to developing a mechanism for driving energy from different sources and energy of today's world is mainly generated from conventional energy sources which mostly are decreasing day by day. Moreover, these conventional energy sources cause pollution and are responsible for global warming. To solve these problems, researchers are trying frequently to explore new energy sources which are clean, environment friendly, sustainable, and promising in order to meet the future electricity demand of the generation. And it is also essential to focus more on renewable (unconventional) energy sources for electricity generation and it is also paramount to think more specific to the utilization of kinetic energy which is helpful to reducing dependence on conventional sources of electricity generation [1].

## 1.2 STATEMENT OF THE PROBLEM

The various energy resources are required for generation of electrical power and supply of energy. Expected energy crisis has led to the idea of generating electrical power using diversified and renewable energy resources to sustain the requirement of power and energy demands. The number of vehicles passing over speed breaker is increasing day by day but little efforts are being made to generate power from vehicles passing over speed breakers. In this thesis work, an attempt is made to study, investigate and analyze electric power generation from the kinetic energy of vehicles over the speed breakers. It is expected that that electric power generation from the vehicles passing over speed breakers will help to reduce the load demand on conventional power plants.

## 1.3 OBJECTIVES

### GENERAL OBJECTIVE

The main objective of this thesis is to study, investigate and analyze electric power generation utilizing the kinetic energy of vehicles over the speed breakers.

### SPECIFIC OBJECTIVES

The specific objectives of the thesis include the following

- To study and analyze mathematical model of the electromechanical system of power generation from kinetic energy of vehicles.
- To determine the amount of power and energy generated from the vehicles passing over speed breakers.

- To design the power electronic circuitry to convert the generated DC power to a single phase 220 voltage AC System
- To Carry out the simulation studies using the developed model of the system
- To determine the size and select the suitable energy storage mechanism for storing the generated energy for further use.
- To analyze the results and make a recommendation based on conclusions.

## 1.4 LITERATURE REVIEW

The energy crisis is one of the great bottlenecks in the supply of energy resources to an economic development. The studies to sort out the energy crisis led to the idea of generating power using speed breaker. Firstly, South African electrical crisis has made them implemented this method to light up small villages of the highway. The idea is basic physics, to convert the kinetic energy into electrical energy that gone wasted when the vehicle runs over speed-breaker [2]. While moving, the vehicles possess some kinetic energy and it is being wasted. This kinetic energy can be utilized to produce power by using a special arrangement called Power Hump, which comprises Electro-Mechanical unit. All this mechanism can be housed under the dome, like speed breaker, which is called Hump. It utilizes both mechanical technologies and electrical techniques for the power generation and its storage whenever the vehicle is allowed to pass over the dome it gets pressed downwards, then the springs that are attached to the dome are compressed and the rack, which is attached to the bottom of the dome moves downward in reciprocating motion. Since the rack has teeth connected to gears, there exists conversion of reciprocating motion of rack into rotary motion of gears but the two gears rotate in opposite direction. A flywheel is mounted on the shaft whose function is to regulate the fluctuation in the energy and to make the energy uniform and so, the shafts will rotate with certain rpm. These shafts are connected through a belt drive to the dynamos, which converts the mechanical energy into electrical energy and the conversion will be proportional to the traffic density [3,4] Since then, a lot has been done in this field.

An amateur innovator, Kanak Gogol in Guwahati has developed a similar contraption to generate power, when a vehicle passes over speed-breaker. The idea has caught the eye of IIT-Guwahati, which funded the pilot project related to generate electricity from speed-breakers. They have evaluated the machine and recommended to the Assam government. Their work has provided the need to think on this alternative to generate electricity on the large scale, as it proves to be a boon to the economy of the country [3].

We have to investigate some approximate, alternative, new sources for the power generation, which is not depleted by the very few years. It suffers all the living organisms of all kinds as on the land, in aqua and in air. Power stations and automobiles are the major pollution producing places. Therefore, we have to investigate other types of renewable sources, which produce electricity without using any commercial fossil fuels, which is not producing any harmful products. Already there existing such systems using renewable energy such as solar, wind etc. for power generation. The latest technology which is used to generate the power by such renewable energy is “power generation using speed breaker” [5] where crank-shaft and spring mechanism is applied. In this system, a new mechanism called roller mechanism is introduced to generate electricity from speed breaker by converting vehicle kinetic energy to mechanical energy. As the vehicle passes over the speed breaker wasted kinetic energy can be converted into the rotational motion of roller to generate electricity. Such new mechanism provides higher efficiency and higher output at a lower cost than the mechanism used previously. A roller having some kind of grip is placed between the speed-breaker and so, when vehicle pass over the breaker, it rotates the roller [6].

A number of researches have been done in this project. ln some countries it has been implemented. Implementation of a project named “Power Generation from Speed Breaker by Rack and Ratchet Mechanism” by researchers of Kshatriya College of Engineering [6].

There are papers published regarding energy production using the specified method, to mention some of the published papers on the International Journal of Engineering Science and Innovative Technology (IJESIT) in titled “Generation of Electricity Using Road Transport Pressure” by researchers of Rajshahi University of Engineering &Technology [7]. Amanpreet Kaur, Shivansh Kumar Singh, Rajneesh, Parwez, Shashank, described such phenomenon with a paper in titled “Power Generation Using Speed Breaker with Auto Street Light”, on International Journal of Engineering Science and Innovative Technology [3]. "Intelligent Traffic Signal Control System Using Embedded System” by Dinesh Rotake et al. is another important paper reveling the promising nature of the resource and technology [8,9]. A related paper in titled "Development of A Microcontroller-Based Traffic Light System for Road Intersection Control” by Ganiyu R. A.et al. explores the design and implementation of a microcontroller-based traffic light system for road intersection control after pointing mechanisms to explore such energy enhancing alternative [8].

Many researchers are trying to develop system to meet the roadside energy consumption via clean, environment friendly and sustainable way. C. K. Das et al. showed the possibility of tapping the wasted kinetic energy in the road speed breaker using roller mechanism [5]. Researchers of Kshatriva College of Engineering, Chepur, Armoor, Nizamabad implemented a power generation system from speed breaker by rack and ratchet mechanism [6]. A system using road transport pressure to generate electricity developed by Md. Saiful Islam et al [7]. Abdul Razzak Pathan et al. proposed power generation system through speed breaker using rack and pinion mechanism [12]. A system developed by Shakun and Asthan to produce electricity from speed breakers using roller mechanism [8]. A paper was published on IOSR Journal of Electrical and Electronics Engineering named design of power generation unit Using Roller Mechanism [11, 12]. Alok Kumar Singh et al. implemented a system for electricity generation through speed breaker based on spring coil mechanism [13]. Researchers of Rajshahi University of Engineering & Technology designed a system to generate electricity using road transport pressure [3]. D. Venkata Rao et al. designed a power generation system using speed breaker [14]. Aniket Mishra et al. published a paper on electricity generation from speed breakers [15]. Electrodynamics based models by Ankita and Meenu Bala to generate power from speed breaker [16] have also been suggested, but can’t be used a large scale very easily due to its cost and complicated calculation.

Power can be produced from conventional and non-conventional energy sources. But power generation from vehicle pressure limited to the rack-pinion, spring-coil, crank-shaft and roller mechanism. Rack-pinion mechanism is used to generate electricity using speed breaker, which provides a means for harvesting the potential energy to rotational energy and rotational energy to electrical energy final format [17]. Speed breaker, rack and pinion combination, springs, freewheeling bearing, gear combination, micro generator, charging circuit, battery, dark sensing & switching circuit, inverter circuit, step up transformer and street light are used to design the system in the research work of students from Chittagong University of Engineering and Technology with paper in titled “Roadside Power Harvesting for Auto Street Light” by 2015.

Flywheel energy storage system (FES) is getting more and more attention during the last few decades. Compared with other energy storage techniques namely, Superconducting energy storage and Super capacitance energy storage technique. FES technique is mostly used in electromagnetic launch applications system (EML), which is mainly attributable to the fact that is provides more design flexibility, does not depend on the breakthrough of certain critical technology, and thus are particularly attractive for long-term high-speed operation, which is essentially a great importance for FES systems.

Flywheel technology has been considered an attractive energy storage choice due to its potential for reduced weight and volume, high duty-cycle tolerance, and low maintenance requirement [18,19]. Another topology is presented that, the FES system is used to deliver the storage energy to the generator to get its rated speed, because the flywheel store energy in terms of inertia [20].

An electromechanical flywheel energy storage system is used to enhance the electrification, where the various machine topologies have been used to design for high-speed application such as convention inductance machines, synchronous reluctance motor, switched reluctance machine are designed and developed for FES system, but most commonly permanent magnetic generator (PMG) used for high-speed fly-wheel system needed for low power requirement loads [21].

For system comprising a spring component it is obvious the system will regain its previous position when the applied force is removed but for such type of system with Flywheel the up and down movement of the rack and the spring result uni directional rotation or displacement due to the presences or the “Regulatory Flywheel” therefore the system in general will develop a longer displacement or rotation delay [9, 21].

Electromagnetic or Magnetic induction is the production of an electromotive force or voltage across an electrical conductor due to its dynamic interaction with a magnetic field. Michael Faraday is generally credited with the discovery of induction in 1831, and mathematically described it as Faraday's law of induction. Lenz's law describes the direction of the induced field. Faraday's law was later generalized to the Maxwell-Faraday equation, which is one of the equations in James Clerk Maxwell's theory of electromagnetism. Electromagnetic induction has found many applications in technology, including electrical components such as inductors and transformers, and devices such as electric motors and generators [22].

A single magnet falling without acceleration inside a vertical conducting pipe is frequently presented in lectures, demonstrations, science exhibits, and in literature [23]. Magnetic braking has also been studied in the context of a con-ducting disk rotating between the poles of a magnet [24].

The fall of a strong magnet inside a conducting pipe is damped by the gradually increasing and opposing magnetic force that the pipe wall exerts on the magnet. The braking force on the magnet arises from circular eddy currents, also known as Foucault currents. These eddy currents are generated in the pipe by the emf induced in the pipe by the time-varying magnetic flux that the falling magnet produces [25].

A well-known problem in electromagnetics is the famous creeping magnet experiment. The “creeping magnet” were a permanent magnet is dropped inside a vertical copper pipe whose diameter is only slightly larger than that of the magnet. Shortly after its release the magnet reaches a steady velocity that is significantly less than the free fall velocity, as if the magnet was creeping through a highly viscous fluid. The cause of the retardation are eddy currents induced by the movement of the permanent magnet inside the electrically conducting (nonmagnetic) pipe. These eddy currents generate a secondary magnetic field which counteracts the field of the permanent magnet and thus slows down its fall [26].

Derby and Olbert [27], Partovi and Morris [28], and Knyazev et al. [29] evaluated the braking force on falling magnets through conducting pipes. In these studies, they considered the interaction between the primary magnetic field of the magnet and the secondary field from the induced eddy currents, leading to field suppression and skin effect in case of high velocities. Because of its ease and inexpensive realization, it is a great illustration of Faraday's law of induction. In the paper the analytical calculation of motion-induced eddy currents in the case of harmonic motion of current carrying coils or permanent magnets in the vicinity of electrical conductors was studied. Despite the academic nature of this problem, analogies can be found in many modern engineering problems where oscillations occur and motion-induced eddy currents together with the associated forces are utilized [30].

This thesis work attempts to study and analyze power generation alternative from renewable resource, using specialized speed breaker topology. In the system study, we try to imposing two type of induction techniques, translational and rotational induction. In the system study units are studied and  confined to a single set for power generation mechanism, as well to bring the induced voltage to a single phase voltage specification.

## 1.5 SIGNIFICANCE OF THE STUDY

This thesis work will provide environmental friendly electric production technology alternative with simple construction, mature technology and easy maintenance and also energy available all year round with minimal space consumption and able to provide electricity near the load center supporting all the advantage granted for Distributed power generation.

## 1.6 METHODOLOGY

The first step towards achieving the objectives of this thesis is the design and modeling of Electro Mechanical system which mainly comprise rack and pinion mechanism with a spring unit. The model is based on vehicular weight and traffic density or vehicular flow rate as a driving input for the proposed speed breaker system. The pinion driven by the rack is used to convert the linear motion of the rack to angular displacement. CATIA 5 software is used to develop model of the mechanical system and to evaluate the performance of the system for the proposed vehicular weight.

Depending on the relative motion path, between the conductor and the magnetic field, two types of induction mechanisms namely, rotational induction and translational induction are considered for electric power generation. A permanent magnet Direct current (DC) generator is coupled with the pinion to convert the kinetic energy of the vehicles over speed breakers to electrical energy by the process of electromagnetic induction.

The proposed model will provide power only when there are vehicles over the speed breaker unit. To solve the above-mentioned problems the system also accompanied with power electronics circuitries to bring the generated voltage to 12V Dc voltage level and then to 24V Dc voltage level and finally with the help of an inverter and single phase step up transformer the 24V DC voltage will be transformed to 220 V,50 Hz single phase Alternating current (AC) voltage specification. The DC-DC and DC- AC power electronics circuitry was design and simulated using Electronic simulation technique, Multisim14 software. Finally, suitable and adequate battery storage unit was sized to provide electricity at the required time.

## 1.7 ORGANIZATION OF THE THESIS

The thesis is sub-divided into five chapters. Chapter one presents background of the study, statement of the problem and objectives of the thesis. It also includes literature review, significance, methodology and scope of the study.

Chapter two deals with the design and modeling of electromechanical systems used for electric power generation from waste kinetic energy of vehicles while it moves over the speed breakers. Determination of waste kinetic energy of vehicles and electrical power generation using this energy is also presented in detail.

Chapter three provides description of a mechanism for interfacing the mechanical and electrical units including DC-DC boost converter, DC-AC converter, Pulse width Modulation (PWM) signal generator, switching circuit, step up transformer and electric energy storage mechanism.

Chapter four presents details of simulation model, simulation studies and analysis of the results.

Chapter five gives conclusions and recommendations based on the results of this thesis. Suggestions for future work are also provided at the end of this chapter.

# CHAPTER 2

# DESIGN AND MODELING OF ELECTROMECHANICAL SYSTEMS

## 2.1 INTRODUCTION

Chapter two presents the design and modeling aspects of the electromechanical Units. The Electromechanical unit mainly comprises a Spring, Rack, Pinion (Ratchet gear), upper and lower metallic plates, hollo pipes

## 2.2 MECHANICAL UNIT DESIGN

Whenever a vehicle is allowed to pass over the speed breaker system it gets pressed downwards then the springs which are attached to the moving portion of the system will be compressed and the rack which is attached to the upper speed breaker plate will move downward in the same direction. The rack has teeth which, connected to a specific gear. Therefore, there exists a conversion of linear motion of rack into rotary motion of gears since a rack -pinion arrangement was employed in the system.

A flywheel which, mounted on the permanent magnet generator shaft whose function is to regulate the energy fluctuation and to make the energy uniform. So, that the shafts will rotate with certain R.P.M., these shafts are connected through gears to “small” DC generators, which convert the mechanical energy into electrical energy. The conversion will be proportional to traffic density. Whenever an armature rotates in a magnetic field the Electro motive force is induced. Therefore, for the E.M.F induction an armature coil has to rotate, for rotating this armature it is connected to a shaft. By rotating the DC generator shaft the same E.M.F. will be induced, for this rotation the kinetic energy of moving vehicles will be utilized as source of energy. The propose model developed and the general lay out for the mechanical portion is illustrated in sketch diagram (Figure2.1.)

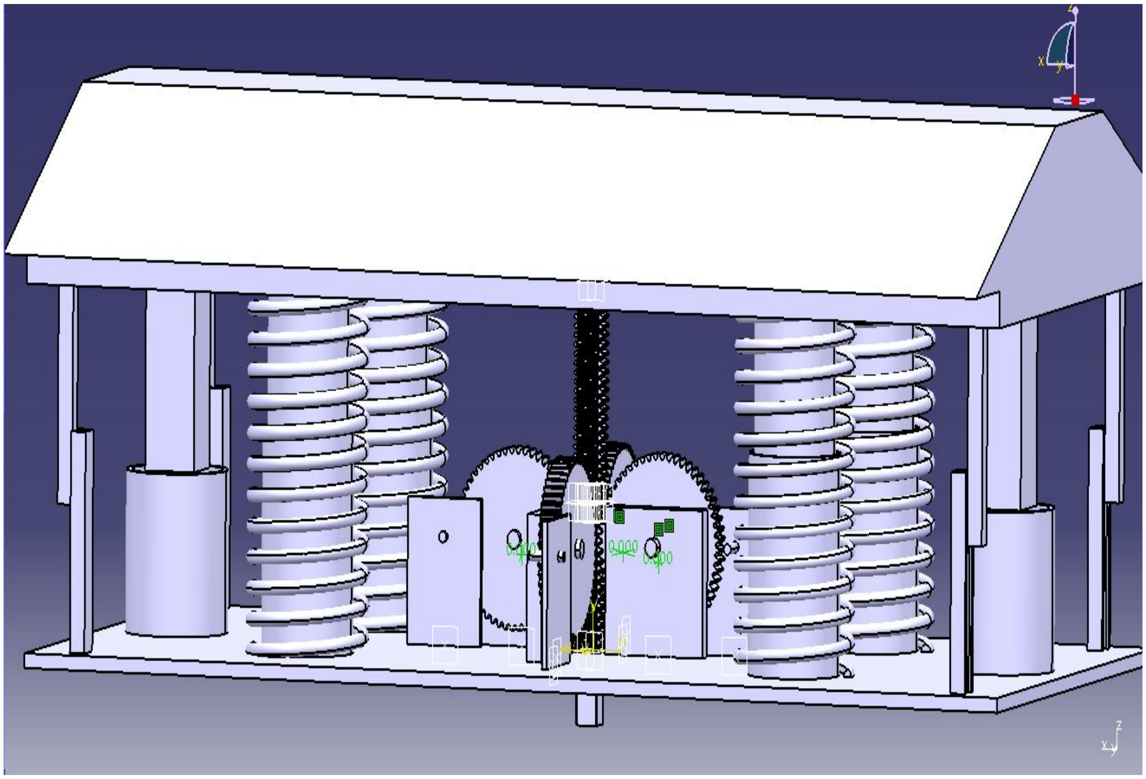


**Figure 2. 1 The proposed System speed breaker unit**

The power generating system mainly comprise an electromechanical system. For simplicity and better visualization, we designed the general system in two phases, in the first phase Mechanical unit designed using CATIA 5 (Appendix I**)** and in the second phase Electrical unit mathematical modeling developed.

**RACK AND PINION GEARS**

The rack and ratchet is used to convert the rotary motion in to linear motion. The rack is a flat toothed part and the ratchet is a geared circular portion. The diameter and the number of tooth of the gear determine the speed that the rack moves as the pinion turns. Rack and pinions are commonly used in the steering system of cars to convert the rotary motion of the steering wheel to the side to side motion in the wheels. In addition to that a ratchet is a mechanical device that allows continuous linear or rotary motion in only one direction while preventing motion in the opposite direction. Rack and ratchet gears provide a positive motion especially compared to the friction drive. In to consideration of the above facts for our system we employ flywheel for regulatory purposes and the ratchet gear for unidirectional displacement.

For the speed breaker, a 10 cm effective vertical rack penetration with a driving load of 2000 N was assumed to model the system as well as to estimate the possible kinetic energy that can be trapped by the system and further more mathematically to develop the possible electric power generation capability. With the above specified assumption, plus with an assumption of vehicles frequency at the speed breaker with Ten seconds (10s), the mechanical units and possible input output relationship developed as shown below.

**The Rack speed is given by**

$$v = \frac{length\ traveld\ by\ the\ rack}{time\ taken\ for\ the\ travel}$$

$$v = \frac{dl}{dt}$$

$$= 10 / 10$$

$$v_{rack} = 0.01 \text{ m/sec}$$

**Ratchet Angular Speed**

$$Angular\ speed\ = \frac{linear\ speed\ of\ the\ driving\ system}{Radius\ of\ the\ angular\ system}$$

$$\omega_{ratchet} = \frac{v_{rack}}{r_{ratchet}}$$

$$\omega_{ratchet} = 0.0806\ rad/sec$$

**Angular Speed of the Pinion (DC-Generator driving Gear)**

$$\frac{\omega_{ratchet}}{N_{ratchet}} = \frac{\omega_{pinion}}{N_{pinion}}$$

$$\frac{\omega_{ratchet}}{\omega_{pinion}} = \frac{N_{ratchet}}{N_{pinion}}$$

$$\omega_{generator\ gear} = \omega_{pinion} = 0.0403 \text{ rad/sec}$$

$$= 0.0642 \text{ rev/sec}$$

In account to the "regulatory flywheel" and the ratchet gear the two-directional displacement of the rack as a uni-directional impact and to come up nearly with 0.1284 rev/sec angular speed.

**Compression Spring Design**

Compression spring can be defined as an elastic body that distorted when loaded and recover its original shape as well as position when the applied impact is removed. It cushions, absorbs or controls energy either due to shocks or due to vibrations.

In our system design, the actual height of the spring was made 500cm and the number of turns in the spring to get the deflection of 10cm for the proposed rack penetration was determined as shown below

$$n_a = {}^{\delta G d^4}/_{64WNR^3}$$

$$n_a = {}^{\delta G d^4}/_{64WNR^3}$$

= 100* (*8*10^5) *(40^4) / (64*2000* 4 *(400^3)

$$n_a=5$$

$$n_t = n_a + 2$$

$$n_t= 7$$

With the above specification, the pitch of the spring was calculated as

$$p = {}^{l}/_{n_t}$$

$$= \frac{500}{7}$$

$$= 70\ cm$$

The spring constant of the system calculated as

$$k = mg/x$$

$$= 2000/0.1$$

$$= 2 * 10^4 N/m$$

We assumed Four (4) springs. Therefore, for an individual spring we should come up with a spring constant of

$$k_w = k_{tot}/N_s$$

$$=2 * 10^4/4$$

$$= 5 \text{ kN/m}$$

## 2.3 ESTIMATION OF THE WASTE KINETIC ENERGY

The average weight of a vehicle loaded over the speed breaker that will ride over the speed breaker rack for a 10 cm vertical displacement approximately estimated to be nearly 2 $kN$

Work done = weight of the body * distance travelled by the vehicle

Distance traveled by the body = Height of the speed breaker = 10cm

$$W = \frac{1}{2}mv^2 = mgh$$

$$=2000 * 0.1$$

$$= 200\text{J}$$

Power = Work done/time

As it already specified above for any vehicle to force the speed-breaker rack a penetration of 10 cm depth a maximum of ten (10 s) seconds time period is elapsed.

$$p = \frac{dW}{dt}$$

$$= 200/10$$

$$= 20 \text{ w}$$

With the help of the “regulatory Flywheel” and ratchet mechanism, which is capable to unify the up and down movement of the rack to a uni-directional displacement, the above power can be sum up as a uni directional impact therefore the total estimated power should be 40 w. Output Power developed for a vehicle passing over the speed breaker arrangement for one hour will be

$$= 40* ((60*60) /10) = 14.4 \text{ kw}$$

Energy developed for 12 hours = $\sum_{n=1}^{12}$ Power developed for an hour

$$=12*14.4*10^3$$

$$= 172.8 \text{ kWhr}$$

Generally, four identical Electric producing units are accompanied within the system therefore, total estimated energy that can be trapped from the system will be four times of a single unit, ($4 * 172.8*10^3 \approx 691.2$ kWhr) 691 kWhr.

As shown above the maximum possible power that can be extracted within 12hrs/per day bases is estimated 691 kWhr. As the system is exposed for two directional impacts, during the force is applied the rack goes down and when the force is removed it goes up ward to its previous position. Through the process of the rack trying to restore its original position; with the help of the Fly wheel the same amount of power, as it goes down proportionally can be extracted.

## 2.4 EMF GENERATION

Electric production unit mainly imposes two ways of electric voltage induction techniques, depending on the relative motion type (Rotational or Translational) accomplished between the conductor and the field winding. In both Rotational induction and Translational induction methods faraday's laws of electromagnetic induction is the main principle to come through. The basic differences are, in case of Rotational induction the DC generator is driven by the rack- ratchet combined impact and operates as the “normal” DC generators except its revolution per minute (RPM) is very low. In case of Translational induction there is a permanent magnet which vertically attached to the speed breaker upper plate and set up a changing magnetic field to a wound coil around the cylindrical copper pipe when the speed breaker made up and down swing.

In the next two consecutive sections, the rotational induction voltage generation and translational induction voltage generation design briefly presented.

### 2.4.1 ROTATIONAL INDUCTION VOLTAGE GENERATION

The E.M.F generation in the armature winding of a dc machine under no load condition is given by

$$E_g = \frac{P\phi NZ}{60a}$$

As shown in the above equation if the flux per pole which in turns depends upon the field current of the system is kept constant the generated emf if directly proportional to the Armature speed

**DC GENERATOR SELECTION**

The shunt excited dc machine with the following specifications: - wave winding type, four Pole, two Armature windings accompanying a flux per pole of 25 mWb with 500 number of armature turns. With the above specific type of generator, we have a total of 1000 ($Z = 2 \times 500$), armature conductors.

Substituting these values in the above equation will give us 12.841V DC voltage at the generator output terminals.

$$E_g = \frac{4 * 2510 - 3 * 0.2568 * 1000}{2}$$

$$= 12.841 \text{ V}$$

### 2.4.2 TRANSLATIONAL INDUCTION VOLTAGE GENERATION

When the magnet goes through a nonmagnetic cylindrical copper pipe, the changing magnetic flux generates eddy current (Figure 2.2), and as the magnet quickly reaches the end point of the pipe the current reaches a steady state value [31]. The magnitude of the eddy current at any position is related to the changing flux as stated by Faraday's Law of electromagnetic induction.

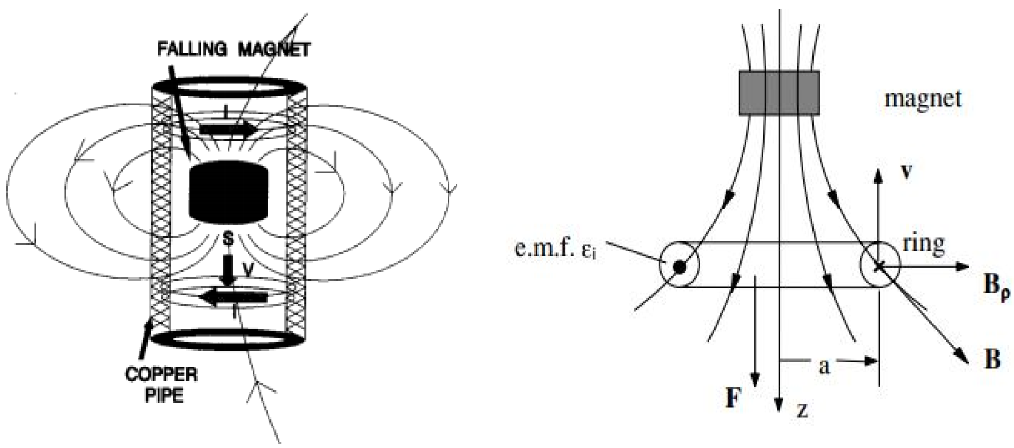



**Figure 2.2 A diagram showing a magnet pass through a nonmagnetic pipe.**

For a Conducting ring of radius $r_w = r$ moving with axial velocity v towards a magnet, If μ is the magnet dipole moment, the radial component of the changing magnetic flux of the magnetic field $B_\rho$ can be written using the well-known magnetic dipole approximation [31,32] as

$$B_\rho(r_w, z) = \frac{3\,\mu_0\,\mu}{4\pi}\frac{rZ}{[r^2 + Z^2\,]^{5/2}}$$

The thin wire coils of N turns, separated by a distance of $\Delta z$, are wound onto the cylindrical nonmagnetic, Electrical conducting pipe and when the magnet is allowed to fall with speed v along the hollow tube. The expression for the induced emf in the coil due to the passing magnet traveling at speed v is given by the following expression [33].

$$\varepsilon_i\ (t,z)=N\int_{lw} B_\rho(r,z)dl.\dot{Z}=\ 2\pi r\ B_\rho\dot{Z}$$

$$= 6\tilde{\mu}\pi r\ N\frac{r*z}{[r^2+Z^2\,]^{5/2}}\frac{dz}{dt}$$

$$6\tilde{\mu}\pi rN\frac{r*z}{[r^2+Z^2\,]^{5/2}}\ v$$

$$v^{\cdot}=\frac{dz}{dt}=\frac{hight\ covered\ by\ the\ magnet)}{Time\ taken\ by\ the\ magnet\ to\ travel\ the\ specified\ hight}$$

A circulating electric current (eddy current) ***di*** is induced in the pipe as the magnet falls down through the cylindrical pipe with velocity of v. A coil wrung onto the cylindrical pipe will collect the induced E.M.F. in the pipe. If $\sigma$ the conductivity of the material of the pipe wall and *dA* denotes the cross-sectional area of the cylindrical ring of length $l$=2$\pi$r, then the conductance of this ring is dC= $\sigma dA/l$. And the induced current $di$ along such a ring can be expressed as follow [33]. If R denotes electrical resistance, $\sigma$ is the conductivity of the pipe wall and $\tau$ is the pipe thickness, then the conductance of a ring of height dz defined on the pipe wall is by the definition $\frac{\tau\sigma dz}{2\pi r}$ [34].

Appling ohm's law (*v*= *IR*)

$$di\ =\ \varepsilon_i\ d\left(\frac{1}{R}\right)$$

$$=\varepsilon_i\text{dC}$$

$$= \varepsilon_i \frac{\sigma dA}{l}$$

$$= (2\pi r v B_\rho) \frac{\sigma dA}{2\pi r}$$

$$= \mathrm{B}_\rho v \sigma dA$$

From N number of small rings or coils spaced with an average distance of $\Delta z$ each, will result a total current as specified below

$$i = N \left( \frac{3\,\mu_0\,\mu}{4\pi} \frac{rZ}{[r^2 + Z^2\,]^{5/2}} \right) v\sigma \left( \frac{\pi}{4} D^2 \right)$$

Here we assumed that the total cylindrical system as a sum total of ***N*** number of small circular ring constitutes or parts which is equal to the number of turns wrung around the conducting pipe.

In electrical system, electric power is give as a product of the system voltage, current and Cosine of the phase angle between the two parameters.

$$P = VI \cos\theta$$

For the above scenario, instead of V we have the equivalent induced voltage $\varepsilon_i$ and the possible maximum power that can be extracted, applying the technique can be estimated as indicated below

$$dp = \varepsilon_i * di$$

$$dp = \varepsilon_i * \varepsilon_i \frac{\sigma dA}{l} = {\varepsilon_i}^2 \frac{\sigma\, dA}{l}$$

$$p = 2\pi r\, N \left( \frac{3\,\mu_0\,\mu}{4\pi} \frac{rZ}{[r^2 + Z^2\,]^{5/2}} \right) v \;*\; N \left( \frac{3\,\mu_0\,\mu}{4\pi} \frac{rZ}{[r^2 + Z^2\,]^{5/2}} \right) v\sigma\,(\pi r^2)$$

$$= 2\pi^2 r^3 \sigma \left( \frac{3N\, \mu_0\, \mu}{4\pi} \frac{rZ}{[r^2 + Z^2\,]^{5/2}} \right)^2 v^2$$

$$\therefore p \;=\; 1.125\, r^3 \sigma\, (\,\mu_0\, \mu)^2 N^2 \left( \frac{rZ}{[r^2 + Z^2\,]^{5/2}} \right)^2 v^2$$

The expression for the magnitude F of the magnetic force acting on the ring at the vertical distance z from the magnet can be stated as below. Such force that retards the down movement of the magnet is complement with the reaction force on the magnet as specified Newton’s third law.

$$F = \int_{lw} i\overrightarrow{dl}\; x\, \vec{B} = 2\pi r * i * B_\rho$$

$$\text{Appling} \quad i = \frac{d\varepsilon_i}{dR}$$

$$= N \frac{(2\pi r B_\rho)^2 v}{R}$$

If D is the diameter of the conducting ring and $\sigma$ its electrical conductivity, then the electrical resistance R of the conducting ring is given by

$$R = \frac{2\pi r}{\sigma \left( \frac{\pi}{4} D^2 \right)}$$

For N number of loops, we have a total object resistance as shown below

$$R = \frac{1}{N} \left( \frac{2\pi r}{\frac{\pi}{4} D^2} \right)$$

$$= \frac{N (2\pi r B_\rho)^2 v}{\frac{1}{N} \sigma \left( \frac{2\pi r}{\frac{\pi}{4} D^2} \right)}$$

$$= \frac{2\pi^2 r^3 N^2 {B_\rho}^2}{\delta} v$$

Substituting $B_\rho = \left(\frac{3\,\mu_0\,\mu}{4\pi}\frac{rZ}{[r^2 + Z^2\,]^{5/2}}\right)$ *in the above equestion will give us*

$$= \frac{2\pi^2 r^3 N^2}{\delta}\left(\frac{3\,\mu_0\,\mu}{4\pi}\frac{rZ}{[r^2 + Z^2\,]^{5/2}}\right)v$$

$$F = 1.125(\mu_0\mu)^2 r^3 N^2 \frac{\left(\frac{rZ}{(r^2+Z^2\,)^{5/2}}\right)^2}{\delta}\,v$$

Finally, it is essential to consider the ***shape adjustable factor (α)*** to our magnetic component and finalize the design work after introducing its impact to the three important parameters that the study focused on namely induced voltage ($\varepsilon_i$), extracted power (P) and force (F) that possibly retired the falling magnet.

$$B_\rho\ (r,z) = \frac{3\,\mu_0\,\mu}{4\pi}\left(\frac{\alpha Z r}{[r^2 + (\alpha Z)^2\,]^{5/2}}\right)$$

$$\varepsilon_i(t,z) = 1.5\ \mu_0\,\mu r N\left(\frac{r * \alpha z}{[r^2 + (\alpha Z)^2\,]^{5/2}}\right)v$$

$$p = 1.125\,r^3\sigma\,(\,\mu_0\,\mu)^2 N^2\left(\frac{r\alpha Z}{[r^2 + (\alpha Z)^2\,]^{5/2}}\right)^2 v^2$$

$$F = 1.125(\mu_0\mu)^2 r^3 N^2\left(\frac{\left(\frac{r\alpha Z}{(r^2+(\alpha Z)^2\,)^{5/2}}\right)^2}{\delta}\right)v$$

The parameter $\boldsymbol{\alpha}$ is obtained considering the $\boldsymbol{z_{max}}$ value which corresponds with $\boldsymbol{\varepsilon_{imax}}$ of the induced emf

$$\boldsymbol{\alpha} = \frac{\boldsymbol{r}}{2\boldsymbol{z_{max}}}$$

For our magnet, we assumed cylindrical Neodymium magnet having a diameter of 190mm and length of 100mm. With the above data, we come up with an RMS of power p= 1.9195 W for a single press over the speed breaker. In daily base (only assuming such a traffic density which flow only available for 12hrs) we come up with an average energy generation capacity as stated below

$$average\ energy\ in\ 12hr\ bases = Power_{RMS} * (No.of\ hourse * No.of\ pushs\ in\ a\ day)$$

$$average\ energy\ in\ 12hr\ bases = 1.9195 * 12 * \left(60 * \frac{60}{20}\right)$$

$$= 4.2462\ kWhr$$

Generally, our system comprises two of the above types of translational voltage generating units therefore we have a possibility for total power generation of 8.2922 kW.

# CHAPTER 3
# DESIGN AND MODELING OF ELECTRICAL UNITS

## 3.1 INTRODUCTION

Chapter three presents the design of electrical parts of the speed breaker electric power generating unit. The input for the permanent magnet DC generator from vehicles movement is a random magnitude signal which results a random output voltage wave form. The electrical unit mainly comprise DC-DC converter, DC-AC inverter battery bank and a mechanism to make the random signal periodic with some specified frequency and magnitude. The proposed regulatory circuitry was designed in a two-step process, Rectifying the generated voltage and Regulating the rectified voltage to 12 V DC voltage level.

## 3.2 ELECTRICAL UNIT DESIGN

The electrical unit mainly comprises the following sub-units design: - Rectifier circuitry, Boost chopper circuitry (DC-DC), Inverter circuitry (DC to AC), step up Transformer Circuit Design (19V-220V AC) and Electric power storage Unit (Battery Bank). Due to simplicity and compatible nature rectifier and regulator circuity is already accompanied with the mechanical unit. Detail of the rest sub-unit design is presented in the next consecutive portions.

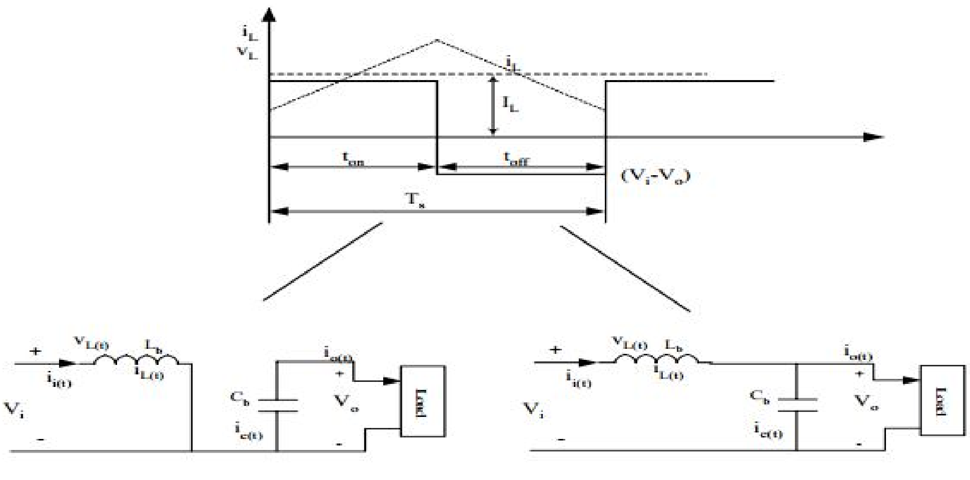
### 3.2.1 DC-DC BOOST CONVERTER DESIGN

This part of the study concerns with design and simulation of DC-DC boost converter (Table 3.1) which only needs four external components: Inductor, Electronic switch, Diode and output capacitor (Table 3.2). The converter can therefore operate in the two different modes depending on its energy storage capacity and the relative length of the switching period. These two operating modes are known as the discontinuous conduction mode, DCM, and continuous conduction mode, CCM, The DC-DC boost converter corresponding to the cases with and without an idling interval respectively [35,36]. In specific words the CCM is for efficient power conversion and the DCM for low power or stand-by operation cases. For our study, we need efficient power conversion means which directly refers the CCM.

**Continuous Conduction Mode**

**Mode 1 (0<t≤ ton)**

Mode 1 begins when the power electronics switched is switched on at t=0 and terminates at t=ton. The equivalent circuit for the mode1. The inductor current *iL(t)* greater than zero and ramp up linearly. The inductor voltage is $V_i$.



(a) (b)

**Figure 3. 1 Equivalent Circuit for boost Converter in CCM**

**Mode 2 (ton<t≤ Ts)**

Mode 2 begins when the power electronics switch switched off at t=ton and terminates at t=Ts

The equivalent circuit for the mode 2 is shown in Fig. 3b. The inductor current decrease until the Switch is turned on again during the next cycle. The voltage across the inductor in this period is Vi-Vo. Since in steady state time integral of the inductor voltage over one-time period must be zero.

$$V_i t_{on} + (V_i - V_0)t_{off} = 0$$

Dividing both sides by $T_s$ and rearranging items yield

$$\frac{V_0}{V_i} = \frac{T_s}{t_{off}} = \frac{1}{1-D}$$

Thus, Vo is inversely proportional to (1-D). assuming a lossless circuit, Pi=Po, which leads to

$$V_i I_i = V_0 I_0$$

and

$$\frac{I_0}{I_i} = 1 - D$$

**Selection of an inductor**

Large inductance values tend to increase the start-up time slightly while small inductance values allow the coil current to ramp up to higher levels before the switch turns off. Inductors with a ferrite core or equivalent are recommended [37]. It should be ensured that the inductor's saturation current rating for highest efficiency and a coil with low DC resistance to be used [36, 38]. Boost inductance is selected based on the maximum allowed ripple current at minimum duty cycle, D, at maximum input voltage, Vi. Given that the switching frequency, Fs, the boost inductor value may be optimally determined to set the converter operating mode in the required load and line range. The critical inductance is defined as the inductance at the boundary edge between continuous and discontinuous modes and is given below [38]:

$$L_{min} = \frac{(1 - D)R}{2f_s}$$

**Selection of a capacitor**

The best practice is to use low Equivalent Series Resistance (ESR) capacitors to minimize the ripple on the output voltage. Ceramic capacitors are a good choice if the dielectric material is X5R or better. Since the capacitor's ESR affects efficiency, low-ESR capacitors will be used for best performance. For reducing ESR it is also possible to connect few capacitors in parallel. The output filter capacitors are chosen to meet an output voltage ripple specification, as well as its ability to handle the required ripple current stress. An approximate expression for the required capacitance is given as [35,38]:

$$C_{min} = \frac{1 - D}{16L_{min}{f_s}^2}$$

**Selection of a Diode**

The boost diode reverse voltage rating is limited to the output voltage. The diode conducts when the power switch is in the “OFF” state and provides a current path for the inductor to the output. Similar to the power electronic switches the worst–case peak current through the diode occurs at low line input voltage and maximum load. Other important considerations in selecting the diode besides its ability to block the required off–state voltage stress and have sufficient peak and average current handling capability, is fast switching characteristics, low reverse–recovery, and low forward voltage drop [37].

**Selection for the Switching component**

The electronic switch has been chosen based on its voltage and current rating which have to be higher than the maximum input voltage and current. For the proposed system, the rating of the converter is 100W with an input voltage of 24. Therefore, electronic switch such as power MOSFET, IGBT, BJT and thyristors with a handling capability for the specification and capability can be selected [39]. The switching element has been chosen to handle the worst case current and voltage stresses. The maximum voltage stress on the switching device occurs when the system is exposed to a system load which, is nearly 2000N and a faster pass over speed of less than Ten seconds.

Table 3. 1 Specifications for Proposed Boost Converter Design

| | |
|---|---|
| Power Rating | 100W |
| Output Voltage | 24V |
| Output current | 4.1667A |
| Input Voltage | 12V |
| Switching Frequency | 30KHz |

Table 3. 2 Proposed Boost Converter Designed components

| **Component** | **Values** |
|---|---|
| Inductor | 2mH |
| Output Capacitor | 500µF |
| Load Resistance | 5.76Ω |
| Diode | MBR1060 (10 A, 60 V Schottky Rectifier) |
| Power-Electronic Switch | IRF540N (HEXFET Power MOSFET 33A; 100V; 0.044 Ohms) |

### 3.2.2 DC - AC CONVERTER DESIGN

DC to AC converters are known as inverters. The function of an inverter is to change a dc input voltage to a symmetric ac output voltage of desired magnitude and frequency. The output voltage could be fixed or variable frequency at a fixed of variable frequency. A variable output voltage can be obtained by varying the input dc voltage and maintaining the gain of the inverter constant. On the other hand, if the dc input voltage is fixed and it is not controllable, a variable output voltage can be obtained by varying the gain of the inverter, which is normally accomplished by pulse-width-modulation (PWM) control within the inverter. The inverter gain may be defined as the ratio of the ac output voltage to dc input voltage [40].

Basically, there are three types of DC-AC inverters available on the market, which are classified by their output type. These are Square wave, Modified sine wave and Pure sine wave. Pure sine wave inverters offer more accuracy and less unused harmonic energy delivered to a load, but they are more complex in design and more expensive. Pure sine wave inverters are power devices with more accuracy, less power loss, and less heat generation [41].

As a result of the above reasons, Pure sine wave inverters are proposed for conversion of a 24V direct voltage to a 220V, 50Hz alternative single phased voltage level.

The most common and popular technique of digital pure-sine wave generation is PWM which involves generation of a digital waveform, for which the duty-cycle is modulated such that the average voltage of the waveform corresponds to a pure sine wave. The simplest way of producing the PWM signal is through comparison of a low-power reference sine wave with a triangular wave. Using these two signals as input to a comparator, the output will be a 2-level PWM signal. The final PWM signal can then be used to control H- bridge switches connected to a high-voltage DC voltage bus, which will replicate this signal at the appropriate voltage. Finally putting the H-bridge output through an LC filter will clean up into a close approximation frequency sine wave.

For signals required for the switching circuitry of the inverter control an Oscillators which can produce specific, periodic waveforms such as square, triangular, saw tooth, and sinusoidal. There are two main classes of oscillator relaxation and sinusoidal. Relaxation oscillator generates the triangular, saw tooth and other non-sinusoidal waveforms. Sinusoidal oscillators consist of amplifiers with external components used to generate oscillation, or crystals that internally generate the oscillation [42].

Our focus is to wards sine wave oscillators, and triangular wave generators created using the operational amplifiers. Design of sine wave oscillator type RC phase shift and triangular wave generators has been combined to come across a get driving square wave for single phase inverter switch drive.

For the design, we used, a theoretical design aspect as well as a simulating software to insure and verify the proposed design accuracy. For simplicity, each oscillator is designed independently and combined to have the required square wave used for triggering the four power electronic switches.

**Rc phase shift sine wave generating circuit design**

There are many types of oscillator circuits depending on the component used in the circuit. These oscillator circuits are RC oscillator, LC oscillator, Colpittes oscillator, Hartley oscillator, Wien bridge oscillator and Crystal oscillator [43]

Op-Amp sine-wave oscillators operate without an externally applied input signal. Instead, some combination of positive and negative feedback is used to drive the Op-Amp into an unstable state, causing the output to cycle back and forth between the supply rails at a continuous rate. The frequency and amplitude of oscillation are set by the arrangement of passive and active components around a central Op-Amp [44].

The operational amplifier has an extremely high gain, and these circumstances leads to saturation within the amplifier. As saturation implies working in the non -linear section of the characteristics, harmonics are produced. Because of this, a square wave output is produced for a sinusoidal input. The amplifier has ceased to amplify and it has become unstable. There are many reasons why an amplifier may become unstable, such as temperature changes or power supply variations, or a very high gain of the operational amplifier [45].

This can be overcome by introducing a feedback network between the output and the input. When a negative feedback, whereby a part of the output voltage of an amplifier is fed to the input with a phase angle that opposes the input signal applied to an amplifier, the overall gain can be reduced and controlled so that the operational amplifier can function as a linear amplifier [46].

The oscillator gain must be unity at the oscillation frequency. Under normal conditions, the circuit becomes stable when the gain exceeds unity, and oscillations cease. However, when the gain exceeds unity with a phase shift of –180°, the nonlinearity of the active device reduces the gain to unity and the circuit oscillates. The nonlinearity becomes significant when the amplifier swings close to either power rail because cutoff or saturation reduces the active device gain. The paradox is that worst-case design practice requires nominal gains exceeding unity for manufacturability, but excess gain causes increased distortion of the output sine wave and distributed among the buffers, the more stable the gain, the better the purity of the sine wave output [47].

The feedback type is voltage series and to obtain the output voltage and the required phase shift oscillator the analysis is as follows

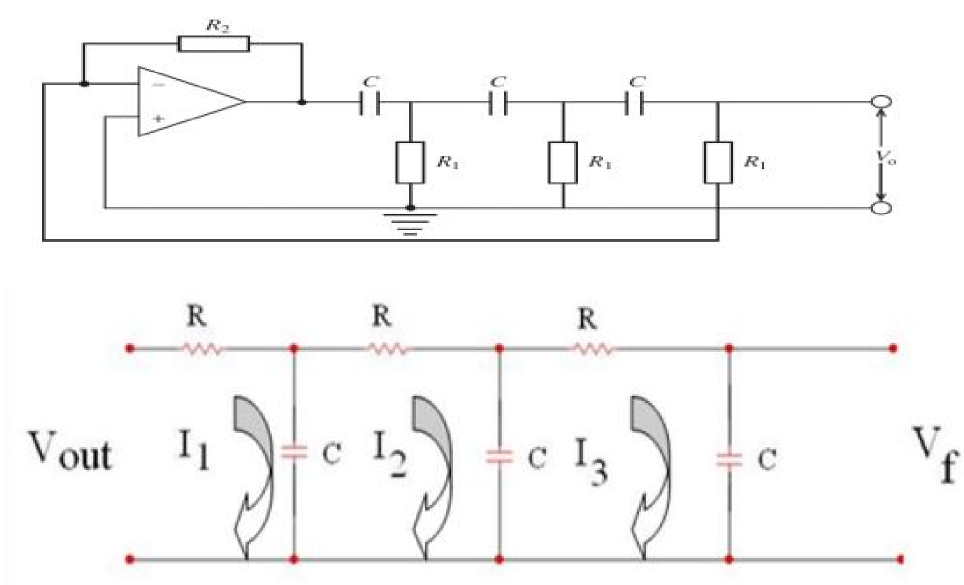



**Figure 3. 2 Sine wave Oscillator Circuitry Topology**

From the circuit shown in Figure above we can drive the following

$Loop$ 1 $$\left(R+\frac{1}{j\omega c}\right)I_1-\frac{1}{j\omega c}I_2+0=V_o \quad (3.1)$$

$Loop$2 $$-\frac{1}{j\omega c}I_1+\left(R+\frac{2}{j\omega c}\right)I_2-\frac{1}{j\omega c}I_3=0 \quad (3.2)$$

$Loop$3 $$0+-\frac{1}{j\omega c}I_2+\left(R+\frac{2}{j\omega c}\right)I_3=0 \quad (3.3)$$

$$\Delta = \begin{bmatrix} R + \frac{1}{j\omega c} & -\frac{1}{j\omega c} & 0 \\ -\frac{1}{j\omega c} & R + \frac{2}{j\omega c} & -\frac{1}{j\omega c} \\ 0 & -\frac{1}{j\omega c} & R + \frac{2}{j\omega c} \end{bmatrix}$$

$$\Delta = \left(R + \frac{1}{j\omega c}\right)\left[\left(R + \frac{2}{j\omega c}\right)\left(R + \frac{1}{j\omega c}\right) + \left(\frac{1}{\omega c}\right)^2\right] + \frac{1}{j\omega c}\left[-\frac{1}{j\omega c}\left(\left(R + \frac{2}{j\omega c}\right)\right)\right]$$

$$\Delta = \left(R + \frac{1}{j\omega c}\right)\left[R^2 + \frac{4R}{j\omega c} - \left(\frac{2}{\omega c}\right)^2 + \left(\frac{1}{\omega c}\right)^2\right] + \frac{1}{j\omega c}\left[-\frac{R}{j\omega c} + \left(\frac{1}{\omega c}\right)^2\right]$$

$$\Delta = \left(R^3 + \frac{4R^2}{j\omega c}\right) - R\left(\frac{2}{\omega c}\right)^2 + R\left(\frac{1}{\omega c}\right)^2 + \frac{R^2}{j\omega c} - R\left(\frac{2}{\omega c}\right)^2 - \frac{4}{j(\omega c)^3} + \left(\frac{1}{\omega c}\right)^2 + R\left(\frac{1}{\omega c}\right)^2 + \frac{2}{j(\omega c)^3}$$

$$\Delta = R^3 + \frac{5R^2}{j\omega c} - 6R\left(\frac{1}{\omega c}\right)^2 - \frac{1}{j(\omega c)^3}$$

$$\Delta_{33} = \begin{bmatrix} R + \frac{1}{j\omega c} & -\frac{1}{j\omega c} & V_{out} \\ -\frac{1}{j\omega c} & R + \frac{2}{j\omega c} & 0 \\ 0 & -\frac{1}{j\omega c} & 0 \end{bmatrix}(\omega c)^2$$

$$\Delta_{33} = V_{out}\left(\frac{1}{\omega c}\right)^2$$

$$I_3 = \frac{\Delta_{33}}{\Delta} \qquad (3.4)$$

$$I_3 = \frac{V_{out}\left(\frac{1}{j\omega c}\right)^2}{R^3 + \frac{5R^2}{j\omega c} - 6R\left(\frac{1}{\omega c}\right)^2 - \frac{1}{j(\omega c)^3}} \qquad (3.5)$$

$$\beta = \frac{V_f}{V_{out}} \qquad (3.6)$$

$$V_f = \frac{I_3}{j\omega c} \qquad (3.7)$$

$$\beta = \frac{I_3}{j\omega c \, V_{out}} \qquad (3.8)$$

$$= \frac{\dfrac{V_{out}\left(\frac{1}{\omega c}\right)^2}{R^3 + \frac{5R^2}{j\omega c} - 6R\left(\frac{1}{\omega c}\right)^2 - \frac{1}{j(\omega c)^3}}}{j\omega c \, v_{out}}$$

$$\beta = \frac{\dfrac{-V_{out}}{(\omega c)^2\left(R^3 + \frac{5R^2}{j\omega c} - 6R\left(\frac{1}{\omega c}\right)^2 - \frac{1}{j(\omega c)^3}\right)}}{j\omega c V_{out}}$$

$$\beta = \frac{-1}{j(\omega c)^3\left(R^3 + \frac{5R^2}{j\omega c} - 6R\left(\frac{1}{\omega c}\right)^2 - \frac{1}{j(\omega c)^3}\right)}$$

$$\beta = \frac{-1}{(5(R\omega c)^2 - 1) + j((R\omega c)^3 - 6R\omega c)}$$

Imaginary part=0

$$(R\omega c)^3 - 6R\omega c = 0$$

$$(R\omega c)^3 = 6R\omega c$$

$$(R\omega c)^2 = 6$$

$$\omega = \frac{\sqrt{6}}{Rc} \qquad (3.9)$$

$$\omega = 2\pi f_o \qquad (3.10)$$

$$oscillatory\ Frequency, f_o = \frac{\sqrt{6}}{2\pi Rc}$$

$$\beta = \frac{-1}{5(R\omega c)^2 - 1} \qquad (3.11)$$

Substituting for $\omega = \frac{\sqrt{6}}{Rc}$ $in\ equation$ (3.11)

$$\beta = \frac{-1}{5R^2 \frac{6}{R^2C^2} C^2 - 1}$$

$$\beta = -\frac{1}{29} \ \textit{which refers the}\ \text{Oscillatory condition}$$

The oscillator gain ($\boldsymbol{A\beta} = 1 < -180$) must be unity at the oscillation frequency

Which implies 1- $\boldsymbol{A\beta}$= 0

$$1 - A\beta = 0$$

$$A\beta = 1$$

$$A = \frac{1}{\beta} = -29$$

The voltage gain of the circuit must have negative gain

$$A = A_v = -29 = \frac{R_f}{R_g}$$

$$\frac{R_f}{R_g} = 29 \ so\ A > 29$$

$$f_o = \frac{\sqrt{6}}{2\pi Rc}$$

for our design, we choose $R_f = 200K\Omega$ and $R_g = 1K\Omega$ Which implies, a voltage gains of A= ranged between 200 and 29 as $R_f$ varied in the acceptable range.

For the proposed system, our request is a 50Hz oscillator and we assumed C= 0.01$\boldsymbol{\mu F}$ capacitor and calculate the resistance value and it becomes 780.0922KΩ

**Triangular wave generating circuit design**

Triangular wave generator is an oscillator composed of a Schmitt trigger and an integrator for the production of a high frequency triangular carrier signal.

The equation for the frequency of oscillation and for peak to peak voltage are calculated as follow

$$f_0 = \frac{R_3}{(4R_1R_2C)}$$

$$V_{p-p} = 2\left(\frac{R_1}{R_3}\right)V_{sat}$$

$$V_{sat} = 0.9V_{cc}$$

For our case, we assumed

$V_{p-p} = 2.5V$, C= $0.01\mu F$, $V_{cc} = 12V$, Oscillating frequency $f_0 = 30KHz$

Then after evaluating for the rest parameters we come across with the following parameter values $R_1 = 670\Omega$, $R_2 = 10k\Omega$ *and* $R_3 = 84k\Omega$

### 3.2.3 PWM SIGNAL GENERATION

Sine wave inverters that utilize PWM for wave shaping have a comparator stage to generate the PWM signal. The high-frequency triangular wave is compared to the sine wave many times per sine wave cycle. The comparator output is a PWM signal whose duty cycle is related to how long the sine-wave amplitude is greater than the triangular wave.

In PWM generation, the two very important characteristics are $\boldsymbol{m_a}$ and $\boldsymbol{m_f}$, where $\boldsymbol{m_f}$ is the ratio between the frequency of the triangular wave to the sine wave signal, and is generally an odd integer. This number is significant in that it determines the frequency of the harmonics in the PWM output signal. The significant components of this output are the primary, the harmonic at frequency $m_f * f_c$ where $f_c$ is the frequency of the sine wave control, and the harmonics at $m_{f+2} * f_c$ and $m_{f-2} * f_c$, $m_f$therefore, determines the frequency of the harmonics of the output, which of course affects how easily they can be filtered out [48].

$m_a$represent the ratio of the amplitudes of the sine wave to the triangular wave form. The value above 1 results in clipping and non-linear amplitude relationships, whereas $m_a$between 0 and 1 possibly solves the above described problems but come across a decreased amplitude of the primary voltage level. At the same time, though, the amplitude of the harmonics increase, and the $m_f$harmonic actually becomes larger than the primary voltage level just for above $0.8m_a$ [48].

In our design the triangular wave amplitude peak is being set at $V_{tri} = 1.25V$ and for the controlling signal, the sine wave generated being $V_{sin} = 1V$ which refers $m_a = 0.8$ and $m_f = 600Hz$.

### 3.2.4 SWITCHING CIRCUIT DESIGN

Inverters can use a controlled turn-on and turn-off devices like Bipolar junction transistors, metal oxide semiconductor field-effect transistors, insulated-gate bipolar transistors, metal oxide semiconductor-controlled thyristors, static induction transistors and gate-turn-off thyristors [45].

With two important assumptions:- The reference voltage remains approximately constant because one carrier frequency period is very short compared to the reference sine wave period and switches on or off in no time with the above two assumptions, we have the output voltage as shown below

$$V_{av} = \frac{V_{sin}}{V_{tri}} V_{dc} \sin \omega t$$

In our design, we have already set $V_{dc} = 24V, V_{tri} = 1.25V \; and \; V_{sin} = 1V$ therefore the average output voltage from the inverter becomes $V_{av} = 19.2 \sin \omega t$

**H-Bridge Components selection**

While designing a power, electronics witching circuitry, a choice had to be made between the two main types of switches used more often. The first one is the power MOSFET, which is much similar to a standard MOSFET, but designed to handle relatively large voltages and currents. The other is the insulated gate bipolar transistor, or IGBT. Each has its advantages, and there is a high degree of overlap in the specifications of the two [46].

IGBTs tend to be used in very high voltage applications, nearly always above 200V, and generally above 600V. They do not have the high frequency switching capability of MOSFETs, and tend to be used at frequencies lower than 29kHz. They can handle high currents, are able to output greater than 5kW, and have very good thermal operating ability, being able to operate properly above 100 Celsius. One of the major disadvantages of IGBTs is their unavoidable current tail when they turn off. Essentially, when the IGBT turns off, the current of the gate transistor cannot dissipate immediately, which causes a loss of power each time this occurs. This tail is due to the very design of the IGBT and cannot be remedied. IGBTs also have no body diode, which can be good or bad depending on the application. IGBTs tend to be used in high power applications, such as uninterruptible power supplies of power higher than 5kW, welding, or low power lighting [44, 46].

Power MOSFETS have a much higher switching frequency capability than do IGBTs, and can be switched at frequencies higher than 200 kHz. They do not have as much capability for high voltage and high current applications, and tend to be used at voltages lower than 250V and less than 500W.

MOSFETs do not have current tail power losses, which makes them more efficient than IGBTs. Both MOSFETs and IGBTs have power losses due to the ramp up and ramp down of the voltage when turning on and off.

Generally, IGBTs are the sure bet for high voltage, low frequency (>1000V, <20kHz) uses and MOSFETs are ideal for low voltage, high frequency applications (<250V, >200kHz). In between these two extremes is a large grey area. In this area, other considerations such as power, percent duty cycle, availability and cost tend to be the deciding factors. Our application in this project is 100w, with a 24VDC bus, and a switching frequency around 30kHz. These specifications made Power MOSFETs the ideal choice for the design. [46, 47]

First, we need to determine what Power MOSFET we wanted to use. We know that in an H-bridge, the highest voltage a single Power Switching Switch that is off will experience is double the voltage of the DC power rail, which is in our case is 2*24 = 48 V. We want to have a healthy safety margin above this voltage as well, with doubling the value being a good idea. A rated voltage of 100-200V is therefore a good target for our choice. In addition, we are going to be providing approximately 100W for our output, which will be a 220Vrms sine wave. This means that the max rated current we should have coming out of our inverter will be 0.4545A. We should certainly overshoot this value by some healthy margin, and in some ways our eventual choice will be a little more than we need but if availability, cost, and other considerations allow this, it's not necessarily a bad thing.

Our PWM output signal will switch at a frequency of 30kHz, which refers our Power MOSFET need to be relatively fast-switching as well. Considering all the above facts we determined that the IRF540N (HEXFET Power MOSFET 3A; 100V; 0.044 Ohms) was sufficient enough for our design.

**Filter Components selection**

The required output from the H-bridge is ideally a 50Hz sine wave with an rms voltage of 220V. The system is encoded using a 30 kHz PWM signal therefor for the expected signal frequency it must be filtered. Due to the high voltage of our output, the only option is a passive filter, which is an inductor and capacitor in series, with the load connected across the capacitor. We desired a cut-off frequency comfortably below our switching frequency and above our ideal 50Hz output. In an LC filter, the cutoff frequency is given by the following relationship:

$$f_{cut-off} = \frac{1}{2\pi\sqrt{LC}}$$

Using a capacitor of 15μF and an inductor of 40μH, we obtain a cutoff frequency of 6.5 kHz. We also needed components which are capable of handling the rated voltage and current output of our system, so we needed an inductor which could handle at least 4.2 A, and a capacitor which could handle at least 24 V.

### 3.2.5 STEP-UP TRANSFORMER DESIGN

The maximum possible output voltage that can be extracted from the inverter side is less than the DC input voltage, which is 24 V. We require a 220 V rms 50 Hz RMS, AC supply therefore, we designed a transformer (Table 3.3 & Appendix II**)** to transform the inverter output voltage level (19.2V,50Hz frequency RMS) to a single-phase voltage specification (220V, 50Hz) level. The transformer (Table 3.4) design processed as shown below.

1. Input data of Transformer design

- Total apparent power required at the secondary side (VA)
- Primary and secondary voltage (V)
- Frequency f (Hz)

2. Data that are prefixed or calculated by the designer

    - Utilization (machine) factor Ku which depends on the type of transformer
    - Maximum flux per column

$$\emptyset = Ku\sqrt{\frac{KVA}{f}} \quad (Wb)$$

    - Maximum induction B in iron and current density
    - Width of column

    C=$\sqrt[4]{VA}$ $\quad (cm)$

    - Kind of lamination
    - Packing coefficient $K_s$
    - Voltage drop and efficiency
    - Filling coefficient $K_r$

Table 3. 3 Specific input data of the designed Transformer

| | |
|---|---|
| Transformer type | Single-phase shell |
| Operation Type | pulsed |
| Total apparent power | 100VA |
| Primary voltage | 19.2V |
| Secondary voltage | 220V |
| Frequency | 50Hz |
| Cooling method | Air |

Table 3. 4 Assumed parameters and coefficients

| | |
|---|---|
| Voltage drop consideration | 5% |
| Efficiency | 90% |
| Utilization factor ($K_u$) | $3*10^{-2}$ |
| Filling coefficient | 1.05m |
| Packing coefficient ($k_s$) | 0.88 |
| Lamination type | paper |
| Lamination thickness | 0.35 |
| Maximum induction B | $1Wb/m^2$ |

**SIZING OF CORE**

- Flux per column

$$\emptyset = Ku\sqrt{\frac{KVA}{f}}$$

$$= 3 * 10^{-2} * \sqrt{\frac{0.10}{50}}$$

= 1.3416 mWb

Therefore, when the magnetic field density is fixed at B = 1.0 T, it is possible to calculate the area of the net iron section as shown below.

$$A_{iron} = \frac{\emptyset}{B}$$

$$= \frac{1.3416 * 10^{-3}}{1} m^2$$

= 1341 $mm^2$

- Width of column

$$C = \sqrt[4]{VA}$$

$$= \sqrt[4]{100}$$

$$= 3.1622\ cm$$

Therefore, a commercial lamination can be selected with external size 100 x 120, column size 40 x 60 and window size 20 x 60, having 0.5mm thickness including the paint insulation.

- The net thickness of the iron package is

$$L_p = \frac{A_{iron}}{C}$$

$$= \frac{1341\text{mm2}}{40mm}$$

$$= 33.525\ mm$$

- The gross thickness ($L_{gross}$) with assumption of a packing coefficient $K_s = 0.88$

$$L_{gross} = \frac{L_p}{K_s}$$

$$= \frac{33.525}{0.88}$$

$$= 38.0965\ mm$$

- Number of Lamination

  The corresponding lamination to the specified gross thickness is

$$\frac{L_{gross}}{unit\ thickness\ of\ the\ lamination}$$

$$\frac{38.0965mm}{0.5mm}$$

$$=76.1932 \approx 77$$

To mount the core, the laminations are inserted into 40 x 40 nylon reel on which the winding mounted; the laminations are alternatively inserted, so that the joints are staggered.

**CALCULATION OF WINDINGS**

The voltage per turn is equal 4.44f∅ ($4.44*50*1.3416*10^{-3}$= 0.2978 V)

The number of primary turns is therefore

$$= \frac{19.2}{0.2978}$$

$$=64.465 \approx 65$$

Assuming a voltage drop from no-load to load condition of 5%, the number of secondary turns will be :

$$= \frac{220 + 11}{0.2978}$$

$$=775.688 \approx 776$$

Assuming a 90% efficiency of the transformer, the primary current is calculated as

$$I_1 = \frac{100}{19.2 * 0.9}$$

$$= 5.787 \text{ A}$$

Assuming a current density of 4.5 A/mm$^2$ (here the system is considered as a pulsed operating system), this corresponds to a copper section of

$$A_{copper} = \frac{current}{current\ density}$$

$$= \frac{5.787}{4.65}$$

$$= 1.2445 \text{ mm}$$

Therefore, a commercial single clad, diameter of $\emptyset_2 = 1.25\ mm$ enameled copper wire is selected.

The secondary current is now calculated

$$I_2 = \frac{100}{220}$$

$$=0.4545A$$

This corresponds to a copper section of

$$A_{copper} = \frac{0.4545}{4.65}$$

$$= 0.0977mm^2$$

Therefore, a commercial single clad, diameter of $\emptyset_2 = 0.64\ mm$ enameled copper wire is selected.

$$\emptyset_2 = 0.64mm$$

### 3.2.6 STORAGE BATTERY SIZING

The system is expected to support the grid network load during peak hours. Therefore, a suitable and appropriate energy storage alternative should be accompanied with the system to fulfil the requirement.

In this section the four basic types of batteries used in renewable power technology are discussed. The type of battery more appropriate have been selected and the battery bank is finally sized.

RV or Marine type deep cycle batteries which are basically for boats and campers and are suitable for only very small systems. They can be used but do not really have the capacity for continuous service with many charge/discharge cycles for many years. Regular or Car type batteries should not be used at all because they cannot be discharged very much without internal damage. A very popular battery for small systems is the Golf Cart Battery.

The rest three battery types are heavier industrial type and are all designed for alternative energy systems. They are all also considered Deep Cycle and are usually Lead Acid types with much thicker internal plates that can withstand many deep discharge cycles.

1. **Flooded** types these are Lead acid batteries that have caps to add water. Many manufacturers make these types for Solar Energy use. They are reasonably priced and work well for many years. All flooded batteries release gas when charged and should not be used indoors. If installed in an enclosure, a venting system should be used to vent out the gases which can be explosive

2. **Gel sealed** batteries have no vents and will not release gas during the charging process like flooded batteries do. Venting is therefore not required and they can be used indoors. This is a big advantage because it allows the batteries to maintain a more constant temperature and perform better.

3. **Absorbed Glass Mat (AGM)** batteries are the best available for Solar Power use. A woven glass mat is used between the plates to hold the electrolyte. They are leak/spill proof, do not release gas when charging, and have superior performance. They have all the advantages of the sealed gel types and are higher quality, maintain voltage better, self-discharge slower, and last longer. We may find this type of battery used in airplanes, hospitals, and remote telephone/cell tower installations.

Finally, we found AGM battery types most appropriate for our system storage mechanism. And the required storage battery capacity is determined as follows.

For the whole system 24 V is selected as the system bus bar voltage

Let’s calculate the storage system Amperage (AH/day)

$$Amperage = \frac{total\ energy\ \ of\ the\ system}{bus\ voltage} * \frac{day}{12hrs}$$

$$=2.41447\ \text{kA}$$

$$\approx 1.2\ kA$$

Since the system is designed to be embedded on the transportation line there will be car on road in every day bases so it is logical to consider a single day Autonomy for the system to support.

The number of amps-hours our required calculated as shown below

$$\text{AH} = \left(\frac{\text{amp} - \text{hour requirement}}{\text{day}} * \text{ number of days of Autonomy}\right)$$

$$AH = 1200 * 1 = 1200$$

The depth of discharge for the battery provides a safety factor so that we can avoid over-discharging the battery bank. This number should not exceed 0.8 therefore we marginalized our choices as 65%, which implies

$$= \frac{1200}{0.65} = 1925\ Ah$$

The selected battery is a nominal voltage of 24 V Dc with a nominal capacity of 258 Ah

The number of the batteries wired in parallel will be calculated as

$$\text{batteries wired in parallel} = \frac{\text{total battery capacity required}}{\text{Nominal single battery capaciy}}$$

$$B_P = \frac{1925Ah}{258Ah}$$

$$= 7.45$$

Therefore, we required a total of eight 24V Dc 258Ah, AGM batteries.

# CHAPTER 4

# SIMULATION STUDIES AND ANALYSIS OF RESULTS

## 4.1 INTRODUCTION

In this chapter simulation model of the system is developed using the softwares, CATIA V5, MATLAB 13B and Electronic simulation technique, Multisim 14. The simulation studies are carried out using the above mentioned softwares as well, and the results presented in both qualitative and quantitative form. Analysis of the simulation results is presented at the end of the chapter.

## 4.2 SYSTEM SIMULATION MODEL

The thesis presents the simulation of a speed breaker mechanism for environmentally suitable and all year round energy producing alternative, which is achieved firstly by reviewing literatures analysis with the theoretical background and related equations then simulating the proposed system parts using software like, CATIA V5(figure 4.1 and 4.7), MATLAB 13B (figure 4.8, 4.9,4.10,4.11 and 4.12) Electronic simulation technique, Multisim 14 (Figure 4.2, 4.3,4.4,4.5,4.6,4.13,4.14 4.15, 4.16, 4.17 and 4.18).

A systematic view of converting vehicles kinetic power into an electrical output has been presented. An incoming vehicle of weight nearly 2000 N makes a hump movable portion to displace a distance of 10 cm penetration resulting into rotational of a pair of rack and pinion (ratchet), which are engaged together. The mechanical power is as a result of joules of work done when a vehicle of the specified weight leads into a generation of nearly 40W output power. The assumptions made here that the vehicles are available on the speed breaker at every ten seconds and the mechanical system consumes no energy, and assuming that no heat is produced as the system power generating process.

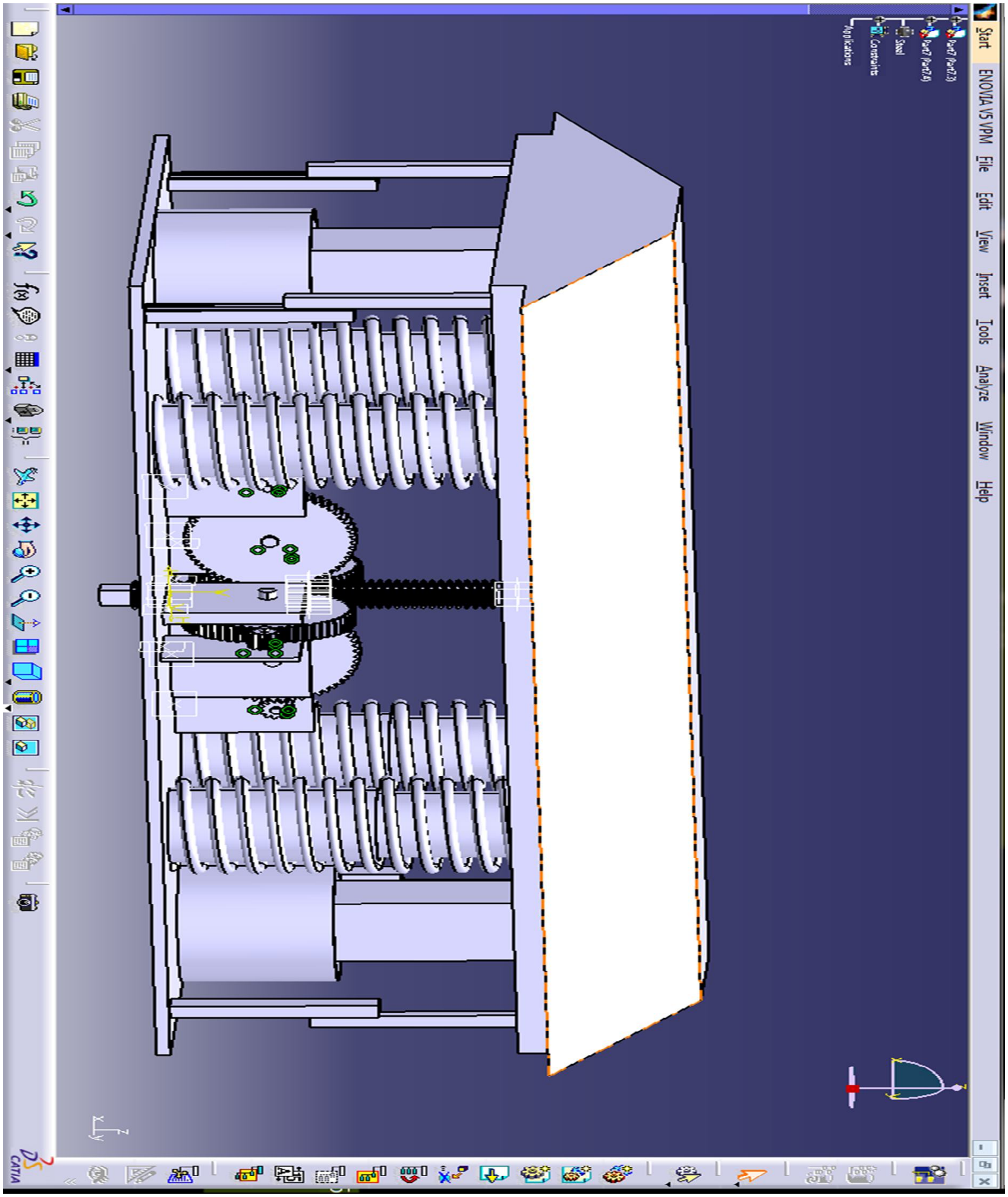


**Figure 4. 1 The Proposed Speed Breaker Model**

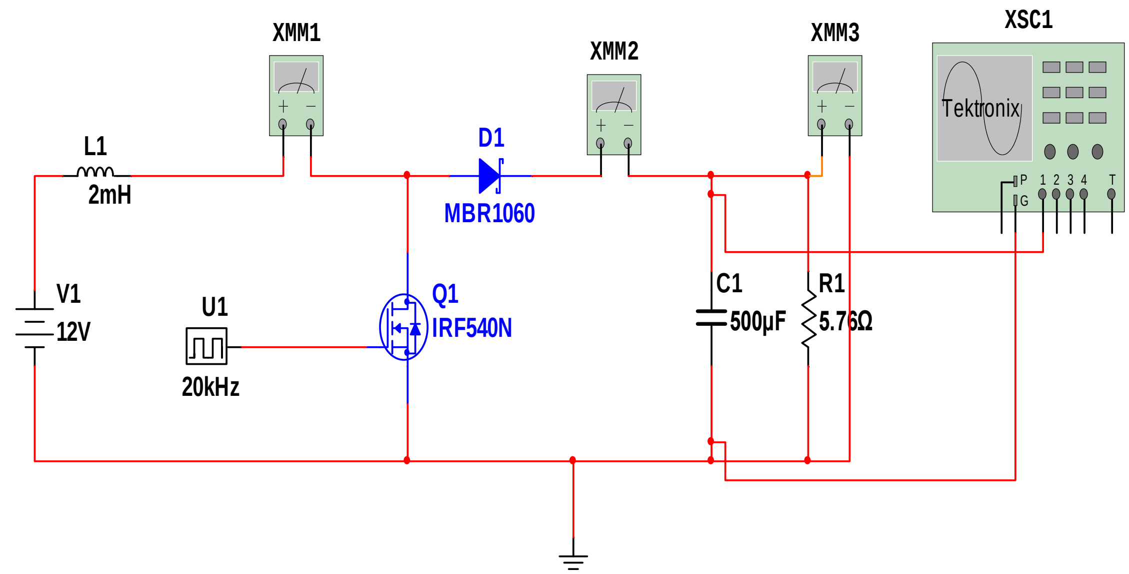



**Figure 4. 2 The proposed DC-DC Converter circuitry model**

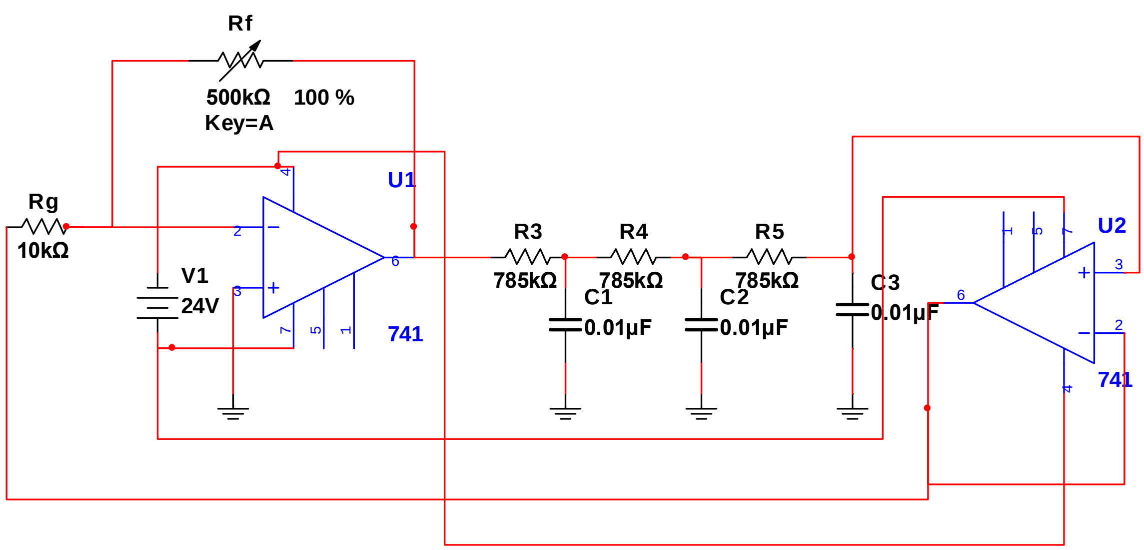



**Figure 4. 3 The proposed Sine wave Oscillator circuitry model**

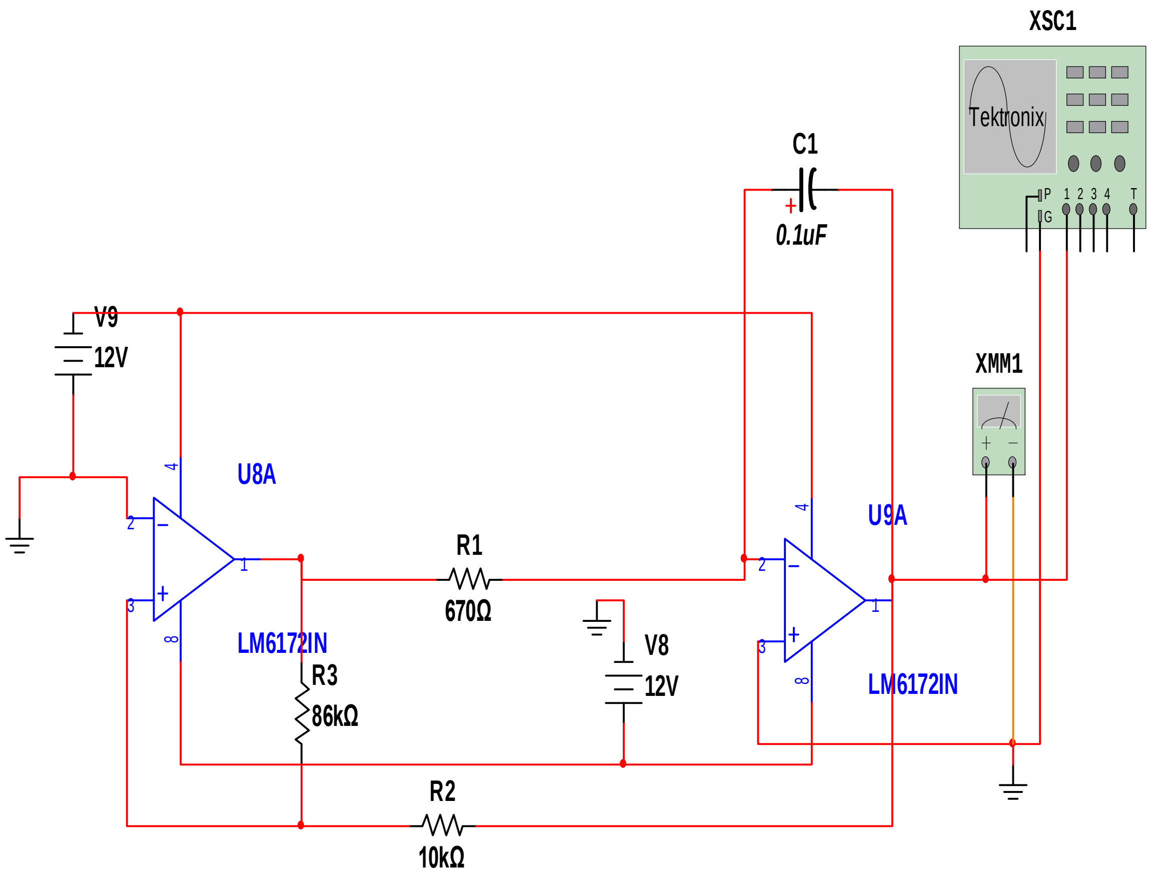



**Figure 4. 4 The proposed Triangular Oscillator circuitry model**

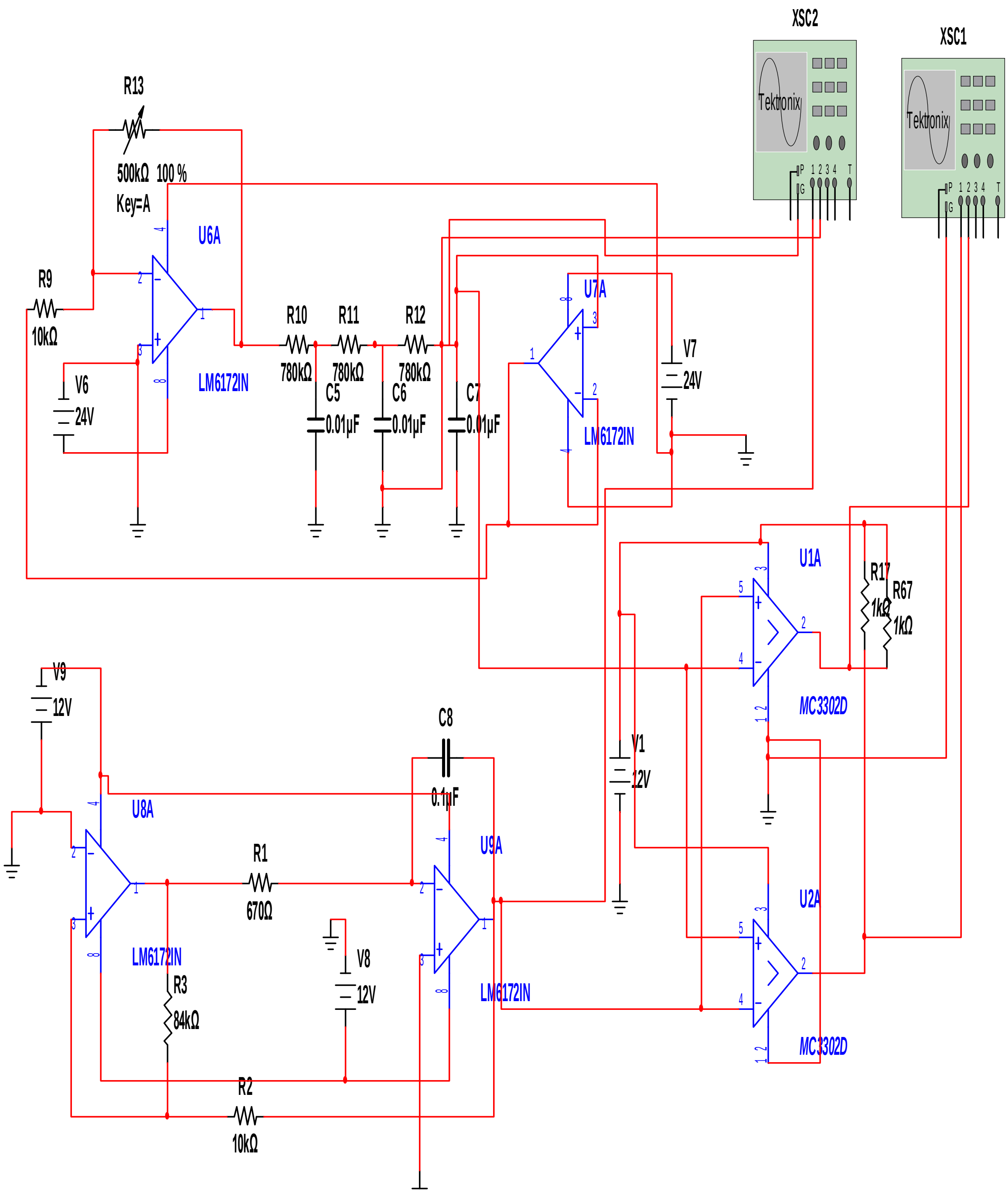



**Figure 4. 5 The proposed PWM generating circuitry model**

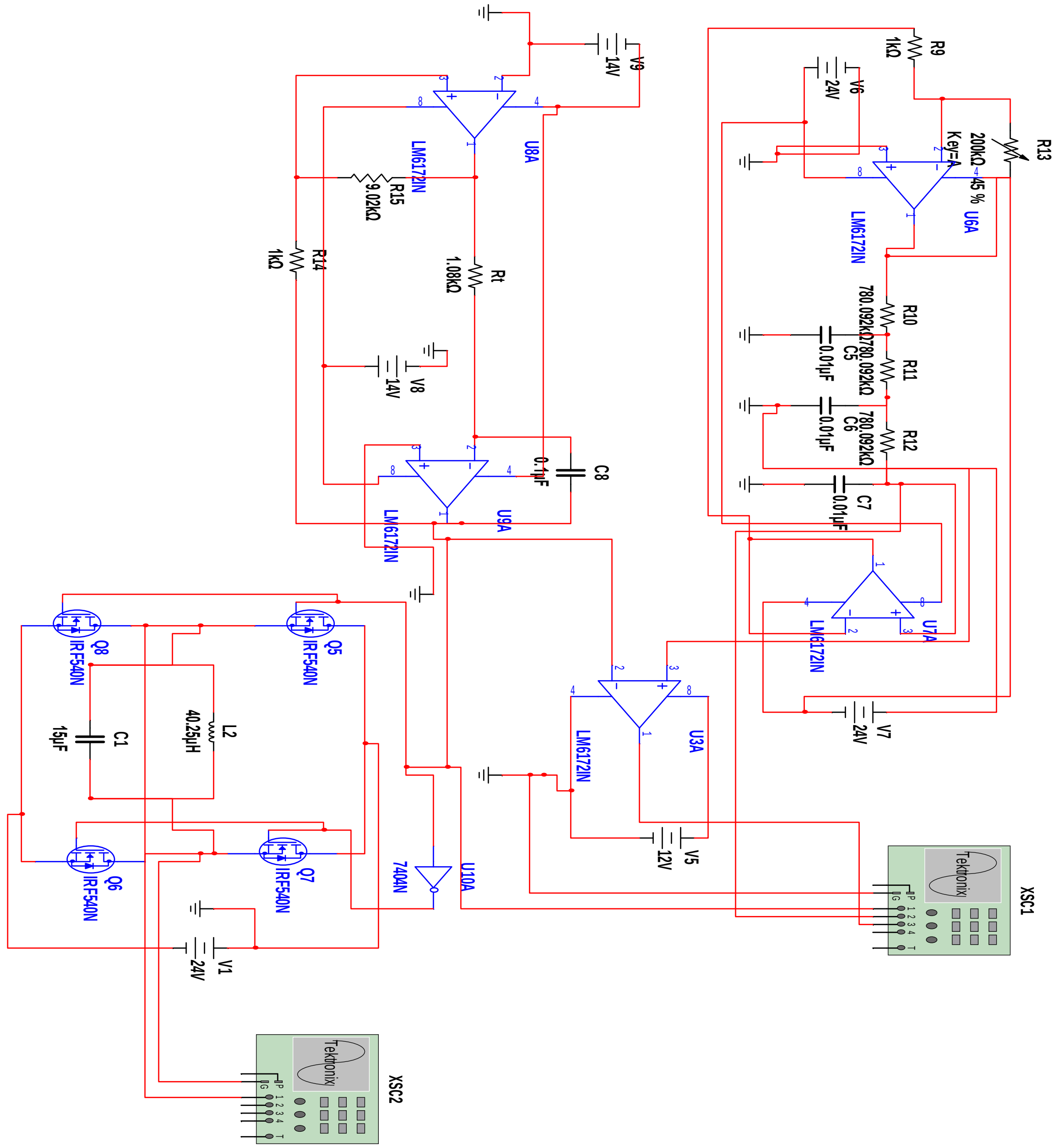
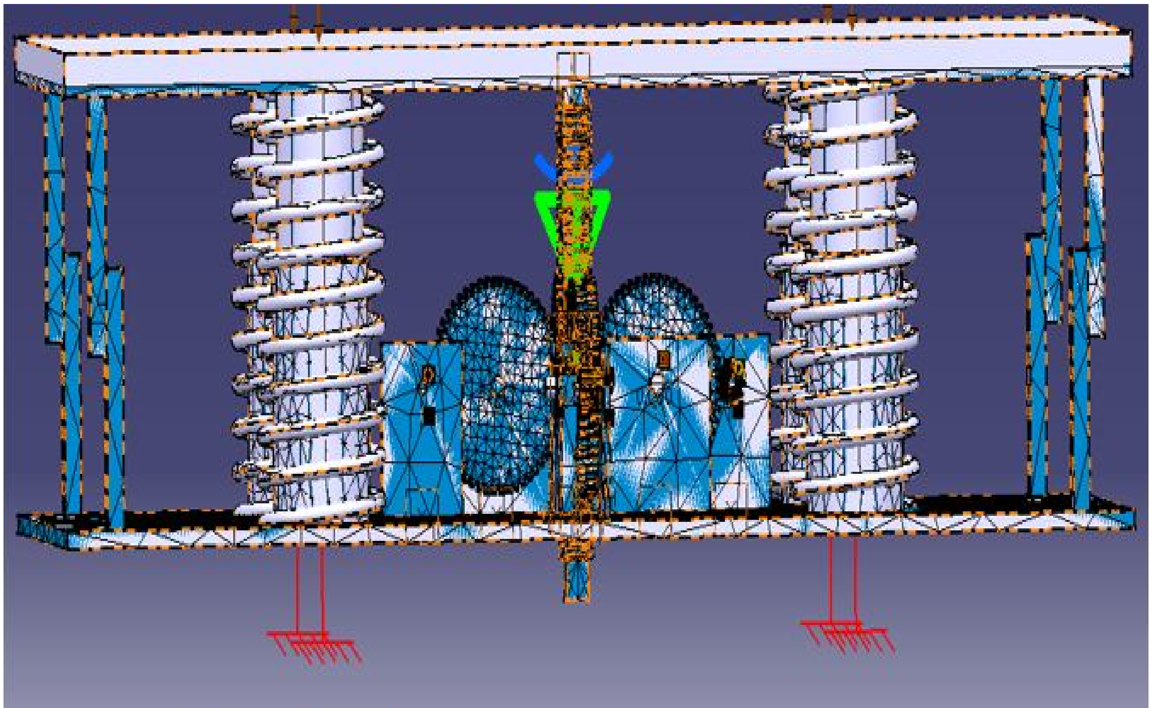
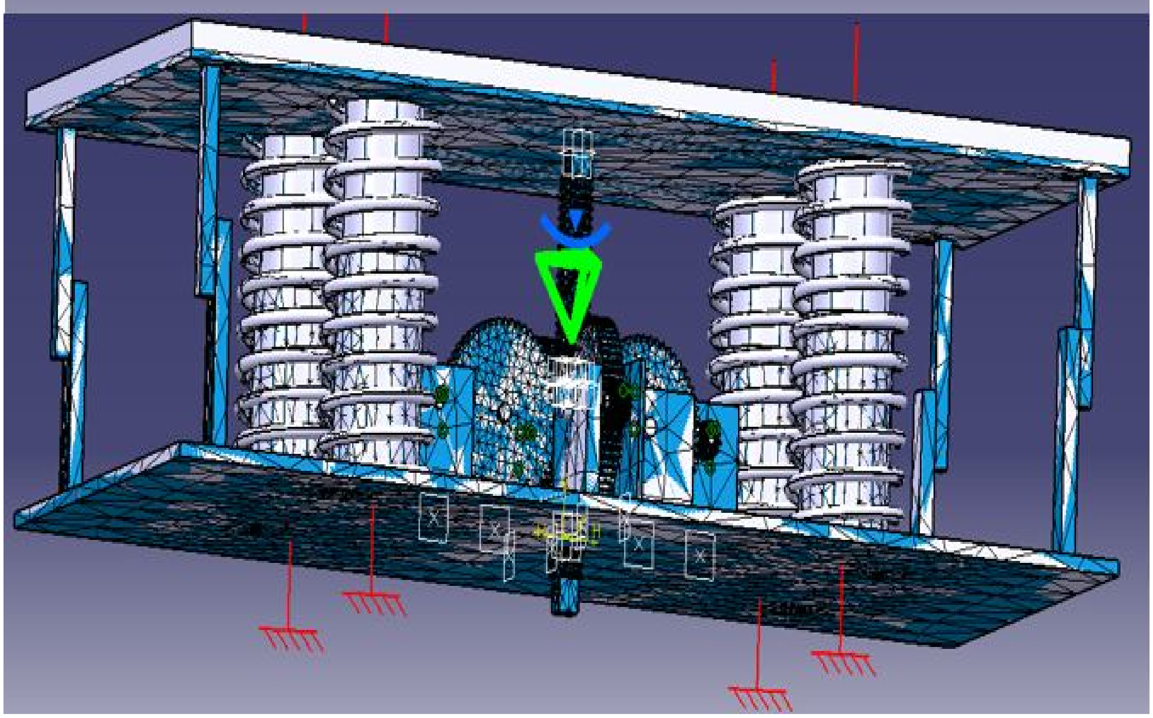



**Figure 4. 6 The proposed Inverter circuitry model**

## 4.3 SIMULATION RESULTS

In this section, the results obtained through simulation studies carried out using simulation softwares will presented.





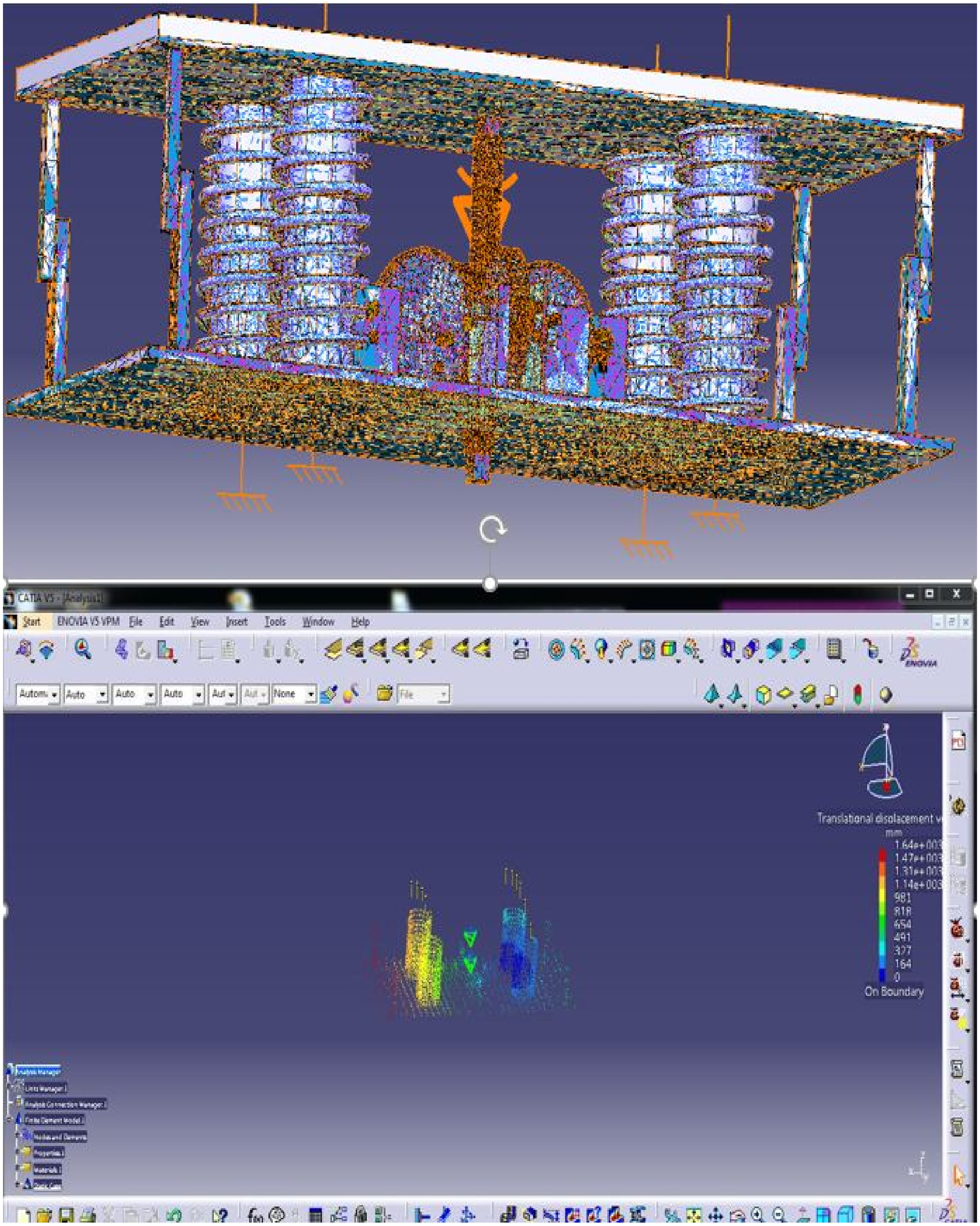



**Figure 4. 7 The proposed speed breaker model 2000 N load distortion response**

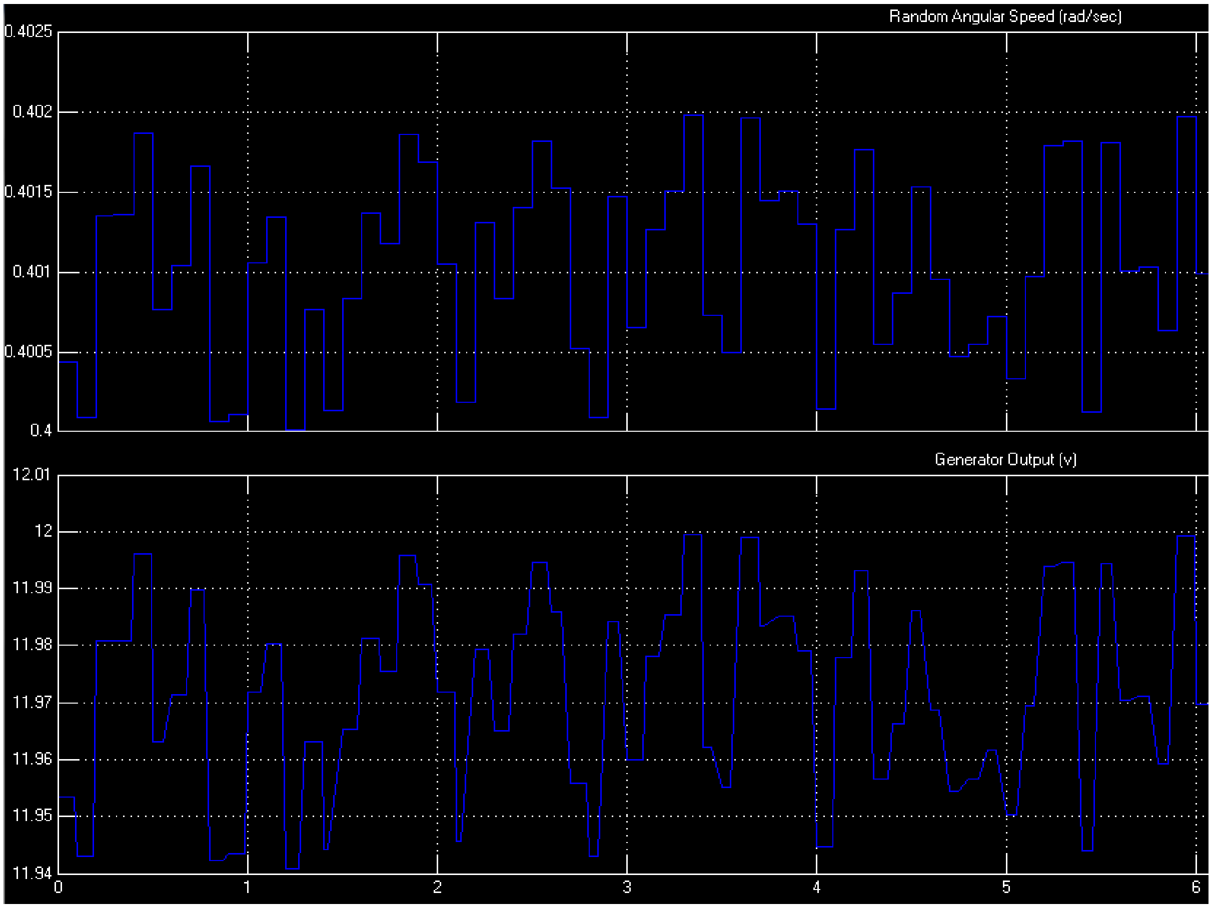



**Figure 4. 8 The generator gears angular speed vs the generated voltage**

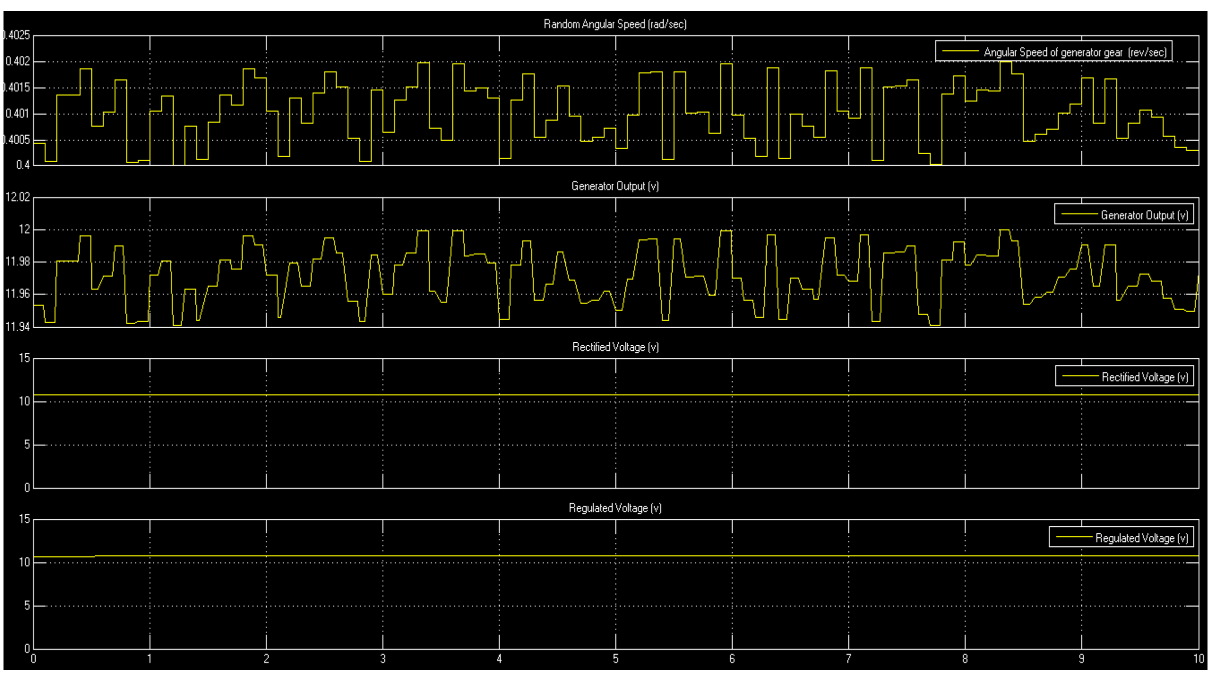



**Figure 4. 9 The rectifying and regulatory circuitry voltage output**

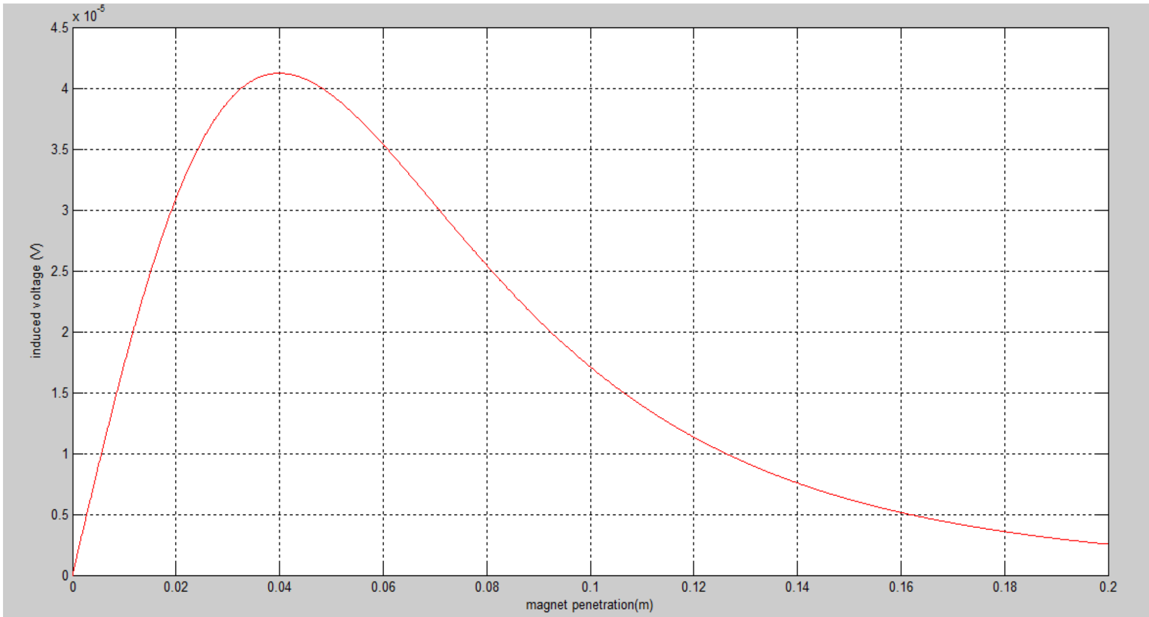



**Figure 4. 10 Magnetic field strength while magnet falling through the pipe**

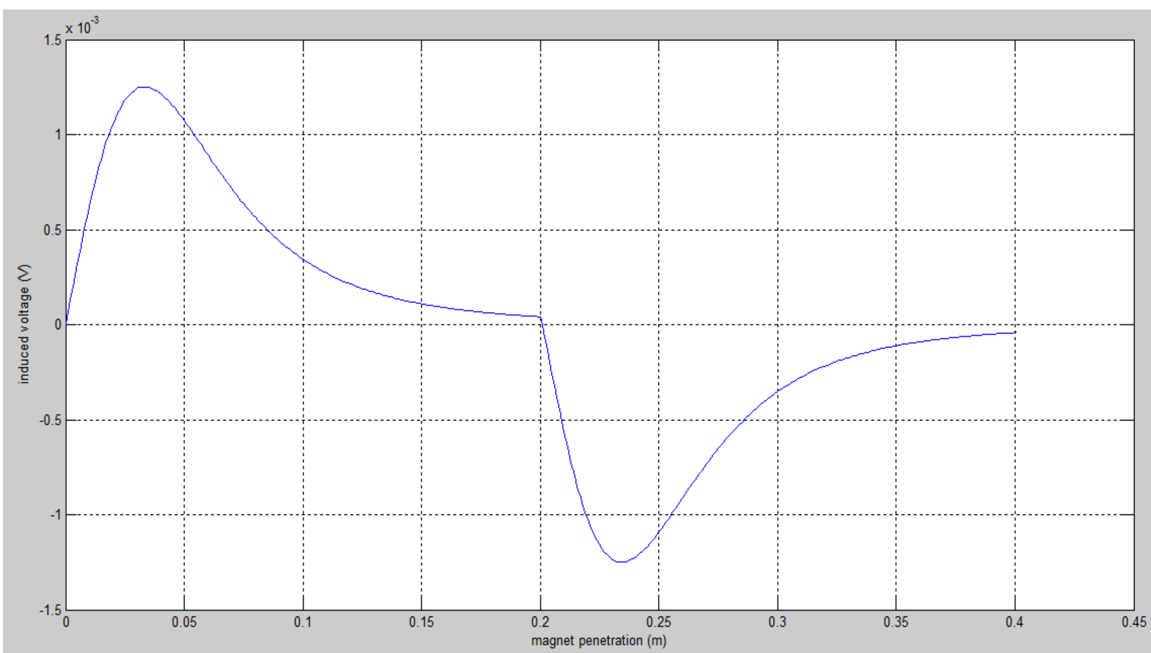



**Figure 4. 11 The induced voltage from Translational-induction**

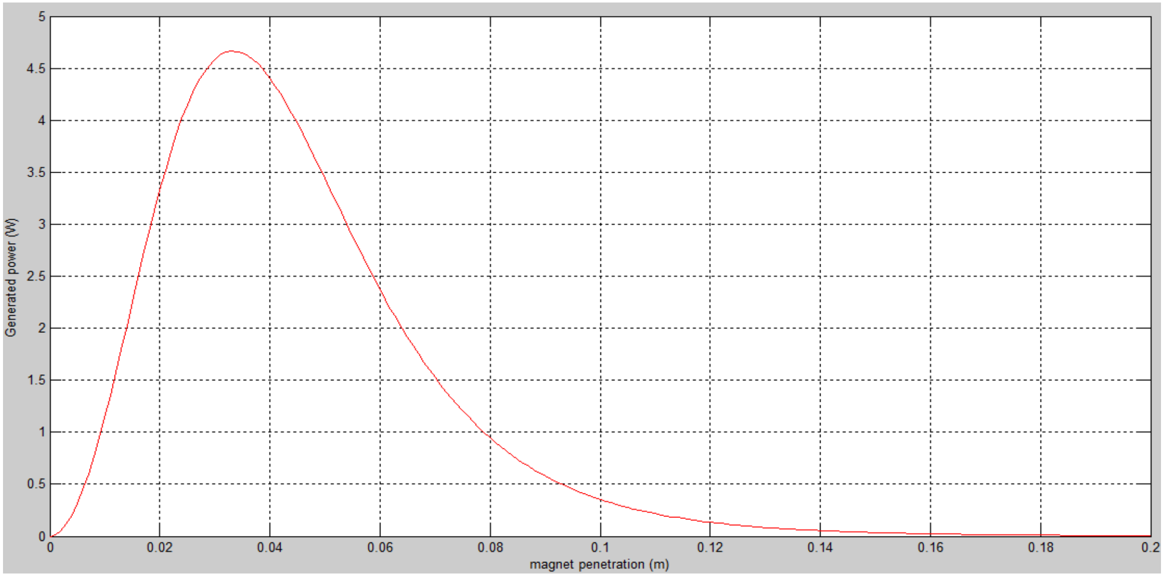



**Figure 4. 12 The Generated power due to Translational Induction**

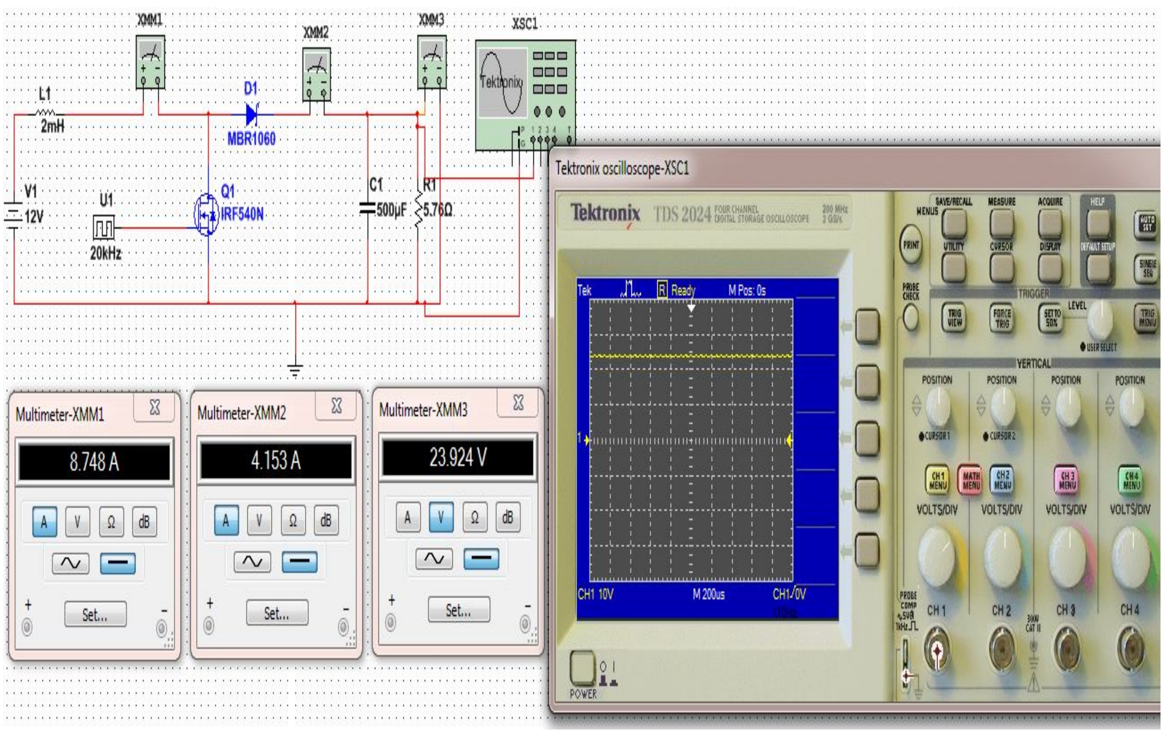



**Figure 4. 13 The proposed DC-DC Boost Converter output**

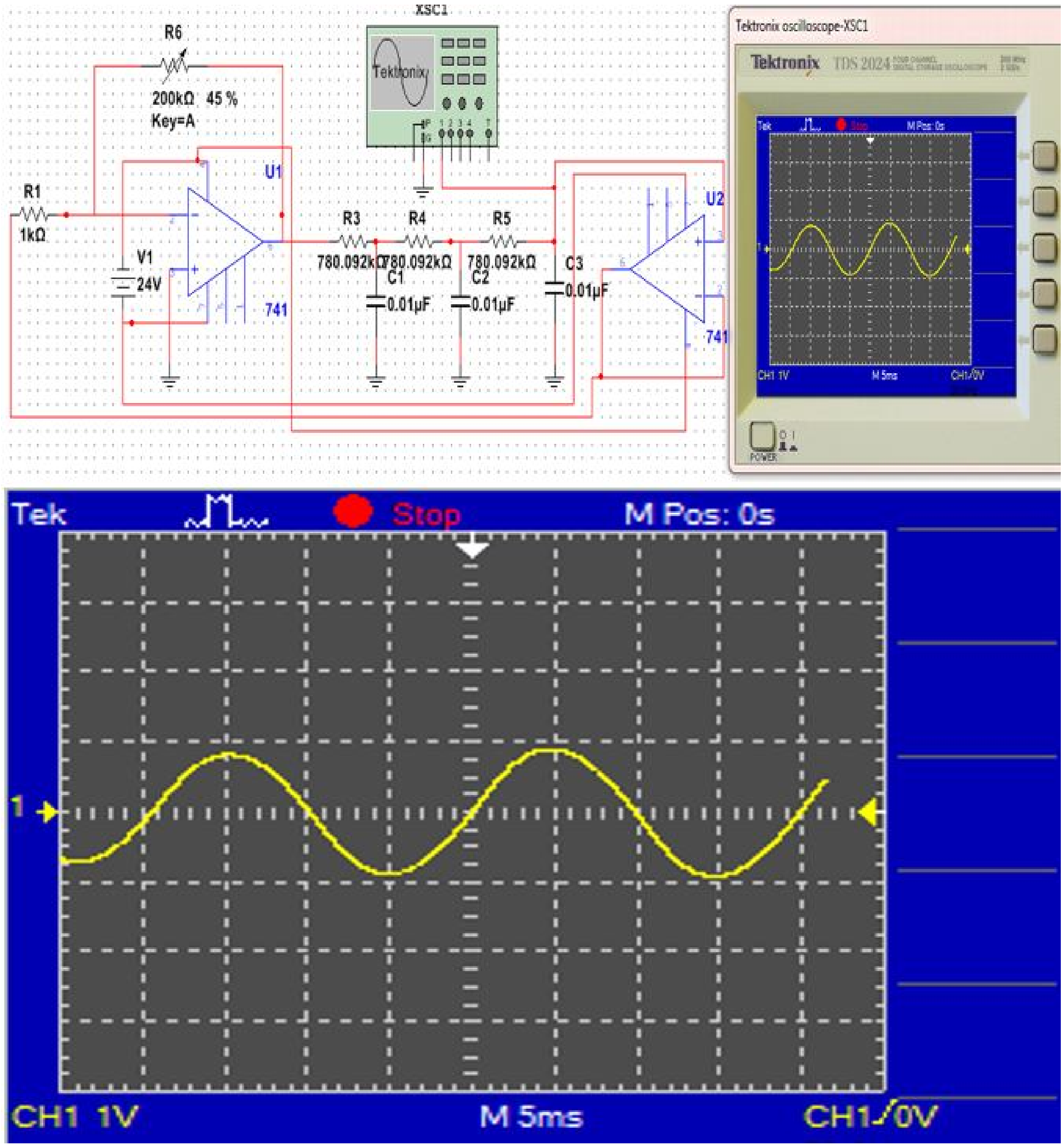



**Figure 4. 14 The proposed Sine Wave Oscillator circuitry output**

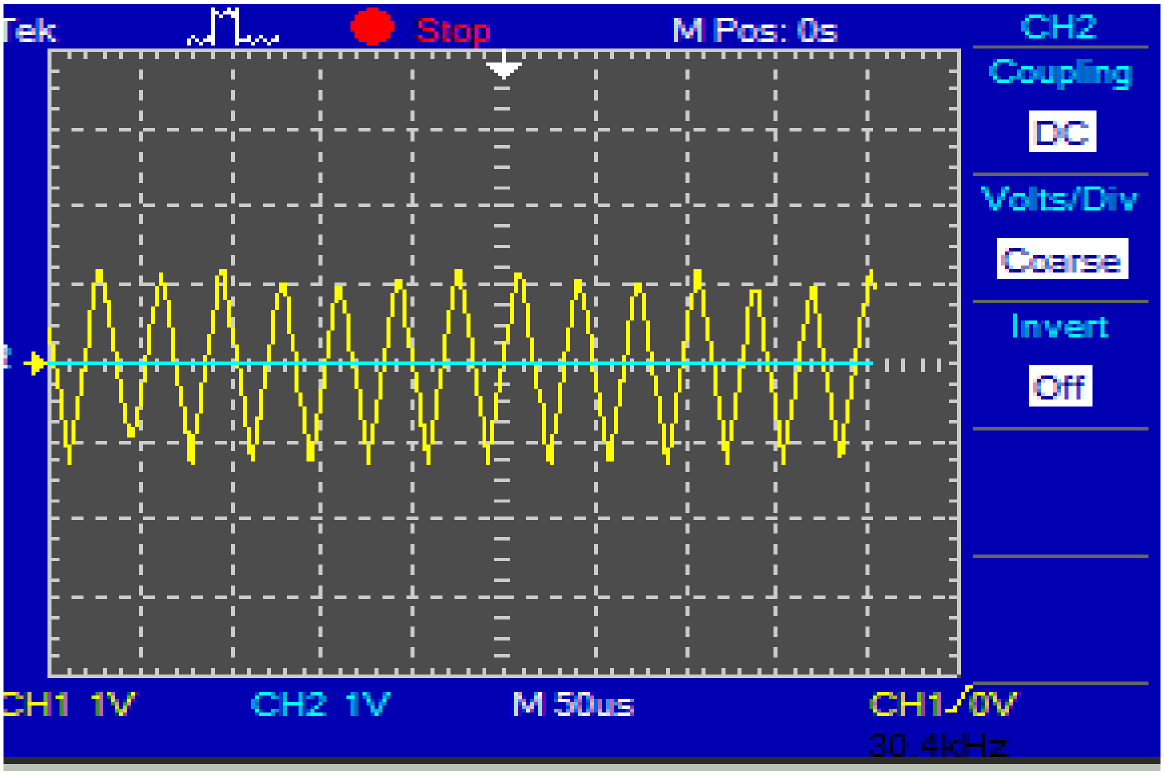



**Figure 4. 15 The proposed Triangular wave generating circuitry output wave form**

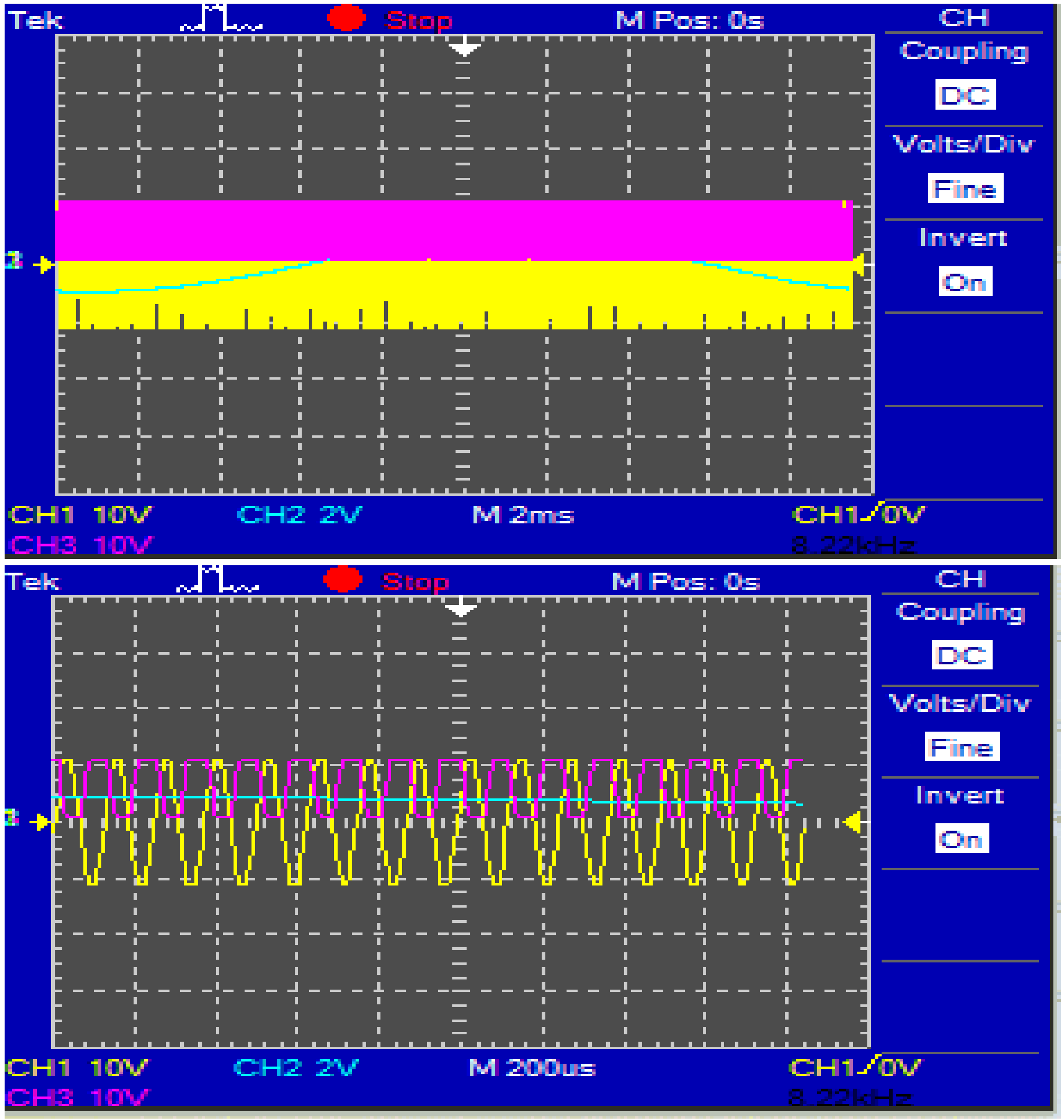



**Figure 4. 16 The combined output from the two oscillatory circuitry**

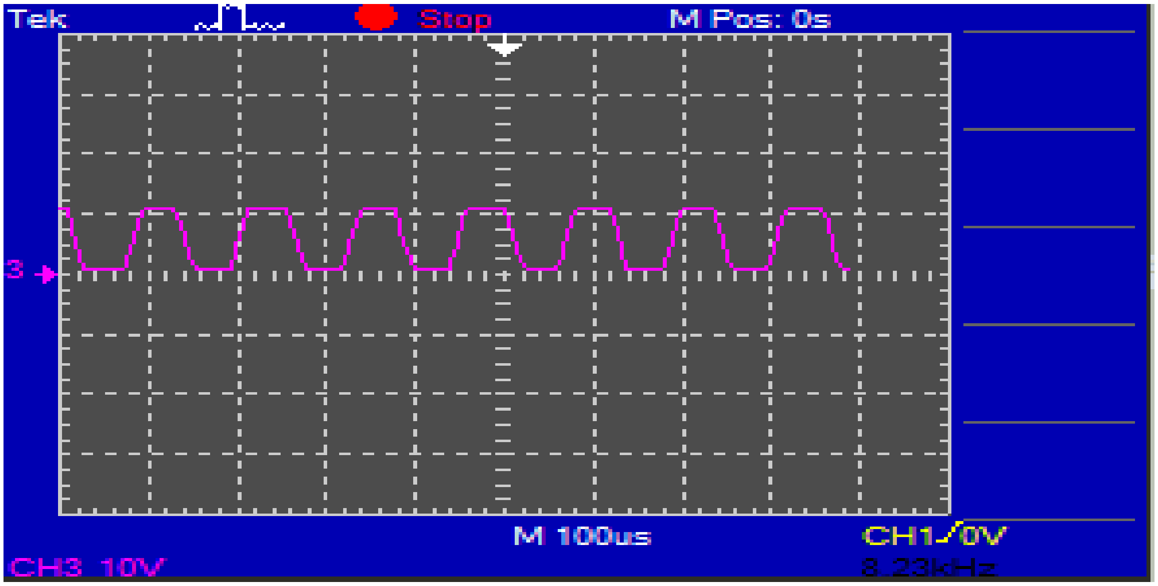



**Figure 4. 17 The switching circuitry final driving signal**

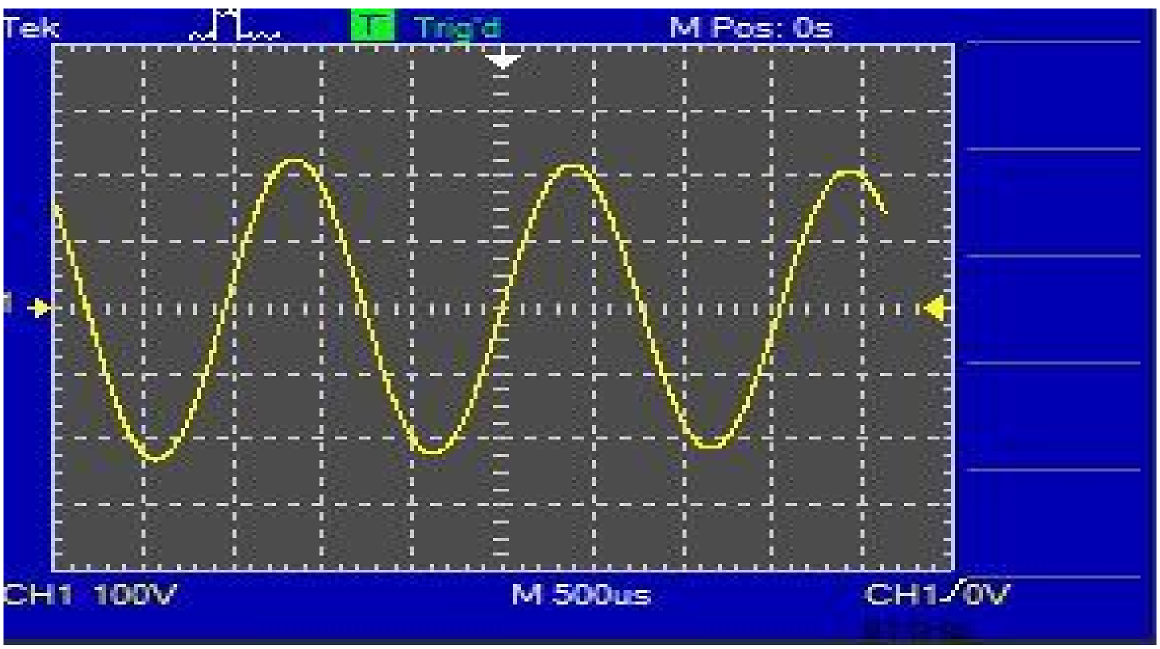



**Figure 4. 18 The inverter output after the step-up Transformer**

## 4.4 ANALYSIS OF RESULTS

In this portion of the thesis the analysis of the simulation results presented referring to their figure number specified in the previous section.

Figure 4.7 shows the full possibility for getting power output from the developed speed breaker generating system, which is tested for 2000 N load. The selected steel structure performed perfectly under the expected material property level and there is no parts displacement and distortion.

The simulation result presented in the figure 4.8 shows that when the angular speed of the generator gear varies in between 0.4-0.403 rev/sec, the generated output voltage lies/comes in the range of 11.91-12 V. It is observed/confirms that the generated voltage is directly proportional to angular speed of the driving system, i.e., generator gear.

Figure 4.9 shows the output power obtained with the regulating circuit. We observed from this figure that the generated voltage is maintained constant at 12V DC with the proposed regulating circuit.

Figure 4.10 shows that magnetic field intensity rises faster at the insertion “point” of the cylindrical copper pipe and attains a maximum value of $41.215\mu T$ at 0.0395 m and ramp out through the magnet journey.

It is observed from the figure 4.11 that when the speed breaker moves downward/goes down through the coiled cylindrical copper pipe with 0.1 m/s linear speed; the maximum induced voltage is 1.3 mV. The value of RMS voltage is 0.6233 mV. The power generation capability for the upward and downward trajectory of the magnet through the proposed magnetic path is presented in Fig. 4.12. It is clear from this figure that the maximum power that can be extracted from the proposed system by using a translational induction is given by 4.6631 W with RMS value of 1.9195 W and average value of 1.1578 W. We observe from figure 4.13 that the proposed DC-DC Boost converter is capable of boosting the 12V input voltage to the 24V with an error of 0.3166 V and nearly 95% efficiency. Figure 4.14 reveals that the developed sine wave oscillator circuitry is capable of generating 2 volts peak-peak voltages at 50 Hz frequency as required. It is observed from figure 4.15 that the proposed triangular wave generating circuitry is capable of generating approximately 2.5volts peak-peak voltage (nearly) at 30 kHz frequency as required. Finally, figure 4.21 reveals that the result that developed transformer is capable of transforming the inverter output voltage level from 19.2 V to a single-phase AC voltage level of 220 V.

# CHAPTER 5

# CONCLUSIONS, RECOMMENDATIONS AND FUTURE WORKS

## 5.1 INTRODUCTION

This chapter presents the conclusion for a conceptual design of a system for producing power output from vehicular traffic when vehicles pass over a specialized speed breaker unit which, mainly comprises a spring and Rack- Pinion arrangement to drive an electromechanical system for EMF induction.

## 5.2 CONCLUSIONS

The system is described on assumption of traffic flow rate and the rack penetration depth of hence producing as a vehicle is inputting a certain mechanical energy for pressing of the proposed speed breaker arrangement. The study of the system tries to justify the possibility of energy harvesting in terms of related equations, modeling and simulation results. The proposed work can serve as a prove of a promising platform for environmental friendly all year-round energy harvesting alternatives from recovery of waste kinetic energy via vehicular traffic on the express way toll, pedestrian crossing logistics center and areas where vehicles are forced to lower its speed for transition.

Design and simulation of a speed breaker mechanism for environmentally suitable and all year-round energy producing alternative, which is achieved firstly by reviewing literatures analysis with the theoretical background and related equations then simulating the proposed system parts using software like, CATIA V5(figure 4.1 and 4.7), MATLAB

13B (figure 4.8, 4.9,4.10,4.11 and 4.12) Electronic simulation technique, Multisim 14 (Figure 4.2, 4.3,4.4,4.5,4.6,4.13,4.14 4.15, 4.16, 4.17 and 4.18).

Finally, it achieved to show the possibility for generation of Electric Power imposing two types of induction techniques, rotational induction (four generating units) and translational induction (two generating units) to generate 691 kWhr and 8.2922 kwhr energy per day in 12 hrs. basis respectively.

This technique of power generation will help to reduce the total burden on the integrated grid system in Ethiopia. The speed breaker system driven by a vehicle on a road as a prime power generation source has many benefits like it does not depend on any type of fuel to run it, no waste production at any stage of the power generation process, power generation is environmental friendly, more sustainable and can be applied on large scale to produce a larger amount of energy to benefit a bigger population.

## 5.3 RECOMMENDATIONS

It is recommended that Ethiopian Electric power corporation (EEPCo) and other interested agency may construct a prototype of the proposed system and test it for its implementation on highways in Ethiopia.

## 5.4 SUGGESTIONS FOR FUTURE WORK

It is suggested to carry out the following research work in this area.

1. Soft design and simulation studies on electromechanical system and estimation of power generation considering the variations in weight and speed of vehicles over the speed breakers.
2. Design a charge controller and a feedback regulator units to control the operation of electrical units in accordance with the varying load for minimum voltage regulation.
3. Carry out simulation studies on the overall electromechanical designed using the as suggested in step 2 above.

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# APPENDICES

## Appendix I: Speed breaker total system and part design specifications

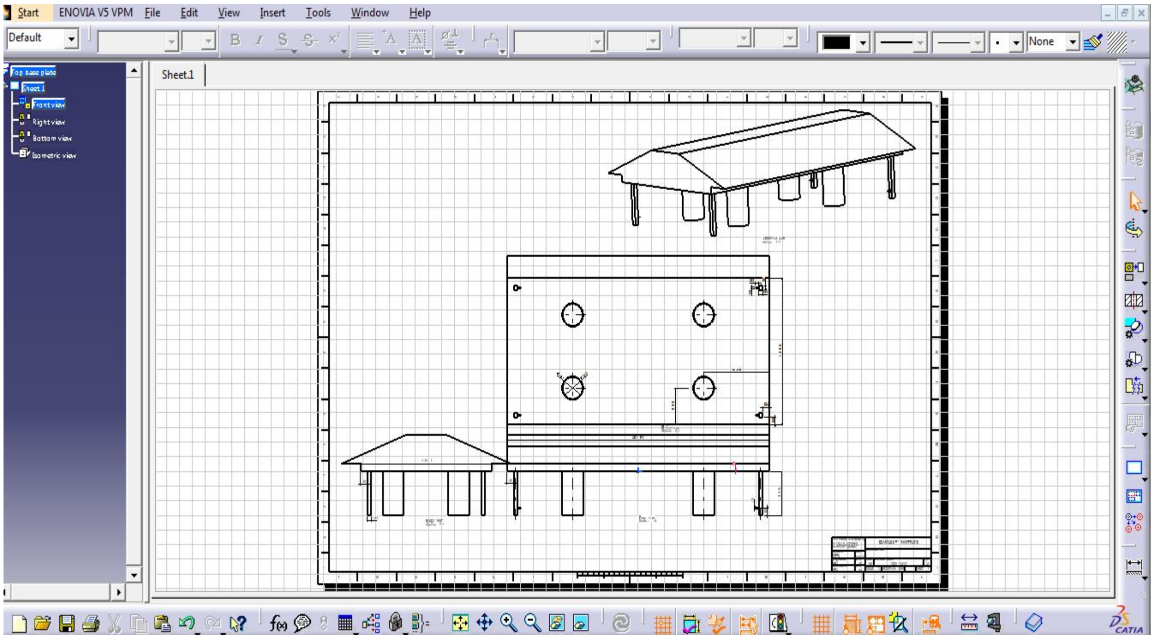


Figure A1: Upper base plate design specification

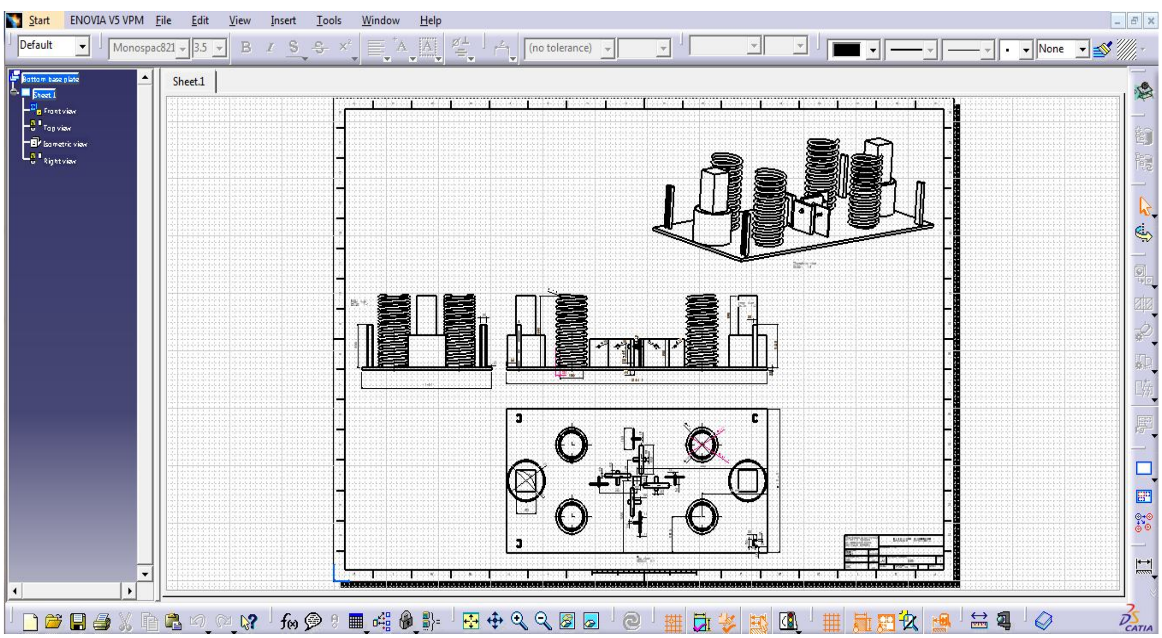


Figure A2: Bottom plate design specification

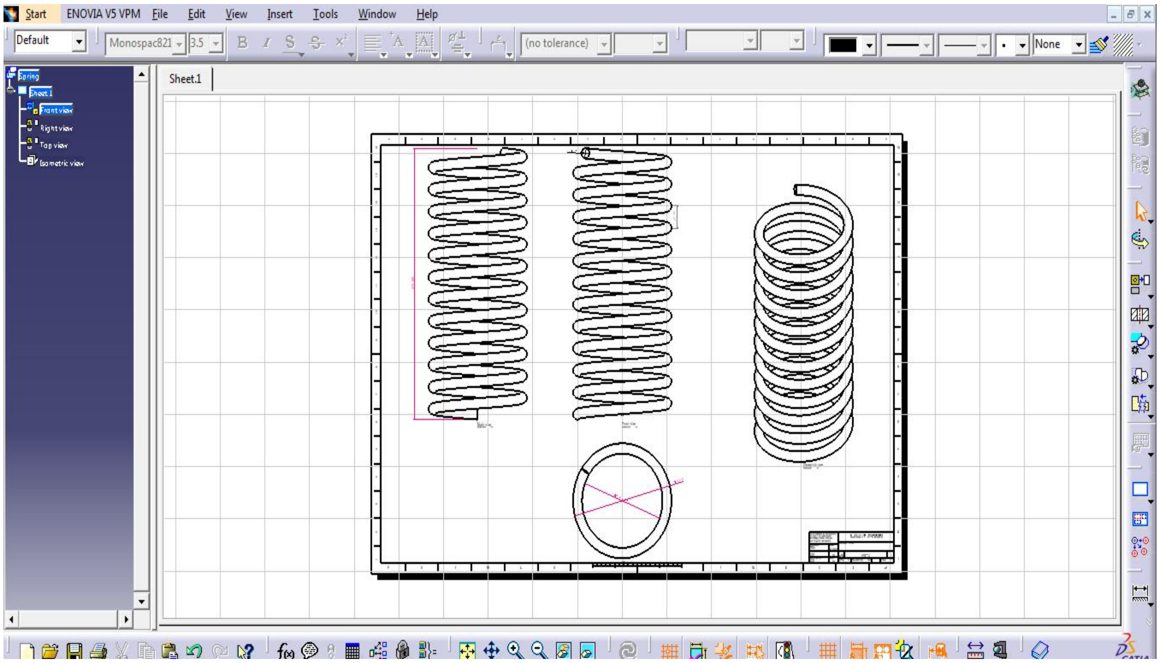


Figure A3: Spring Design specification

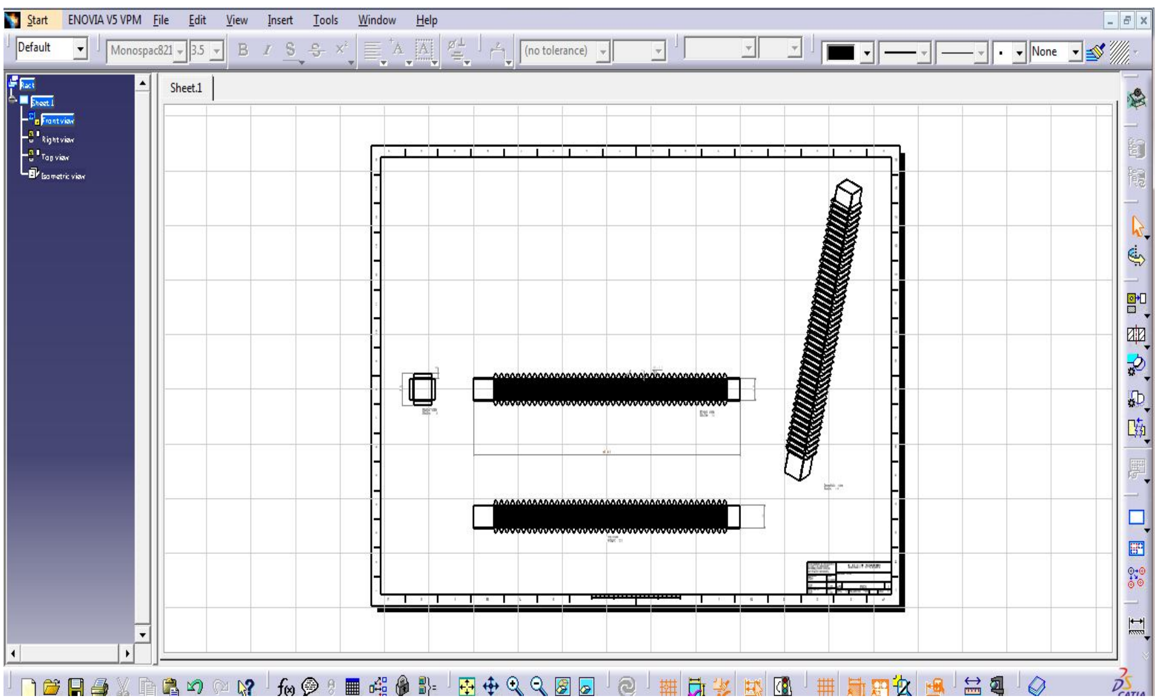


Figure A4: Rack design specification

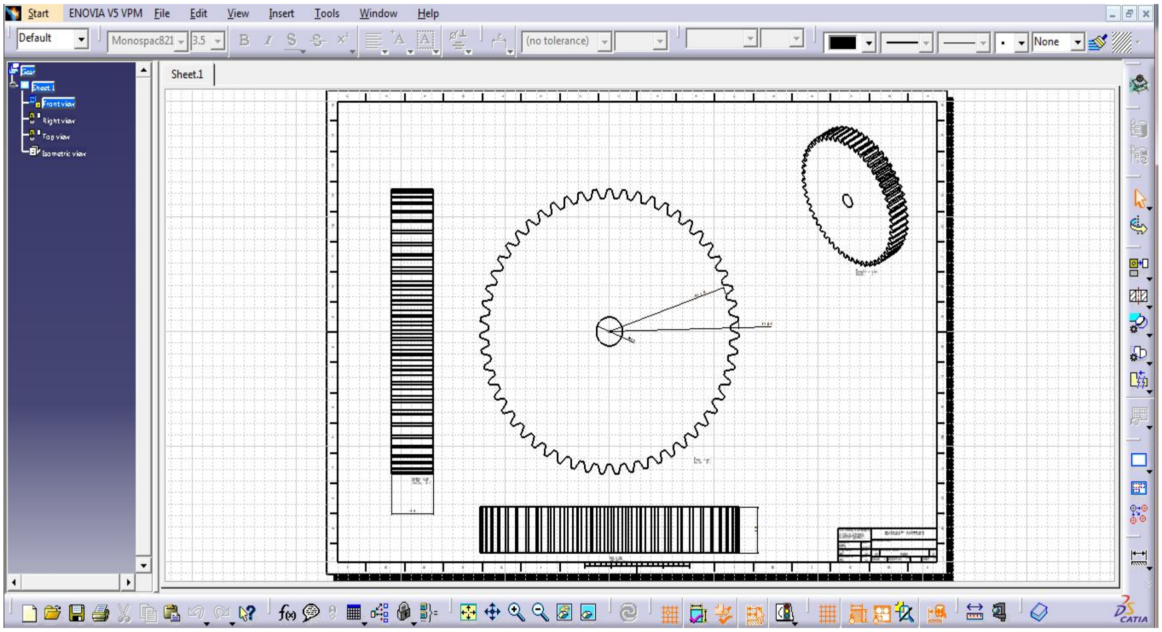

Figure A5: The pinion design specification

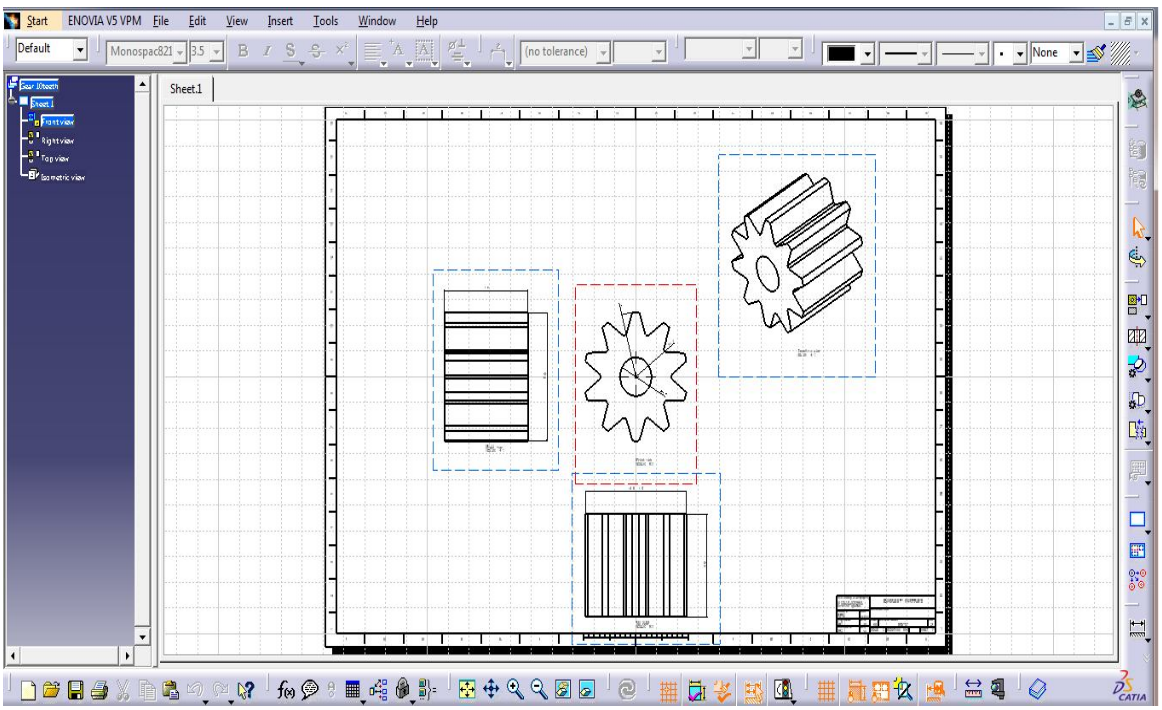

Figure A6: DC generator gear design specification

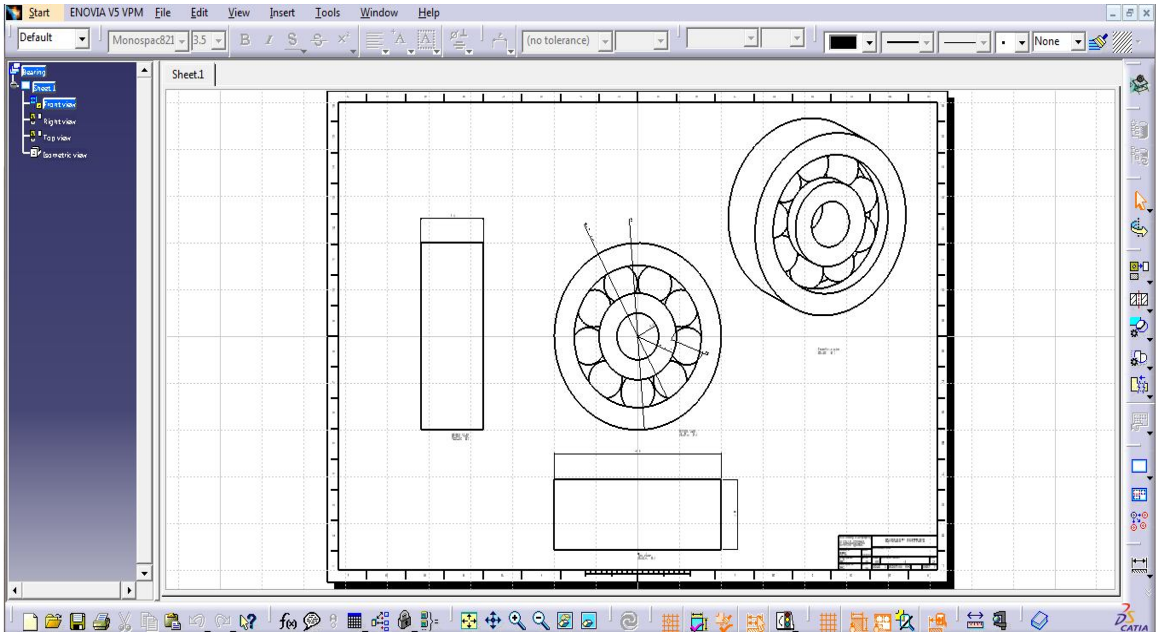


Figure A7: The upper and Bottom plate supporting led Bearing design and specification

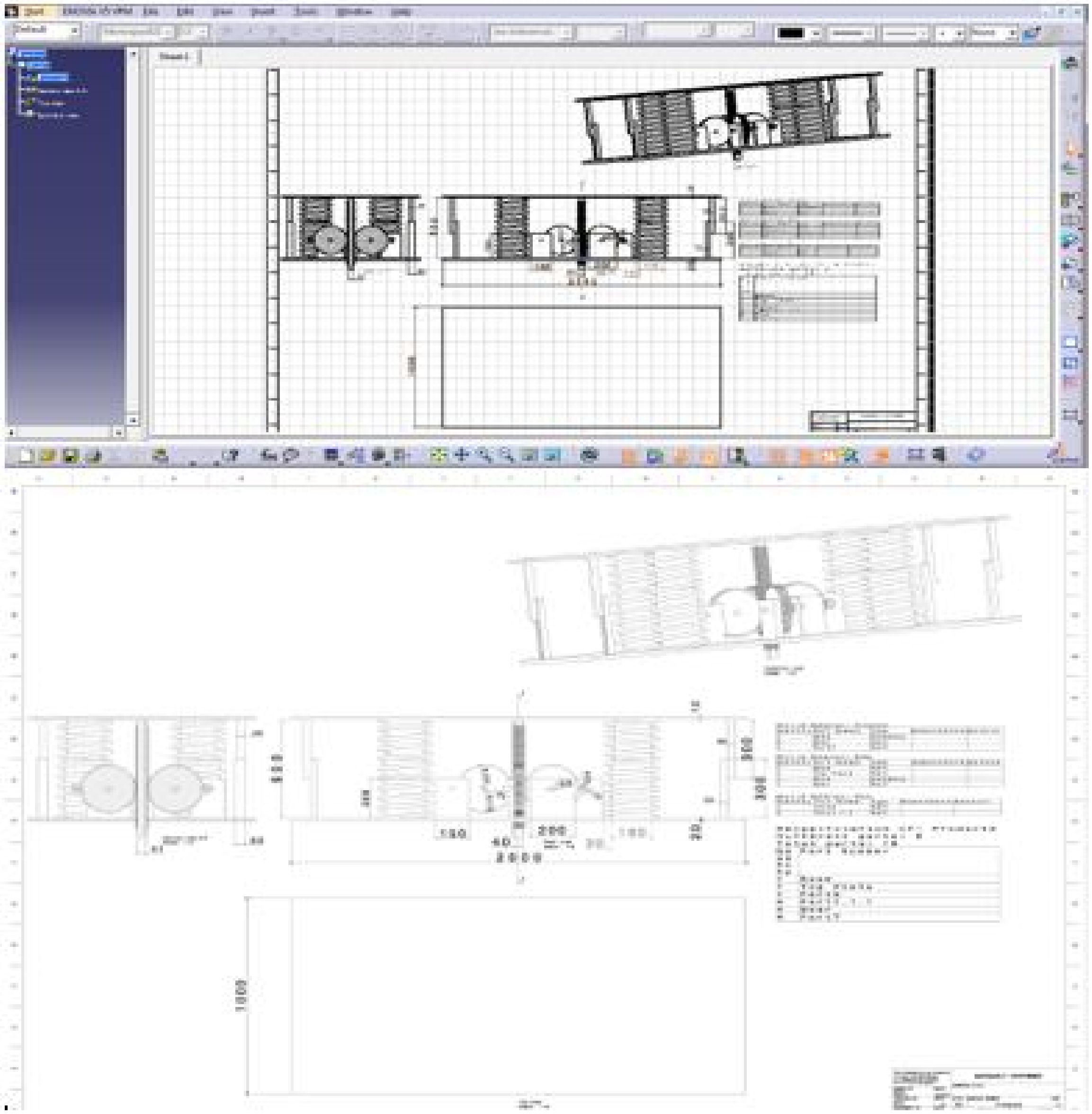

Figure A8: The general speed break system design specification

## Appendixes II: Transformer design prefixes

Table A1: Transformer Utilization factor as prefixed by DE Lorenzo

| Transformer Type | Utilization or Machine factor $\boldsymbol{k_u}$ |
|---|---|
| Single phase Core | (1.2- 1.9) $10^{-2}$ |
| Single phase Shell | (2.5- 4) $10^{-2}$ |
| Three- phase Core | (1- 1.6) $10^{-2}$ |
| Three- phase Shell | (2- 3) $10^{-2}$ |

Table A2: Maximum induction B in iron core and current density as prefixed by DE Lorenzo

| Operation | $B\left(\frac{Wb}{m^2}\right)$ | $\delta\left(\frac{Wb}{m^2}\right)$ |
|---|---|---|
| Continuous | 0.8-1 | 1.8-3 |
| Intermittent | 0.9-1.1 | 3-4 |
| Pulsed | 1- 1.3 | 4-5 |

Table A3: Kinds of Transformer Winding Insulation as prefixed by DE Lorenzo

| Insulation | Thickness | Packing Coefficient $\boldsymbol{K_s}$ |
|---|---|---|
| Paper | 0.5 | 0.88- 0.91 |
| Paper | 0.35 | 0.85- 0.88 |
| Paint | 0.5 | 0.90- 0.93 |
| Paint | 0.35 | 0.88- 0.90 |

Table A4: Voltage Drop and Efficiency of a Transformer as prefixed by DE Lorenzo

| Power Rating VA | $\Delta \boldsymbol{V}$% | η% |
|---|---|---|
| 5-30 | 25-15 | 65-75 |
| 30-50 | 15-9 | 75-80 |
| 50-100 | 9-7 | 80-85 |
| 100-500 | 7-4 | 85-90 |
| 500-1000 | 4-3 | 90-94 |
| 1000-5000 | 3-2 | 94-95 |

Table A5: Filling Coefficient for transformer laminated core as prefixed by DE Lorenzo

| Filling Coefficient $\boldsymbol{k_r}$ | Diameter (mm) |
|---|---|
| 1.1 | 0.05-0.30 |
| 1.05 | 0.30-3.0 |