



## ON GENERATION OF RENEWABLE ENERGY FROM ROAD TRAFFIC

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### ABSTRACT

*This paper investigates the possibility of generating green power from day to day road traffic. This source of green energy is obtained from the proposed systems that harness the wasted energy such as the kinetic and vibrated energy from everyday traffic. These include two proposed systems that were designed and implemented using the MATLAB-Simulink platform. In the first proposed system, the renewable energy is generated using compressed air which is suitable for developing countries and the second proposed system is designed such way to another system to deduce electricity by harvesting the kinetic and vibration energy. The second proposed system is suitable for a developed country based on the implementation expenditures. The system was designed considering all the factors that involved producing a realist outcome. These factors include the load factor, heat loss, power loss, frictional losses and the switching losses that dwell into the field of fluid mechanics, power electronics and element analysis. The system performance was also determined by considering the nature and characteristic properties of the materials, motors and generators used; and the usage time of the system. As a result, incorporating the necessary factors involved in the system designing, the power generated under traffic rate condition at peak and off peak hours for each system was estimated. The obtained results proved that substantial amount of power are generated during peak traffic hours using the two proposed methods.*

**Keywords:** Green energy, Renewable energy, Sustainability, Traffic rate, Pressure, Compressed air, Piezoelectric transducer.

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### Contribution/ Originality

This paper contributes to the very first logical analysis of obtaining power production in kWhr for various case studies. The analysis performed takes into consideration the load factor, speed of travel and impact of stress and strain of the vehicles on the energy harvesters along with its energy penetration level.

## 1. INTRODUCTION

The underlying principle of generating green energy is becoming more demanding due to the fact that total energy of an isolated system remains unchanged as the law of conservation of energy states that the energy can neither be created nor be destroyed but converted from one form of energy into another form of energy. This procedure of transformation is generally expresses as energy transfer that empowers the energy to reside at various states or transforms into another form of energy by means of generators or transducer. Thus, this paper investigates different processes of harnessing unused energy so as to produce environmentally friendly power referred as green energy by harnessing the energy wasted from vehicle traffic to power street lights, traffic signal, radars and residential houses and is accepted to be more effective than the wind or sun based power generation systems. This paper presents relevant theory from previous work that elaborates the principles of fluid mechanics, mechanical engineering, power electronics, the finite element analysis and the classic plate theory involved in the system designing and structuring as they incorporate the concept of generating power from compressed air and piezoelectric materials. This also includes the exploration of basic principle of mechanisms involved in the two proposed methods. In addition to theory, this paper discusses the results obtained from numerical simulations with the help of MATLAB-Simulink environment to analyze the two scenarios and to analyze the anticipated results by keeping in mind that the end goal is to legitimize the hypotheses to a realistic and a sensible scale. After which, the outcomes acquired is completely inspected and broke down in discussion section followed by the references that were utilized to infer to the accompanying conclusions.

## 2. LITERATURE REVIEW

In the first scenario, that is the generation of electricity by utilizing the mass of the vehicles that climb over speed bumps; addressed as 'METHOD 1' is explored. This method is ideal for developed countries as it doesn't require any major road construction and doesn't disrupt the everyday living with minimal infrastructural expenditure. The initial idea for implementation of this methodology was discussed in [Omari and Huseyin \(2015\)](#) where multiple air pumps were embedded onto to the speed bumps on the roads as observed in Figure 1.



**Figure-1.** Installation of Air pumps in a cross road

The system design of these air pumps deals with the field of material science and mechanical engineering in order to design a most appropriate speed bump that comprises of air pumps specially designed with a unique spring to mass ratio along with a material that engulfs these air pumps to form the required robustness of a speed bump. The internal structure of the air pumps is represented using Figure 2.



Figure-2. Internal Structure of the Air pump  
Source: Ibrahim (2014)

In the study, it was found that the material known as the Type 2-TWB membrane was the most appropriate material that can be utilized to engulf the air pump. As this membrane is equivalent to the structure of a car tire and it is a heavy duty material, so it can withstands the ambient temperature including the wear and tear characteristics. This material not only withstands the climatic, traffic and pavement conditions; it also protects the air pumps installed on the pavement.

Then the next stage of the proposed system is to collect this compressed air in an air tank that will be placed on the other side of the pavement with the rest of the system as observed in Figure 1 and from now on it will be referred to as the control system; as the system controls the entire production of energy. The air tank within the control system operates the pneumatic motor by regulating the pressure at a constant rate. Since the system utilizes compressed air as a source of its input, the system has to deal with fluid mechanics. The basis of fluid mechanics was to understand the compression air techniques and the pump system which is briefly discussed in Keith (2000). Then the circuit analogy of the pneumatic motor is required to process this compressed air. The pneumatic motor is used to expand this compressed air and thus produce mechanical power. However, the working, the minimal requirements and conditions of the pneumatic motor involves the pneumatic circuit analogy and the safety of the piping and the valve system was discussed in Keith (2000). In order to understand the pneumatic motor functionality, the input air power, the volume flow rate, the heat dissipation was all computed by applying the pneumatic equations from Keith (2000). The troubleshooting of the pneumatic system and valves and its fittings were also discussed in Keith (2000). The next stage of transforming the mechanical power in to electrical power, alternators were

recommend and the characteristics and properties of an alternator was discussed in [Jianjun \*et al.\* \(2015\)](#). Despite the havoc in designing this system, this scenario was proposed keeping in mind the beneficial factor for a developing country in regards with its economic aspects. However, it has been discussed in [Ibrahim \(2014\)](#) that a vehicle weighing a ton that climbs up a 10 cm ramp produces about 0.98 kW while using a highly efficient pneumatic motor and an abstracted alternator. This methodology is the most appropriate for developing countries as this method requires least infrastructural attention and cost of installment and manufacturing.

In the second scenario, that is the generation of electricity from the pavement (or road) addressed as ‘METHOD 2’ is explored. This method of implementation is suitable for developed countries as implementation of the system will require major road construction and disrupt the everyday living. Hence, the country needs to have enough resources and organization to run the course of implementation smoothly and proper financial status in comparison to the other method referred to as Method 1. Moreover, in this method several piezoelectric transducers were laid out at 5 cm beneath the surface of the road as the placement of the transducer plays a vital role in determining the output. However, this form of implementation was achieved by altering the foundation structure of the pavement such that it behaved like a plate resting on the Winkler foundation was discussed in [Zhiwei \*et al.\* \(2015\)](#). Moreover, they have carried out various analyses that estimated this particular position of the transducer which yielded an average power of 250 kW/hr/km per lane for 20 vehicles passing per minute and it also yielded a maximum power output of 1.2mW with an electric potential of 98 V at 20 Hz frequency. As these piezoelectric transducers captures vibrations and utilizes the deformation of the road as its input source. In order to deduce the deformation of the road the dynamic response of the pavement denoted by (2) was obtained using classic plate theory namely the Kirchhoff-love plate theory equation represented by (1) that incorporates trigonometric Fourier series, transform and Cauchy’s residue theorem ([Xu \*et al.\*, 1996](#)).

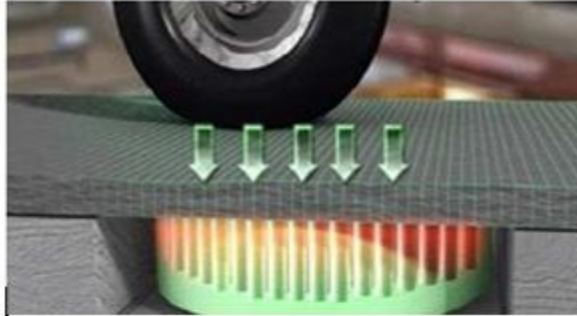
$$D \nabla^4 \omega(x, y, t) + \rho h \frac{\partial^2 \omega(x, y, t)}{\partial t^2} + K \omega(x, y, t) = F(x, y, t) \quad (1)$$

$$D \left[ \frac{\partial^4 \omega_m(x, t)}{\partial x^4} - 2 \left( \frac{m\pi}{b} \right)^2 \frac{\partial^2 \omega_m(x, t)}{\partial x^2} + \left( \frac{m\pi}{b} \right)^4 \omega_m(x, t) \right] + \rho h \frac{\partial^2 \omega_m(x, t)}{\partial t^2} + K \omega_m(x, t) = f_m(x, t) \quad (2)$$

Using Equation (2), the displacement of the pavement due to the load intensity of the vehicle considering the coefficient of friction was obtained. Then the direct piezoelectric law, stated by equation (3) was used to determine the output voltage and power of a single piezoelectric generator observed in Figure 3 ([Goldfarb and Jones, 1999](#); [Hongduo \*et al.\*, 2014](#); [Zhiwei \*et al.\*, 2015](#)).

$$C_0 \frac{dV(t)}{dt} + \frac{V(t)}{R} = \frac{dQ(t)}{dt} \quad (3)$$

However, the modeling and the structuring of the piezoelectric transducers on its own involves the process of finite element analysis to choose the appropriate material namely the PZT-5H. The finite element modeling of the piezoelectric transducer was discussed and the finite element analysis to determine the structure and the material to be used to design a piezoelectric transducer was discussed in (Hongduo *et al.*, 2014; Omari and Huseyin, 2015).



**Figure-3.** Placement of Piezoelectric Transducer  
Source: Zhiwei *et al.* (2015)

From the study, it was found that the man made PZT-5H element was appropriate as it exhibits highest piezoelectric property from  $25^{\circ}$  to  $170^{\circ}$  which is well within the curie temperature and about 8 to 16 PZT piles were recommended for 0.04 m<sup>2</sup> pavement area where the PZT piles were of round shape and multi-layering the structure of PZT was suggested to decrease the electric potential on pavement generator. These analogies and discussed methods (Keith, 2000; Reddy, 2006; Hongduo *et al.*, 2014; Jianjun *et al.*, 2015; Zhiwei *et al.*, 2015) were used to design the piezoelectric generator and the system also comprises of various other power electronic systems such as rectifiers, inverters, DC boost converter, LC filter, PWM modulation and PI controller (Ned *et al.*, 2003).

### 3. METHODOLOGY

#### 3.1. Design Model for 'Method 1' Energy Harvester System

This methodology is ideal for developing countries as the installation process does not disrupt the traffic and does not require any additional major road construction. First, a basic block design for this type was structured depicted by Figure (4).

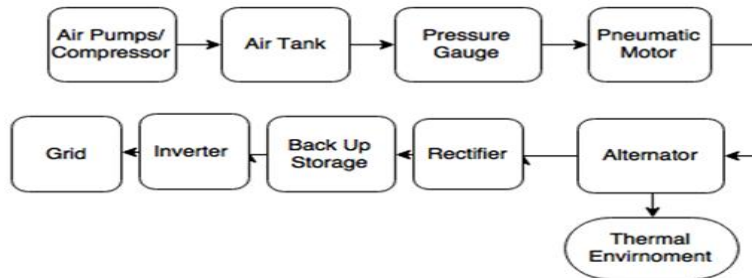


Figure-4. Process Flow Chart

#### 4. METHODOLOGY

The flow chart shown in Figure (4) represents the working process of the entire proposed system. As mentioned in the literature review, the system comprises air pumps that will be embedded on to the pavement and these air pumps will act as the air compressor that generates the input source for the control system located across the pavement. For these air pumps a proper thermal environment is set up as to release the heat produced during the compression of the air. Then, this air flows through the tube that inter connects the air pumps at the bottom which creates a path to the air tank. The air tank constant regulates the value such that it detects the amount of pressurized air contained; if it is less than the set value, the air tank continues to inlet the air from the air pumps otherwise it starts to supply the compressed air to the pneumatic motor. This supply of compressed air at a certain pressure and air delivery rate will cause the pneumatic motor to rotate; which produced the required mechanical power output that will rotate the alternator to set up a field voltage at first.

After which, the alternator produces the electrical power output that is regulated at the desired voltage level using a voltage regulator. However, the alternator emanates heat during the process of converting mechanical energy into electrical power output and is taken care of a thermal environment. This thermal environment works on the principle of convection heat transfer. Moreover, this voltage produced by the alternator is rectified and the power is stored in a backup battery for later use. Then the power stored in this back battery is converted in to AC power using an inverter; the inverter not only converts the DC power into AC, it also steps up the frequency of the power to maintain the power quality of this green energy before supplying it to the grid for further transmission.

This mechanism of the system was carefully implemented using the MATLAB - Simulink environment taking into consideration the following factors that affects the system performance such as,

- Loss in air pressure due to
  - Leakage
  - Change of ambient temperature
  - Malfunctioning of Pneumatic motor
- Choosing the type of pneumatic motor to achieve the desired output and working time.
- Efficiency of the Pneumatic motor

- Inertial loss set up between the motor and the shaft
- Frictional losses
  - Break-Away Friction Torque
  - Coulomb Friction Torque
  - Viscous frictional losses
- On state / Off state Transitional losses
- Linear region velocity threshold
- Choosing the alternator to give a maximum performance in relation to the pneumatic motor.
- Alternator losses
  - Heat loss
  - Minimum torque and velocity to set up rotor field
  - Core loss
  - Copper loss
  - Rectifier losses
- Designing of an appropriate heat transfer system for the alternator.
- Voltage regulation and charging system

All these factors were considered to design a real time working system on Simulink environment where the loss in air pressure is mainly caused due to the unused portion of the compressed air that air at the pneumatic motor to be expanded. As all the air doesn't necessary get expanded to produce relevant amount of output. A fraction of compressed air escapes through the gaps present in the structural design of a pneumatic motor. Then a safety valve system was designed to evacuate this compressed air through this safety valve while maintaining the pressure within the system and the ambient temperature. After which, this expanded air produces the mechanical output (rotational); but this mechanical power output was deduced from the pneumatic motor after overcoming the factors that determine the efficiency of the pneumatic motor. As listed above, the compressed air supplied; first overcomes the inertial tension set up between the motor and the shaft and the frictional losses set up due to the break-away torque required by the pneumatic motor to start functioning (also known as the stall torque). Then the system experiences the coulomb frictional losses mainly caused due to the mechanical damping between the rotatory parts present within the pneumatic motor system. Moreover, the proposed system not only experiences the mechanical system losses but also the losses defined from the processing and non-processing states i.e. , the overall stall torque value of the proposed system increases with every change in the state of the pneumatic motor while transitioning from ON state to OFF state and back to ON state and so on.

Next, the losses due to the alternators were considered as the transition of mechanical energy to electrical power output experience losses within the alternator system as listed. The alternator losses are mainly due to the electrical components uses to structure the alternator such as the windings, the tolerance of the connection within the system namely the copper and core loss. The core loss in an alternator is mainly due to the hysteresis and eddy current losses

when the magnetic field set up by the system varies. Moreover, this field current set up is required by the alternator to start producing the energy transfer. On the other hand, the copper loss in an alternator is caused due to the undesirable energy transfer that produces heat. Therefore, the system was designed to have a thermal system that acts as a heat sink to the alternator system to transfer the heat produced into the environment and maintain the system temperature to prevent any harm or damage of the alternator system. Finally, the proposed system experiences external losses set up by the rectifier system that converts the ac power produced into dc and then the losses set up by the voltage regulator system before storing it a back up battery.

#### 4.1. Design Model for ‘Method 2’ Energy Harvester System

This methodology is ideal for developed countries as the installation process disrupt the traffic and require major road constructions. First, a basic block design for this type was structured depicted by Figure 5.

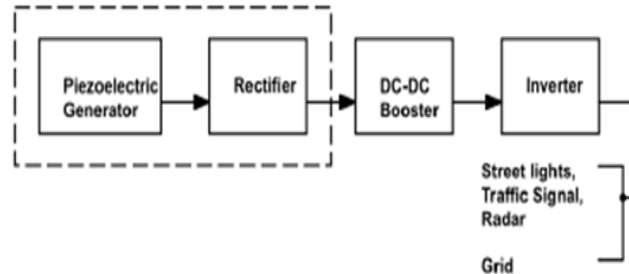


Figure-5. Block diagram representation for Method 2

## 5. METHODOLOGY

The first two blocks in Figure (5) represents the piezoelectric transducer stage where the vibration energy input (mechanical source) is converted into an electrical power output source which is then rectified to a DC output (~up to 100V) stated in Ned *et al.* (2003). Then this output is doubled via DC boost converter for the purpose of transmission, which is then passed through the inverter to produce an AC output for transmission.

This mechanism of the system was carefully implemented using the MATLAB-Simulink environment, first a MATLAB scrip was written to replicate the power generation of the piezoelectric transducer and the function of the script is to take in,

- The dimensions of the road
- Load intensity due to
  - Average speed of the vehicle
  - Rate of traffic
  - Friction of coefficient
- Time duration ( Elapsed time of power generation)

Moreover, the losses experienced in this system is mainly due to the external power electronic devices within the proposed system that constitute the losses from the rectifier,



inverter, LC filter and the DC-DC boost converter systems. These losses experienced are mainly due to the electrical components involved in the circuit analogy of each power electronic system and the switching losses that occur when the pulse width is modulated. Furthermore, the power generation of the system, known as the load factor depends on the factors listed above as the dimension of the road determines the number of piezoelectric transducer that would be embedded beneath the surface of the asphalt road. Next, the speed at which the vehicle travels will have an impact on the percentage of area in contact with the surface of the road that causes displacement within its surface. But the displacement is directly related to the displacement of the piezoelectric transducer embedded. Therefore, the MATLAB script was written that incorporated the piezoelectric material (PZT-5H) properties listed in the Table 1.

**Table-1.** Piezoelectric Material Properties

Parameter	Value
Young's modulus E (Mpa)	27560
Poisson's Ratio, ( $\mu$ )	0.15
Width of the pavement, b	8
Thickness of the pavement, h	0.3048
Density, ( $\rho$ )	2323
Winkler modulus, (K)( Mpa/m )	136
Length of moving load ( $2a_0$ )	0.254
Width, ( $2b_0$ )	0.508
Distributed load of vehicle, ( $p_0$ ) ( Mpa )	0.267
Distance between the moving loads, ( $2d_0$ )	1.22
Length of the transducer, ( $l_p$ )	0.1
Width ( $b_p$ )	0.1
Thickness ( $h_p$ )	0.01
Elastic compliance constant $S_{11}$ ( $\text{pm}^2/\text{N}$ )	16.5
Elastic compliance constant $S_{12}$ ( $\text{pm}^2/\text{N}$ )	-5.74
Piezoelectric constant, $d_{31}$ ( $\text{pV}/\text{m}$ )	-274
Permittivity, $\epsilon_{33}$ ( $\text{nF}/\text{m}$ )	30.06
Resistive load ( $\text{k}\Omega$ )	800

Source: Zhiwei *et al.* (2015)

This MATLAB script also incorporated various techniques stated in the previous section and equations (1), (2) and (3). Following this, the Simulink model (Figure 7) was implemented based on the output readings derived from the MATLAB script and the following aspects were considered that affects the system performance,

- Capacitor Factor of the piezoelectric generator as it may not capture all the kinetic and vibration energy as it has unidirectional orientation.
- Rectifier losses
- Inverter losses
- Switching losses due to the PWM modulation for
  - Inverter

- Controller of the DC boost converter

### 5.1. Results for ‘Method 1’ Energy Harvester System

In order to determine the power generated by the entire system, the rate of traffic per hour during peak hours of a single lane pavement was assumed to be 500 vehicles/hr and 100 vehicles per hour for the off peak timings. This was done to estimate the taken by a 200 psi rated, 10 gallon air tank to fill when 15 air pumps were installed within the speed bump.

Table-2. Tabulated Input Data

Traffic Rate/hr	No. of tank fills	Time Taken to fill the Compressor (minutes)	Volume of Air Pump (cm <sup>3</sup> )	No. of Vehicles to Pass
500	5.707	10.513	1178.097	87.612
100	1.141	52.567	1178.097	87.612

### 5.2. Simulink Results

Based on this mechanism and block diagram shown in Figure (4), the system depicted in Figure 6 was employed using the MATLAB-Simulink environment and was calibrated to have the component rating as specified in Table 3.

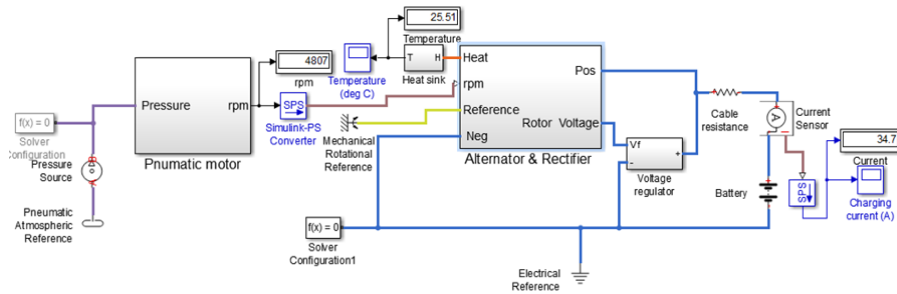


Figure-6. Simulink Model for Method 1

This system is the heart of this methodology that indicates the process after which the compressed air is maintained at a constant rate of 20 psi as indicated in Table 3.

Table-3. Parameter Settings

Pressure regulator	
Set to (psi)	20
Pneumatic Motor	
Nominal Speed (rpm)	3100
Nominal Power (kW)	15
Free Speed (rpm)	6000
Maximum Torque (Nm)	90
Abstracted Alternator	
Rated Voltage (V)	14.5
Rated Current (A)	50

When the pneumatic motor block is set to the parameter rating indicated in Table 3. The pneumatic motor block yields the following results which are tabulated in Table 4.

Table-4. Pneumatic Motor Output

Input (psi)	Output Power (kW)	Output Torque (Nm)	Rotational Speed (rpm)
20	2.770	5.503	4807

Similarly, when the abstracted alternator is set to the parameter values indicated by Table 3, the alternator yields a DC current of value 34.7 Amps and the DC voltage produced is regulated at 12V. Hence the system yields and output power is denoted by (4),

$$P_{out} = V_{DC} * I_{DC} = 12 * 34.7 = 416.7W$$

$$\text{Therefore, } P_{out} = 416.7/746 = 0.56H.P \tag{4}$$

### 5.3. Estimation of Total Power Generated

In order to estimate the total power generated, the volume and the pressure at which the air tank needs to be filled via multiple air pumps that are set up by the vehicles passing over the speed bumps was estimated using equation (5) obtained from Xu *et al.* (1996). For this system, an air tank of 10 gallon rated at maximum allowable working pressure of 200 psi requires a certain amount of vehicles to pass over it to fill this tank and is given by equation (5),

$$\frac{\text{No.of cars}}{15 \text{ Air pumps}} = \frac{(P_{target} - P_{initial}) * V \text{ Tank}}{P_{atmospheric} * V \text{ pump} * 15}$$

$$\frac{(200 - 0) * 0.1136 (m^3)}{14.6 * 1178.1 (cm^3)} = 87.6 \tag{5}$$

However, the time taken for the tank to fill depends on the mass of the vehicle, speed of the vehicle and the friction of coefficient of the vehicle as it changes the pressure exerted on the air pumps which in turn determines the air flow from the tank to the pneumatic motor. Using the air flow detailed obtained from the tank was used to determine the motor working time along with its production time.

Table 5 perceives the required calculated information that estimates the total power generated from a 10 gallon tank via 15 air pumps in an hour by the system referred as 'Method 1' using the power estimated from the Simulink model and Equation (4).

Table-5. Estimation of Power Generation

Duration	Traffic Rate/hr	Motor 'ON' State (minutes)	Production Time (Hours)	Energy Generated
Peak Time	500	25.031	1.417	368.262
Off-Peak time	100	1.001	1.017	20.533

**5.4. Results for Method 2 Energy Harvester System**

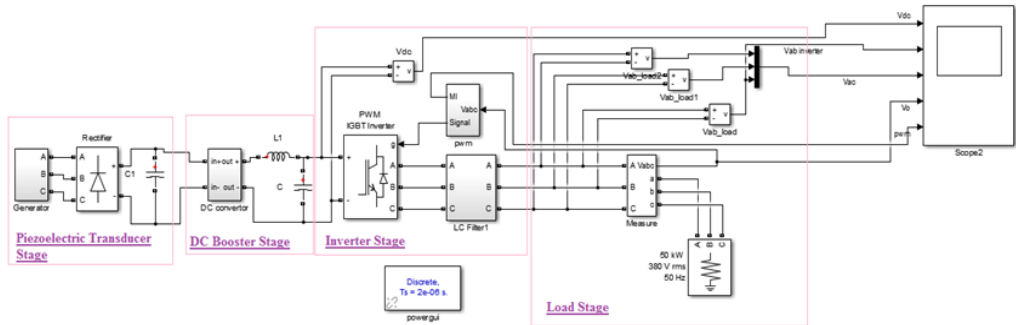
Similarly, in order to determine the power generated by the entire system, the same assumption of traffic rate for peak and off-peak period was considered. The output from a piezoelectric transducer at 20Hz frequency was found to be 0.137 W by applying Kirchoff's plate theory, Fourier series, Cauchy's residue theorem and piezoelectric law that incorporates the characteristic properties of PZT-5H by carrying out vigorous calculations on the MATLAB environment using equations (1), (2) and (3). Then the piezoelectric power for one kilometer stretch single lane pavement is estimated and presented in Table 6.

**Table-6.** Piezoelectric Power Estimation

Duration	Traffic Rate/hr	No of Piezoelectric Transducers/Km	Power Generated / Car /Km/hr	Total Power Generated /Km (kW/hr)
Peak Time	500	3280	68.5	224.680
Off-Peak time	100	3280	13.7	44.936

**5.5. Simulation Results**

Based on this mechanism and block diagram shown in (5), the system depicted in Figure 7 was employed using the MATLAB-Simulink environment.



**Figure-7.** Simulink Model for Method 2

This is briefly sub-categorized into four sections as observed in Figure 7 which is similar to that of the block diagram observed in Figure 5, vis-a-vis the following,

- The Piezoelectric Transducer Stage,
- The DC booster Stage,
- The Inverter Stage,
- The Output/Load Stage

i. Results from Piezoelectric Transducer Stage:

Table 7 depicts the results after running the MATLAB script.

Table-7. Piezoelectric Generator Output

Parameter	Value
Voltage (V)	137
Current ( mA )	0.9
Power (W)	0.123

The MATLAB script generates an equivalent  $V_{dc}$  using the rectifier equation without taking into consideration the diode losses

$$V_{dc} = 137V$$

Then the actual rectified voltage when a diode has a forward voltage drop of 0.7,

$$V_{dc} = V_{dc} - \text{Rectifier losses}$$

Since it is a three phase rectifier, it has 6 diodes and it produces the following V dc value,

$$V_{dc} = 137 - 0.7 * 6 = 132.8V \quad (6)$$

ii. Results of the DC Booster Stage

In order to boost the voltage from the previous stage the DC booster was controlled by a PWM generated triggered using a Proportional-Integral controller of suitable value to attain a duty cycle ratio of ~1.5. Then the  $V_{dc}$  from the previous stage was increased by a factor of ~1.5 using the modulating controller to yield the desired result and the theoretical value is denoted by equation 7.

$$V_{dc-dc} = 1.48 * V_{dc} = 195V \quad (7)$$

Since the theoretical value doesn't take into consideration the switching, heating and diode losses, it varies from the simulation results at the end of the DC booster stage and has a value of,

$$V_{dc-dc} = 188.6V$$

iii. Results of the Inverter Stage

In this stage, the  $V_{dc}$  was converted into a three phase alternating source of magnitude denoted by equation 8.

$$V_{ac}/\text{phase} = V_{dc-dc} = 188V \quad (8)$$

And this has an RMS value denoted by equation 9.

$$V_{ac}/\text{phase} = V_{dc-dc} / \sqrt{2} = 133V \quad (9)$$

However, this system was designed to virtually analyze the process of 'Method 2'. This entire system is used to generate a three-phase output that was connected to an arbitrary load such that the value was high enough to minimize the ripple effect that occurs in the

piezoelectric transducer stage and yielded the following wave-forms that corresponds to each stage.

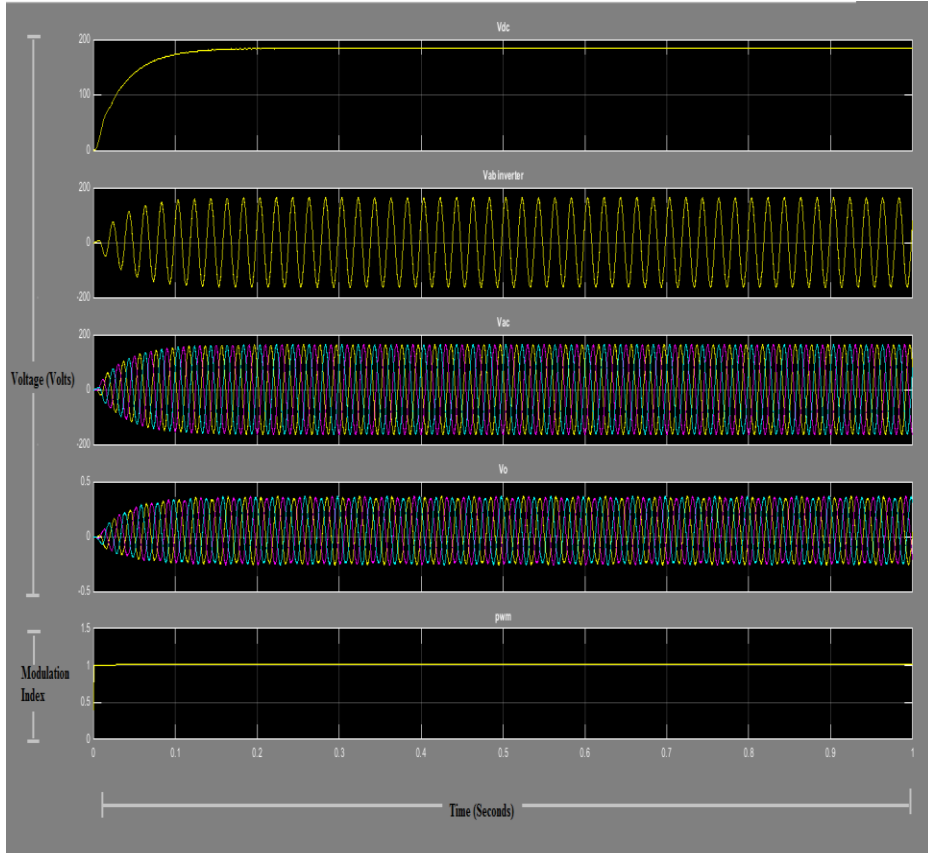


Figure-8. Output Waveforms

The first response indicated as  $V_{dc}$  represents the RMS output from the DC booster stage where the output of the piezoelectric transducer stage was doubled to a value  $\sim 200V$  as observed in Figure 8.

The second response indicated as  $V_{ac}$  represents the output from the inverter stage where the DC output from the DC booster stage is effectively converted into a three phase source of  $\sim 200V V_{peak}$ . Since the piezoelectric generator produces about 1 mA current. Then the overall power generated is denoted by equation (10).

$$P_{generated} = V_{avg} * I_{avg} = 2 * 188 * 10^{-3} \approx 0.376W \quad (10)$$

The third response indicated as  $V_{out}$  represents the output voltage of the arbitrary load connected that minimizes the rippled effect caused in the ac-dc conversion process.

### 5.6. Estimation of Total Power Generated

The total power generated from this entire system is tabulated in Table 8 for one kilometer stretch single lane pavement.

Table-8. Estimation of Total Power Generated

Duration	Traffic Rate/hr	No of Piezoelectric Transducers/Km	Power Generated / Car /Km/hr	Total Power Generated /Km (kW/hr)
Peak Time	500	3280.000	188.000	616.640
Off-Peak time	100	3280.000	37.600	123.328

## 6. CONCLUSION

This paper emphasized on generating green and sustainable energy and this was implicated with the two scenarios of methodologies (Method 1 & 2). In the first method, the voltage produced was low and the current was high.

On the other hand, in the second method the current was low and the voltage produced was high. Hence, it would yield a significant power when these methodologies are to be coherently used. In comparison to the power generated from the simulation results to the stated power outcomes from various authors is a little higher. For instance, the results obtained from Method 1 were significantly higher as the yield depends on the rating of the alternator and the pneumatic motor.

In the second method, the power generation system process was extended from just using the piezoelectric generators to adding few power electronic systems that increased its final voltage yield by a factor that is set by the duty cycle of the DC boost converter system. Also, the cost of implementation of these methods will significantly be economical in comparison to the other means of renewable energy power generation.

However, among these two methodologies, implementation and infrastructure cost for Method 2 will be slightly higher than that cost of implementation of the first method implied as Method 1. These methodologies utilized and harnessed the wasted energy into a form that could be used to satisfy a small amount of energy demand and preserve the existing coal from degrading faster and minimizing the emission of  $CO_2$  emitted by coal up to an extent.

**APPENDIX A****Piezoelectric Output Equations:**

*Kirchhoff's Love plate theory:*

$$\text{Bending Rigidity}(D) = Eh^3/12(1 - \mu^2)$$

*Fourier Series:*

$$\omega(x, y, t) = \sum_{m=1}^{\infty} \omega_m(x, t) \sin\left(\frac{m\pi}{b} y\right) = \sum_{n=1}^N \omega_n(x, t) \sin\left(\frac{m\pi}{b} y\right)$$

$$f_m(x, t) = \frac{2}{b} \int_0^b F(x, y, t) \sin\left(\frac{m\pi}{b} y\right) dy$$

*Piezoelectric Equation:*

$$C_0 = [\epsilon_{33} - (s_{11} + s_{12})^{-1} 2d_{31}^2] \frac{l_p b_p}{h_p}$$

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