

Design of Piezoelectric Based Power Generation System for Electric Vehicle

Hari Prasad Hegde, Ugra Mohan Roy, Mrinal Kumar



Abstract: Increase in demand for vehicles are most threatening for global warming. It cannot be stopped as it is one of the basic needs of the world. Few automobile companies started thinking about alternatives and developed hybrid vehicles, electric vehicles, solar powered vehicles, etc. As industry is directing towards new era, it opens up new problems as well. Many companies, institutions are researching on future electric vehicles and its specific problems. One of the needs in current scenario is dynamic charging of electric vehicle battery as it increases the number of running hours of vehicle, thus efficiency. This project would throw some light on dynamic recharging of electric vehicle battery by using piezoelectric devices installed on its tyres. Study has been conducted majorly on magnitude and signature of the output voltage and current from piezoelectric device and battery charging circuit. Supercapacitor is the primary component used in charging circuit to store the charge and feed back to battery of electric vehicle in running condition. Circuit has been simulated with 6 quantity of piezoelectric devices to understand the functionality of concept. It is concluded that 1.65 mW of power can be generated from 4 tyres of car at applied force of 50 N. But, actual force on tyre would vary from 900 N to 1500 N and it is fair to expect more power generation from each tyre.

Keywords: Dynamic charging, Electric vehicle, Energy harvesting, Piezoelectric device, Supercapacitor.

I. INTRODUCTION

Automobile industry experiencing a major shift in its technology due to its transition from traditional fuel vehicles to electric vehicles. It has opened up many interesting and challenging problems to produce efficient and reliable products to market. One of the primary challenges in electric vehicle is battery efficiency. Expectation is to minimize charging time with maximum running capacity of electric vehicles. Multiple efforts towards finding the solution are in exploration stage [1] but it is really challenging requirement for automobile industry to charge the battery in equivalent time of refueling the fuel vehicle. Proposing dynamic charging concept [2], [3], [4], [5] for Electric Vehicle (EV) to

minimize recharging time of battery which could help further study on this direction. Graphical representation of overall concept is shown in Fig. 1. It consists of multiple piezoelectric devices (5) concealed on tyre surface. A rubber cushioning (1) would protect piezoelectric devices from damages caused by road surface. A copper strips (2) which are arranged in circular format on center of wheel would collect the generated power from piezoelectric devices while running. A pair of carbon brush (3 and 4) can be used to collect power from copper strip and send it to signal conditioning circuit (6) via wires. Output power from signal conditioning circuit is stored in battery (7) of electric vehicle.

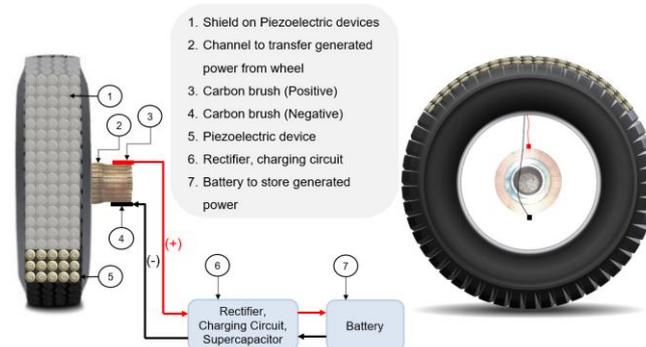


Fig 1. Graphical representation of piezoelectric based energy harvesting system

In this concept, number of piezoelectric devices are connected in series to gain required voltage level and those arrangements are connected in parallel combination to gain more current [6], [7], [8] which is key for fast charging of battery. Concept of copper strip and brush to collect generated from wheel is influenced from motor commutator concept which is seen in every DC motor arrangement. Developed prototype with serially connected 3 quantity of piezoelectric devices to generate power from it. Studied signature of voltage waveform and impact on its magnitude at various load conditions. This study has given the idea on driving current capacity from each piezoelectric device and helped to develop a simulation circuit for further study. More details about prototype output and simulation data are discussed in upcoming chapters.

II. PIEZOELECTRIC OUTPUT STUDY

Developed a prototype with three quantity of piezoelectric devices as shown in Fig. 2 to verify the output voltage waveform from piezoelectric device and tested the same with series and parallel combinations of it.



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This prototype test has given the clear idea about actual power generation capacity from each piezoelectric device and also variation in the output voltage and output current in series and parallel combinations of multiple piezoelectric devices.

Fig. 3 shows the output voltage from a piezoelectric device at no load condition. Fig. 4 shows the output voltage when



Fig 2. Prototype for output voltage waveform verification from piezoelectric device

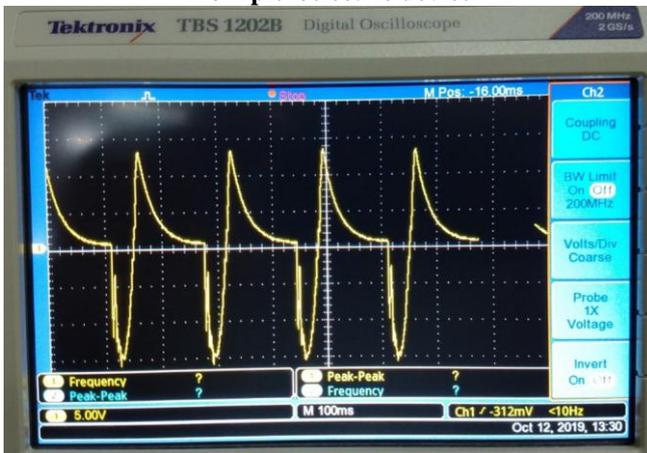


Fig 3. Output voltage from a piezoelectric device at no load condition

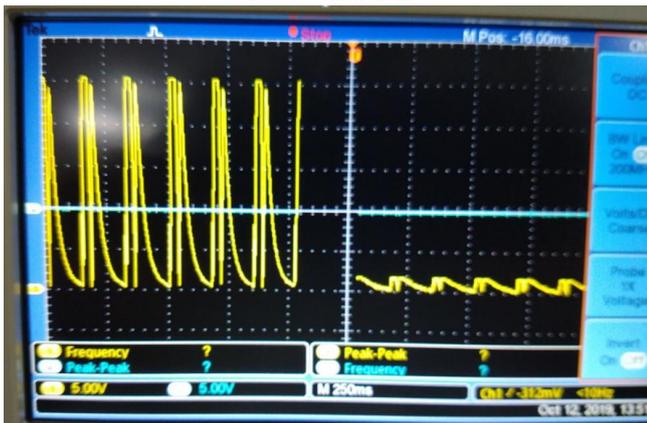


Fig 4. Output voltage from a piezoelectric device during switching to load condition

piezoelectric device is switching from no load condition to load condition at 1 k Ω resistive load. It is very evident that output voltage has been dropped to approximately 2 V due to low current driving capacity of piezoelectric device. As prototype had limitation to apply uniform force on all three piezoelectric devices, magnitude of output voltage has been varied. But it has eventually proved that output voltage of piezoelectric device is directly proportional to force applied

on it. Same is demonstrated in Fig. 5.

Test has been conducted at various load conditions as followed.

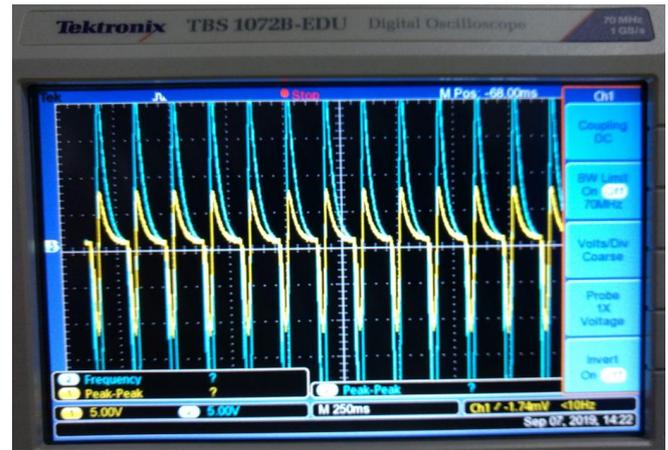


Fig 5. Output voltage from two piezoelectric devices at different forces applied

Piezoelectric model: 3 quantity in series

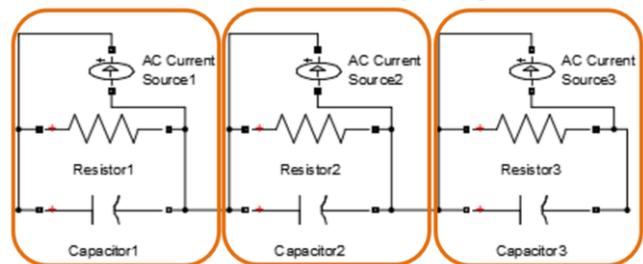


Fig 6. MATLAB model of piezoelectric device

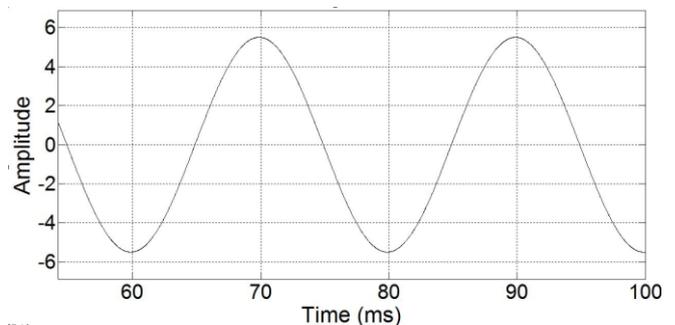


Fig 7. Output voltage of each piezoelectric is 5.4 V

Test 1: At no load condition:

- Voltage obtained from 3 piezoelectric devices connected in series is 30 V (positive cycles).
- Applied force is approximate 50 N.

Test 2: At 200 k Ω load connected across output of piezoelectric devices:

- Voltage has been dropped to approximate 13 V.
- Current calculated: 650 μ A.

Test 3: At 1.8 M Ω load connected across output of piezoelectric devices:

- No voltage drop: Same as generated voltage of 30 V.
- Current calculated: 16 μ A.

Based on the study, selected the value of current source and fed into MATLAB model of piezoelectric device [9] as shown in Fig. 6. In simulation, it is observed that output voltage from each piezoelectric is 5.4 V at an applied force of approximate 50 N as shown in Fig. 7.

III. CHARGING CIRCUIT

Charging circuit is the key in this concept due to low output current from piezoelectric devices. Since battery needs constant current for fast and efficient charging, it is necessary to store generated power in some means and then charge the battery of electric vehicle [10]. Developed charging circuit using supercapacitor [11], [12], [13], [14] and also three diodes which controls the charging voltage across supercapacitor as shown in Fig. 8.

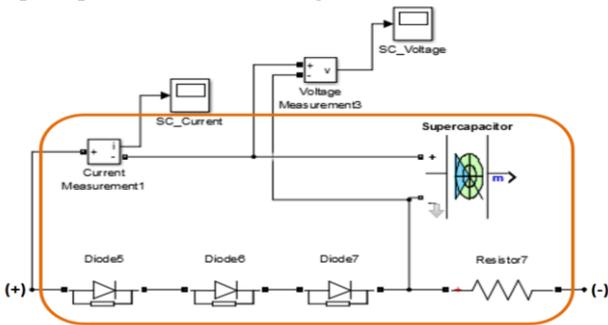


Fig 8. Supercapacitor charging circuit

IV. INTEGRATED CIRCUIT

Integrated piezoelectric model, rectifier circuit and supercapacitor charging circuit as shown in Fig. 9 to simulate the output power. It consists of three serially connected piezoelectric devices and rectifier circuit to convert generated power which is sinusoidal in nature to DC form and then feed into charging circuit. Output of rectifier (DC voltage) is connected to three diodes which are connected in series and then load resistor. Supercapacitor which stores the energy is connected across three serially connected diodes to limit voltage across supercapacitor well within its maximum operating voltage.

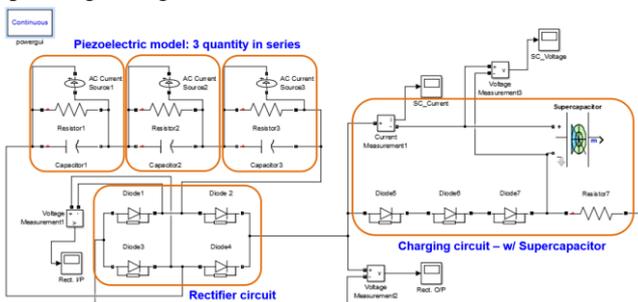


Fig 9. Energy harvesting circuit with 3 quantity of piezoelectric devices in series [15]

Specifications of components are as followed:

- Piezoelectric model:
 - Current source: 650 μ A, 50 Hz
 - Res: 100 M Ω
 - Cap: 1 nF
- Rectifier:
 - Diode: R_{on} : 0.001 Ω , 0.8 V forward voltage
 - Snubber Res: 500 Ω

- Snubber Cap: 250 nF
- Supercapacitor model:
 - Capacitance: 50 F
 - Voltage: 4 V
 - No. of parallel capacitor: 1 quantity
 - No. of series capacitor: 18 quantity
- Load Res: 100 M Ω

V. RESULTS AND DISCUSSION

Test has been conducted at various time periods. Figures 10 to 13 shows the output voltage and current at various locations in the circuit measured for time period of 1 s. Same test has been conducted at revised scenario of piezoelectric combination. Added one more branch of piezoelectric device to increase the driving current capacity where each branch has 3 piezoelectric devices in series. The revised circuit is shown in Fig. 14.

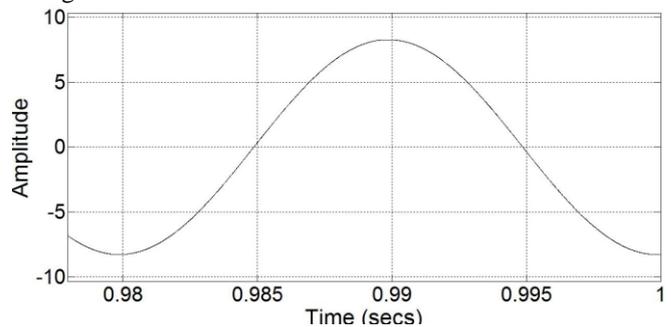


Fig 10. Input voltage to rectifier circuit is 8.28 VP at 1 s

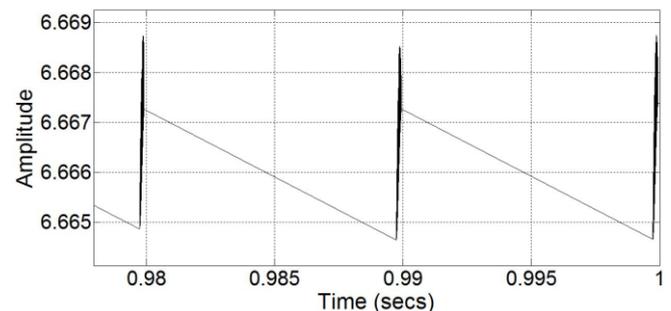


Fig 11. Output voltage of rectifier circuit is 6.66 V at 1 s

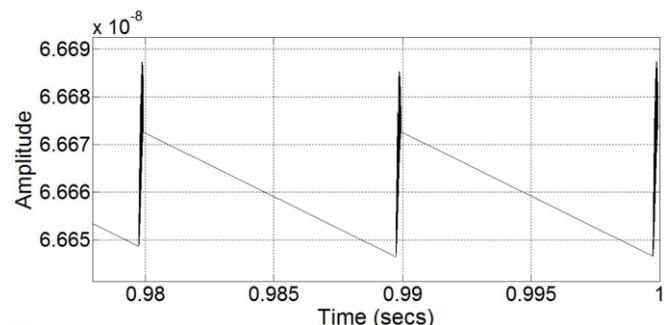


Fig 12. Supercapacitor charging voltage of 0.593 nV at 1 s

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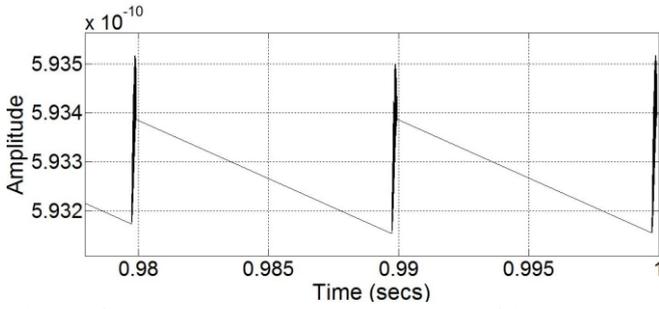


Fig. 13. Supercapacitor charging current of 0.067 μA at 1 s

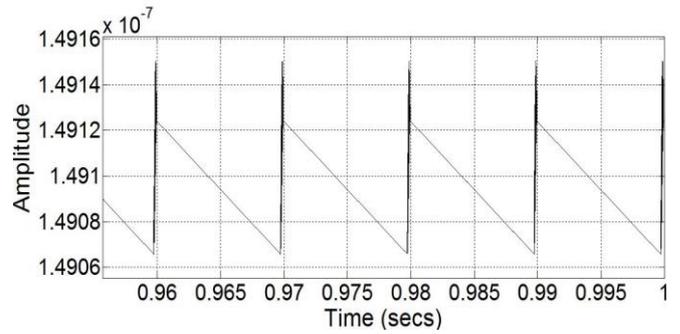


Fig 17. Supercapacitor charging voltage of 1.327 nV at 1 s

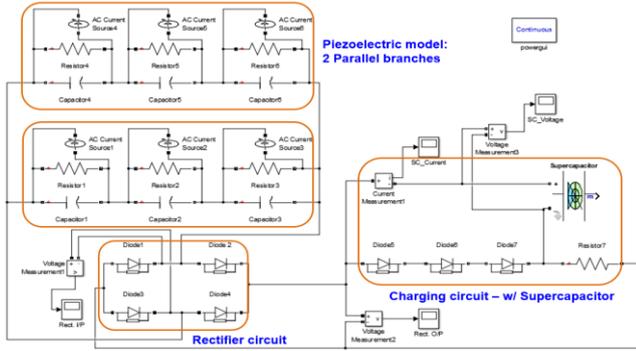


Fig 14. Energy harvesting circuit with 6 quantities piezoelectric devices in series-parallel combination

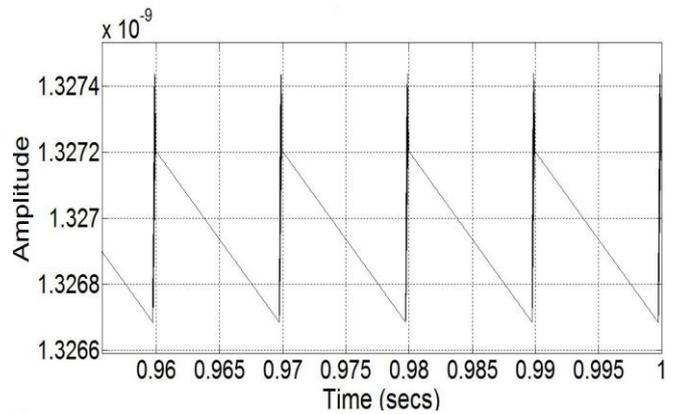


Fig 18. Supercapacitor charging current of 0.149 μA at 1s

Test has been conducted at various time periods. Figures 15 to 18 shows the output voltage and current at various locations in the circuit measured for time period of 1 s.

Due to the limitation of simulation software, it is a challenge to run the circuit for longer period (>10 s) to analyze the results. However, based on the conducted simulations at various conditions it is proved that series-parallel combination of piezoelectric devices at larger number of arrangements would help in increase in the charging current at increased charging voltage.

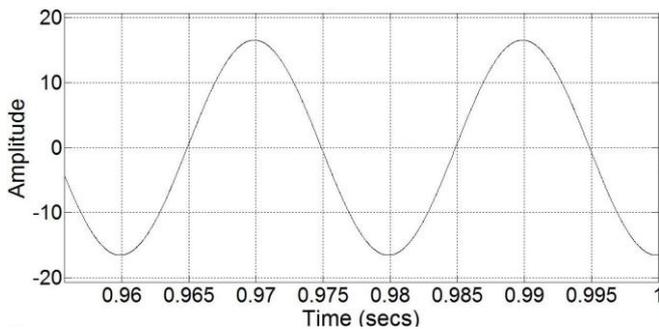


Fig 15. Input voltage to rectifier circuit is 16.5 Vp at 1 s

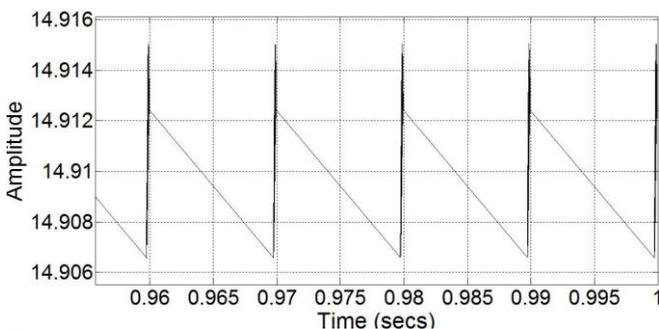


Fig 16. Output voltage of rectifier circuit is 14.91 V at 1 s

Also, it is observed that supercapacitor voltage increases but charging current response is flat (steady state). This is caused due to long charging time of supercapacitor. As per observation laid in solar energy harvesting system [16], it is understood that charging current starts reducing when supercapacitor voltage reaches near to its maximum value. The summary of voltage and current measurements are analyzed and mapped with scalability study. Table 1 provides the summary of input and output voltages of rectifier and also charging voltage and current of supercapacitor at various test cases. Fig. 19 shows the input voltage to rectifier at various test cases mentioned in Table I. Fig. 20 shows the output voltage of rectifier at various test cases and Fig. 21 shows the input voltage to rectifier at various test cases and Fig. 22 shows the input voltage to rectifier at various test cases mentioned in Table I.

Table- I: Summary of results

Measurements	3 quantity of piezoelectric are in series			Two parallel branches. Each branch has 3 quantity in series		
	Case 1 @0.01 s	Case 2 @0.05 s	Case 3 @1 s	Case 4 @0.01 s	Case 5 @1 s	Case 6 @10 s
Input voltage to rectifier (in V)	8.17	8.3	8.28	16.25	16.5	16.5
Output voltage of rectifier (in V)	6.57	6.67	6.66	14.75	14.91	14.91
Supercapacitor charging voltage (in nV)	0.59	0.593	0.593	1.31	1.33	1.33
Supercapacitor charging current (in μA)	0.066	0.067	0.067	0.147	0.149	0.149

Based on these results, performed an analysis on car tyre [17] with diameter of 2 ft (tyre size: 195/55R16):

- Circumference of tyre: 75 inches
- Total number of piezoelectric sets can be installed: 150 sets; each set has 3 quantity of piezoelectric in series.

It can be assumed that, at given time approximate 6 sets in a tyre would touch the ground and generates power. So, from 4 tyres it would be total 24 sets would generate power. So, total amount of charging current (simulated result for 24 sets) is 1.908 μ A.

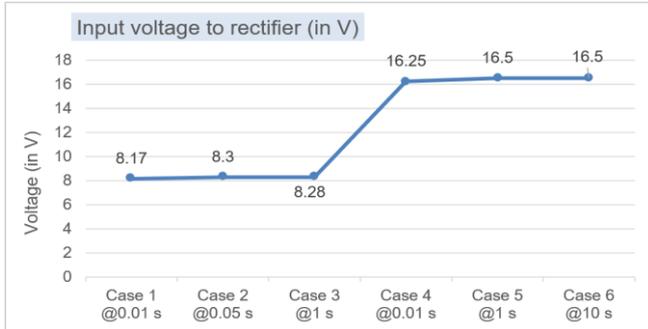


Fig 19. Input voltage to rectifier

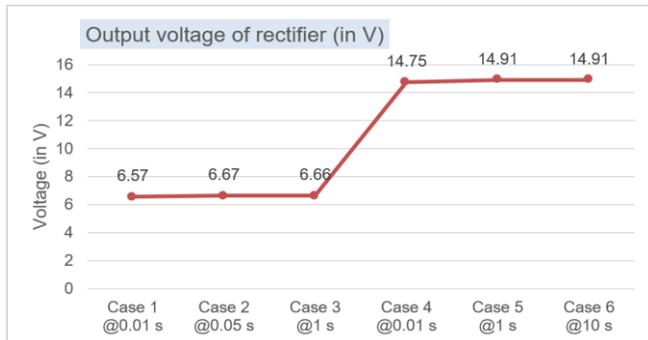


Fig 20. Output voltage of rectifier

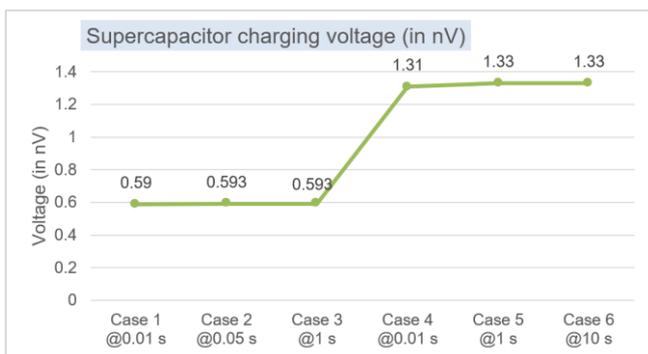


Fig 21. Supercapacitor charging voltage

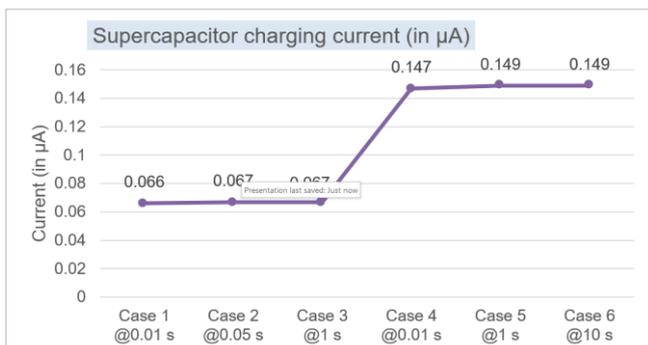


Fig 22. Supercapacitor charging current

Capacitor charging time has been calculated by using equation 1. Where 'C' is capacitance of supercapacitor in Farad, 'I' is charging current in Amps, dv/dt is the rate at which the voltage changes over time.

$$I = C * \frac{dv}{dt} \tag{1}$$

$$\Rightarrow dt = C * \frac{dv}{I}$$

$$dt = \frac{(50) * (2.4)}{1.908 * 10^{-6}}$$

$$dt = 1.05 * 10^6 \text{ minutes}$$

Output Analysis

Total energy, E_T stored in supercapacitor has been calculated by using equation 2. Where 'V' is the maximum voltage applied across supercapacitor.

$$E_T = 0.5CV^2 \tag{2}$$

$$E_T = 0.5 * (50) * (2.4)^2$$

$$E_T = 28.8J$$

Energy stored in an hour has been calculated by using equation 3,

$$E = \frac{E_T}{dt} * 60 \text{ min} \tag{3}$$

$$E = \left[\frac{28.8 * 60 \text{min}}{1.05 * 10^6} \right] = 1.65 \text{ mJ}$$

Total power has been calculated by using equation 4,

$$P = \frac{E}{\text{time}} \tag{4}$$

$$P = 1.65 \text{ mJ}/1 \text{ sec}$$

$$P = 1.65 \text{ mWatts}$$

Based on the analysis, it can be concluded that 1.65 mW of power can be generated from 4 tyres of car which has approximate diameter of 2 ft. Detailed summary is captured in conclusion section of this report.

VI. CONCLUSION

This project has been partially tested and simulated with 6 quantity of piezoelectric devices to understand the functionality of concept. Based on the analysis, it is concluded that 1.65 mW of power can be generated from 4 tyres of car at applied force of 50 N.

But, actual force on tyre would vary from 900 N to 1500 N (depends on tyre pressure as well) and it is fair to expect more power generation from each tyre. The generated power can be stored in supercapacitor and then use to charge the electric vehicle battery in running condition to improve its efficiency. For further analysis, testing is required to enhance the possibility of implementing this concept on EV tyre.

Demo for the mentioned concept can be developed easily but implementation of the same on actual wheel considering speed of vehicle, safety, noise, signal conditioning circuit, etc are really challenging. There is also possibility to explore printing piezoelectric structure on tyre surface to accommodate more piezoelectric devices. Future scope would be to develop safe and reliable construction of circuit on tyre and test the same.

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