Comparison of Green Energy harvested using PZT piezo patch in different series configuration and Optimization of circuitry system

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ABSTRACT: In this paper, a comparison of harvested energy using PZT with hydraulic dynamism has been done considering different factors. The flowing water has been directed towards the PZT patch through nozzle. Output measured in terms of voltage and current according to different values of the distances of nozzle from PZT, different nozzle angle and number of PZT patch (one and two). It has been observed that the maximum output voltage is generated with double patch connected in series.

Keywords: Piezoelectric, vibration, Energy harvesting, Piezoelectric Circuit, Piezo patch

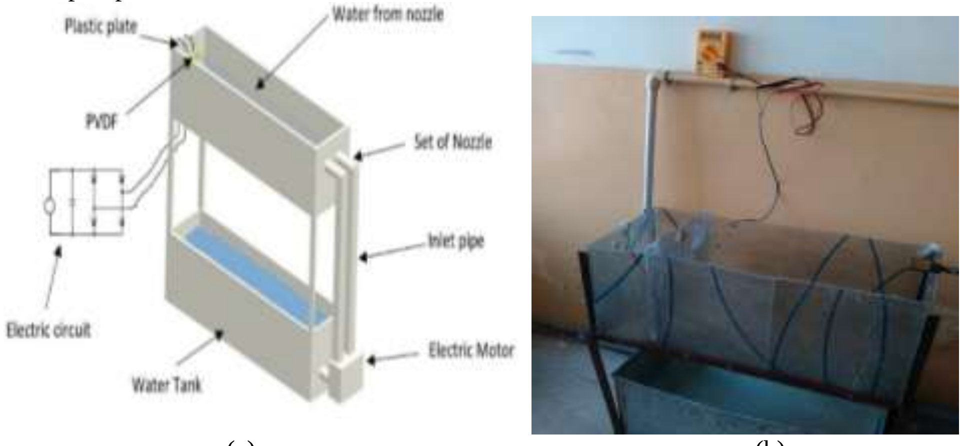
1. INTRODUCTION

Over the period of time, as most of the people are using electronic devices, so there is a huge demand of energy. Today, in most of the application we are using electrochemical batteries, which have limited lifetime. There is a need of self-powered devices in various medical and defense areas. Energy harvesting is the process of converting available ambient energy into usable energy. Scientist and researcher are working on the techniques of energy harvesting. Energy can be harvested using different sources like solar energy harvesting, wind energy harvesting, thermal energy harvesting, hydraulic energy harvesting, vibrational energy harvesting. Energy harvesting system for wind, solar, hydraulic and thermal sources produce huge amount of energy of kW or MW level and call macro level energy harvesting system. In vibrational energy harvesting system, power generated is of low level and these are known as micro level energy harvesting system.

A lot of research is going on in the field of vibration energy harvesting, Dinesh et al (2018). In vibrational energy harvesting, we can use capacitive, electromagnetic and piezoelectric transducer to convert mechanical vibration into electric energy. There is a no of sources available for vibration energy harvesting system, some of them are – common vehicle, industrial machines, wings of aero plane, small household devices, speakers, human body during the walk, heartbeat. The amount of energy harvested from these sources can be used further to give power to small devices. In piezoelectric energy harvesting, we use a piezoelectric material which produces energy by applying mechanical vibrations and vice versa. Static force does not produce vibrations, so for vibration energy harvesting, we need dynamic force. In the past few years, a lot of significant work has been done by various researchers in the field of piezoelectric energy harvesting. For example, at MIT media lab (1996) it was investigated that energy can be harvested from various human activities and Shenck N S (2001) confirmed that energy generated by walking can be collected, with the help of the piezoelectric element. Elvin et al (2001, 2003) and Ng and Liao (2005) used piezoelectric elements for power generation and sensor. Mateu L and Moll F (2005) used the cantilever system to harvest energy. Kim et al (2005) and Ericka et al (2005) make a thin piezoelectric plate to harvest energy. Allen et al (2001) and Taylor et al (2001) used long strips of piezoelectric polymers in the river and ocean water flow to harvest energy. Jeon et al (2005) have made PZT MEMS. Chhabra et al (2011, 2014, 2016) worked on design, analysis of piezoelectric element and optimal placement of piezo actuators on plate structure for active vibration control. Richards et al (2004) gives an analytical formula to predict power conversion efficiency of the piezoelectric element. In this paper, a model is presented for analysis of output generated considering various factors like distance of nozzle, angle of nozzle, number of PZT patch, number of nozzle to create vibration, two types of circuit (classic and voltage doubler).

1.1. Description of the model:

The proposed mechanical model is composed of a water tank, a set of nozzle to increase the velocity of fluid, pipe to circulate the water flow, PZT patches mounted on a plate and voltage doubler circuit to generate output terminal voltage. The model can be used where the water supply is continuous such as river, lakes, bridges, waterfall, etc. In case, if water is present in limited quantity then a reservoir tank can be used to store the water and a pump can be used to recirculate the water.



(a) (b)

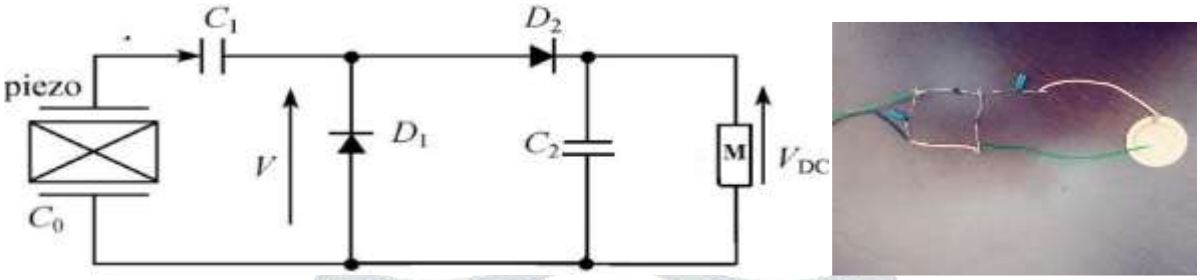
Figure 1(a, b): Schematic diagram and Experimental set-up of the apparatus

Here, the water tank is used to store as well as supply the water. An electric motor is used to recirculate the water. Piezoelectric patch is mounted on a perforated sheet and is allowed to place at different distances from the nozzle. The water from the nozzle strike on the piezo-patch which directly convert the water energy into electrical energy. The electric circuit is used to store the extracted energy.

2. DESCRIPTION OF THE CIRCUIT

The piezoelectric material is capable of producing AC output, which can be converted into DC voltage by using a voltage doubler circuit. Capacitors are used to store the extracted energy.

2.1. Voltage doubler interface: The voltage doubler interface is shown in figure 2. This circuit consist of two capacitors and two diodes and a multi-meter to measure the output. This circuit can generate high voltage from a moderate AC source. This circuit is useful when electric application with high resistance needs more power. We can further modify the circuit and make a voltage tripler circuit to optimize the power.



(a) (b)

Figure:2 (a) Schematic diagram ofvoltage doubler circuit (b) Actual circuit of Voltage doubler circuit

2.2. Series connection:

2.2.1 Series of piezo patches: Two PZT patches are joined in series and connected to a voltage doubler circuit. Figure 3(a) shows the series connection of piezo patches.

2.2.2 Series connection of two circuits for individual piezo patch: Two patches are connected to two voltage doubler circuits individually and outputs of those circuits are connected in series. Figure 3(b) shows the series connection of two circuits.

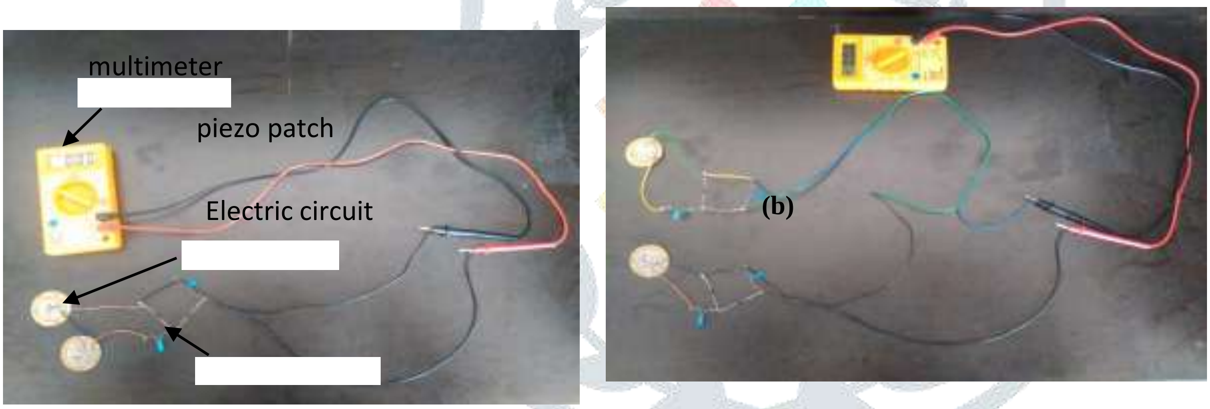
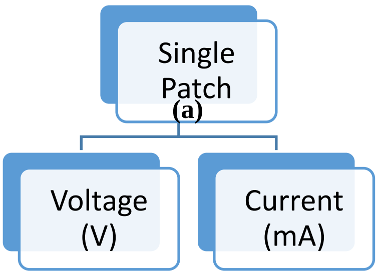
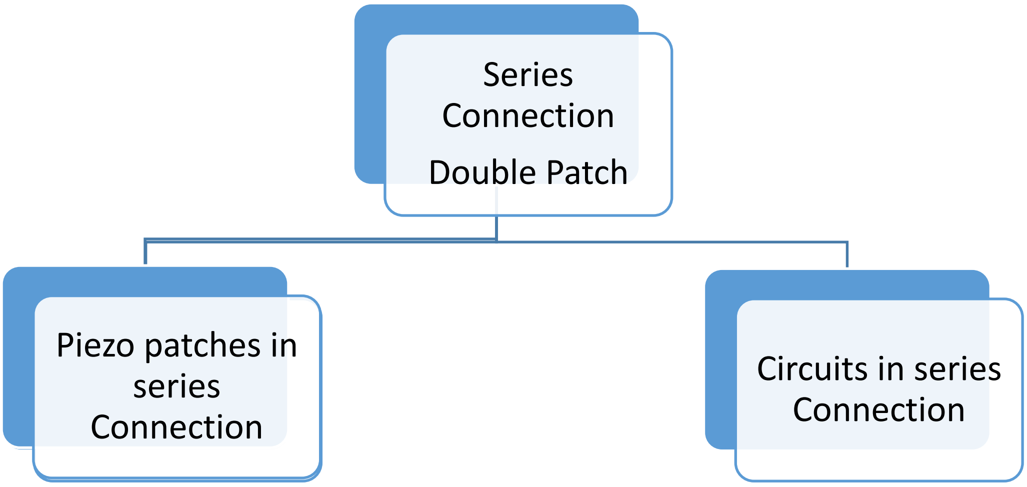


Figure 3. (a) Series connection of two piezo patches (b) Series connection of two circuits

Result and discussion

The energy in terms of output voltage and current, generated by placing a single and double patches of PZT, with different configuration, with one and two nozzles, at different angles of nozzle and at different distances of PZT patches from the nozzle end, is measured by using a multi-meter.Comparison of energy harvested is made by varying different parameters. Fig. 4. shows the flow diagram of single patch and double patch analysis.





(b)

- **Figure 4.: (a) Flow diagram of single patch analysis (b) Flow diagram of Series Connection double patch analysis**

4.2 SINGLE PATCH:

Table 4.1 and figure 4.2 shows the variation in output voltage at two different angles and different distances of piezo-patch from the nozzle. In this chart, the voltage for nozzle at 0° goes on increasing with the distance and the peak voltage (14.02 V) is at distance 112.5cm from the nozzle end. The peak voltage (17.54 V) for nozzle at 35° is at a distance of 75cm from the nozzle end. After that position the voltage goes on decreasing.

Distance (cm)	25	50	75	100	112.5
Voltage at 0° (V)	2.67	7.1	12.44	13.62	14.02
Voltage at 35° (V)	2.53	7.9	17.54	17.01	13.73

Table 4.1: Voltage v/s Distance at two different angles

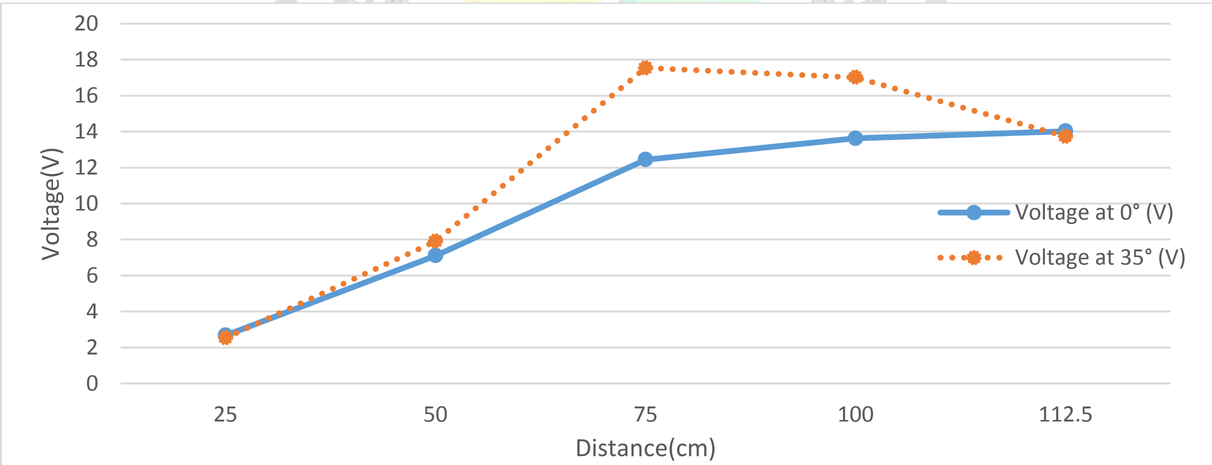


Figure 4.2: Variation of voltage at different distance of piezo-patch from the nozzle

Table 4.2 and figure 4.3 shows the variation in output current at two different angles and different distances of piezo-patch from the nozzle. In this chart, the peak current (2.8 mA) for nozzle at 0°is at a distance 75cm from the nozzle end. After that position the current goes on decreasing. The peak current (3.7 mA) for nozzle at 35° is at a distance of 75cm from the nozzle end. After that position the current goes on decreasing.

Table 4.2: Current v/s Distance at two different angles

Distance (cm)	25	50	75	100	112.5
Current at 0° (mA)	0.24	1.78	2.8	2.51	1.5
Current at 35° (mA)	0.21	1.89	3.7	3.21	1.32

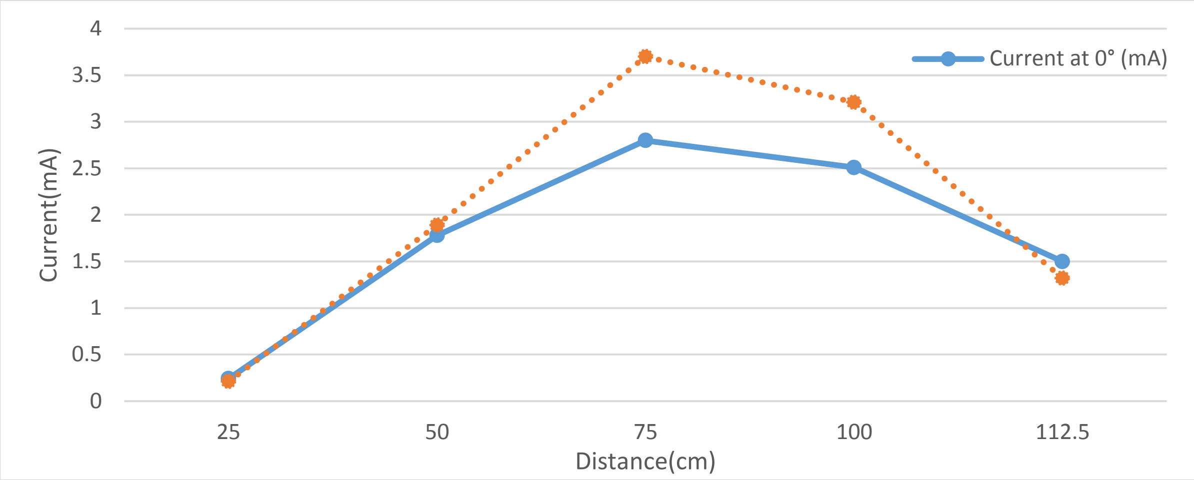


Figure 4.3: Variation of current at different distance of piezo-patch from the nozzle

Table 4.3 and figure 4.4 shows the variation in harvested power at different distances and two different angles of nozzle. In this chart, the maximum power output (34.832 mW) for nozzle at 0° is at a distance of 75cm from the nozzle end. After that position the power goes on decreasing. The maximum power output (64.898 mW) for nozzle at 35° is at a distance of 75cm from the nozzle end. After that the power goes on decreasing.

Distance (cm)	25	50	75	100	112.5
Power at 0° (mW)	0.6408	12.638	34.832	34.1862	21.03
Power at 35° (mW)	0.5313	14.931	64.898	54.6021	18.1236

Table 4.3:Power v/s Distance at two different angles

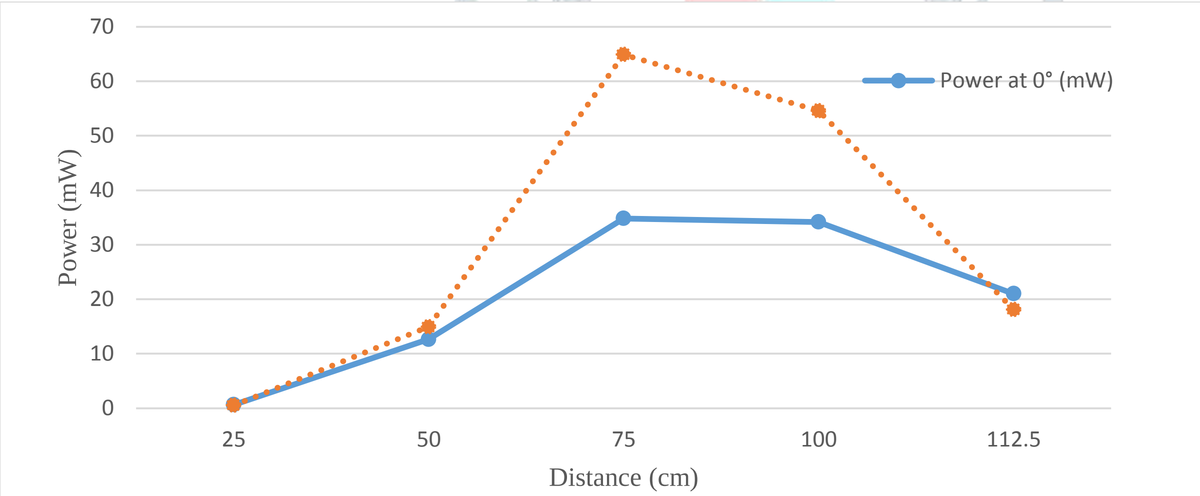


Figure 4.4: Variation of power at different distance of piezo-patch from the nozzle

4.3 TWO PATCHES IN SERIES CONNECTION:

In this configuration, two piezo patches are joined in series and fed into the voltage doubler circuit.Table 4.4 and figure 4.5 shows the variation in output voltage at two different angles and different distances of piezo-patches from the nozzle. In this chart, the voltage for nozzle at 0° goes on increasing with the distance and the peak voltage (6.26 V) is at distance 112.5cm from the nozzle end. The peak voltage (5.9 V) for nozzle at 35° is at a distance of 100cm from the nozzle end. After that position the voltage remains constant up to 112.5cm.

Table 4.4: Voltage v/s Distance at two different angles

Distance (cm)	25	50	75	100	112.5
Voltage at 0° (V)	1.18	3.7	5.8	5.3	6.26
Voltage at 35° (V)	2.43	3.1	5.1	5.9	5.9

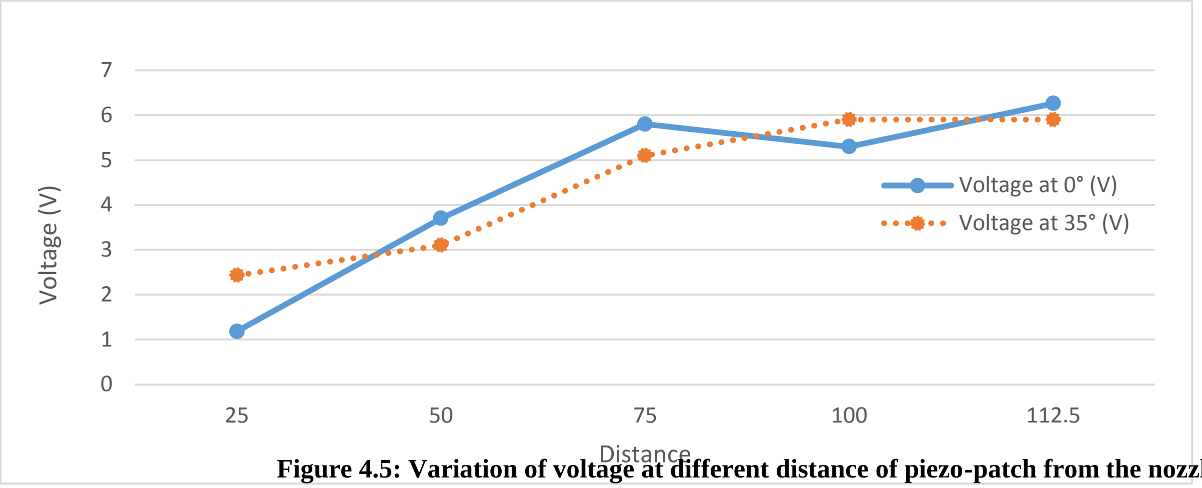


Figure 4.5: Variation of voltage at different distance of piezo-patch from the nozzle

Table 4.5 and figure 4.6 shows the variation in output current at two different angles and different distances of piezo-patches from the nozzle end. In this chart, the peak current (0.49 mA) for nozzle at 0°is at a distance 75cm from the nozzle end. After that position the current decreases. The peak current (0.42 mA) for nozzle at 35° is at a distance of 112.5cm from the nozzle end.

Table 4.5: Current v/s Distance at two different angles

Distance (cm)	25	50	75	100	112.5
Current at 0° (mA)	0.05	0.35	0.49	0.34	0.39
Current at 35° (mA)	0.3	0.26	0.31	0.31	0.42

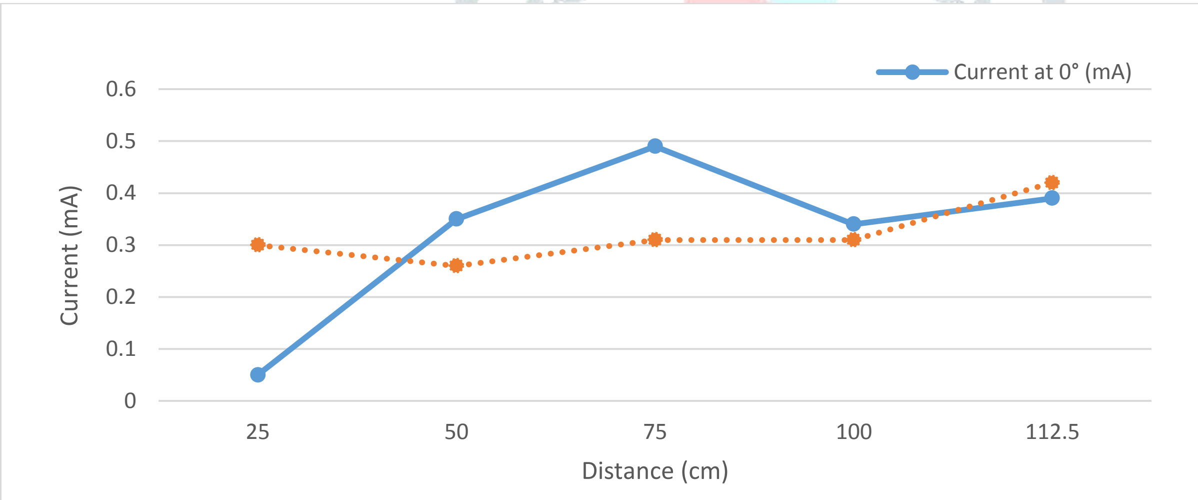


Figure 4.6: Variation of current at different distance of piezo-patch from the nozzle

Table 4.6 and figure 4.7 shows the variation in harvested power at different distances and two different angles of nozzle. In this chart, the maximum power output (2.842 mW) for nozzle at 0° is at a distance of 75cm from the nozzle end. After that position the power goes on decreasing. The maximum power output (2.478 mW) for nozzle at 35° is at a distance of 112.5cm from the nozzle end.

Distance (cm)	25	50	75	100	112.5
Power at 0° (mW)	0.059	1.295	2.842	1.802	2.4414
Power at 35° (mW)	0.729	0.806	1.581	1.829	2.478

Table 4.6: Power v/s Distance at two different angles

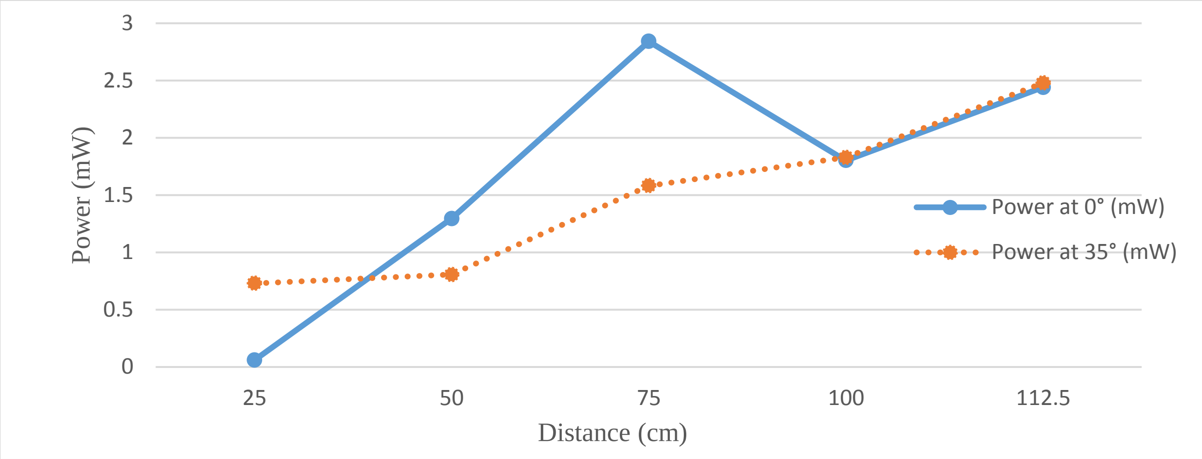


Figure 4.7: Variation of power at different distance of piezo-patch from the nozzle

4.4 SERIES CONNECTION OF TWO VOLTAGE DOUBLER CIRCUIT FOR INDIVIDUAL PIEZO PATCH:

Two patches are connected to two voltage doubler circuits individually and outputs of those circuits are connected in series.Table 4.8 and figure 4.9 shows the variation in output voltage at two different angles and different distances of piezo-patches from the nozzle. In this chart, the voltage for nozzle at 0° goes on increasing with the distance and the peak voltage (19.93 V) is at distance 112.5cm from the nozzle end. The peak voltage (21.45 V) for nozzle at 35° is at a distance of 75cm from the nozzle end. After that position the voltage decreases.

Table 4.8: Voltage v/s Distance at two different angles

Distance (cm)	25	50	75	100	112.5
Voltage at 0° (V)	3.25	9.82	14.23	16.85	19.93
Voltage at 35° (V)	3.18	10.58	21.45	20.89	16.24

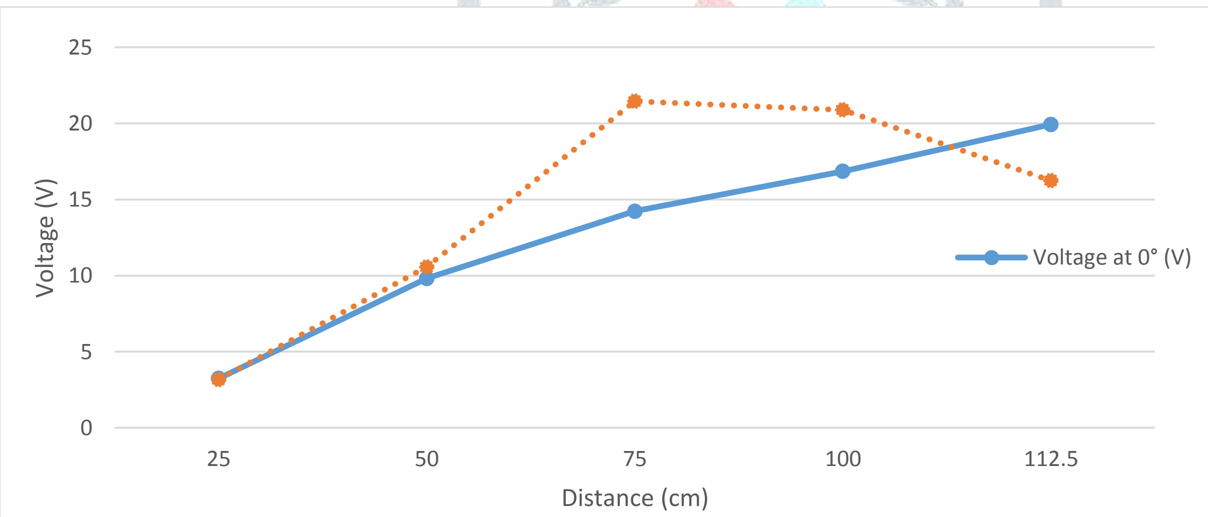


Figure 4.9: Variation of voltage at different distance of piezo-patch from the nozzle

Table 4.10 and figure 4.11 shows the variation in output current at two different angles and different distances of piezo-patches from the nozzle. In this chart, the current for nozzle at 0° goes on increasing with the distance up to the peak current (2.92 mA) which is at a distance 75cm from the nozzle end. The peak current (3.94 mA) for nozzle at 35° is at a distance of 75cm from the nozzle end.

Table 4.10: Current v/s Distance at two different angles

Distance (cm)	25	50	75	100	112.5
Current at 0° (mA)	0.27	1.94	2.92	2.78	1.74
Current at 35° (mA)	0.31	2.12	3.94	3.54	1.78

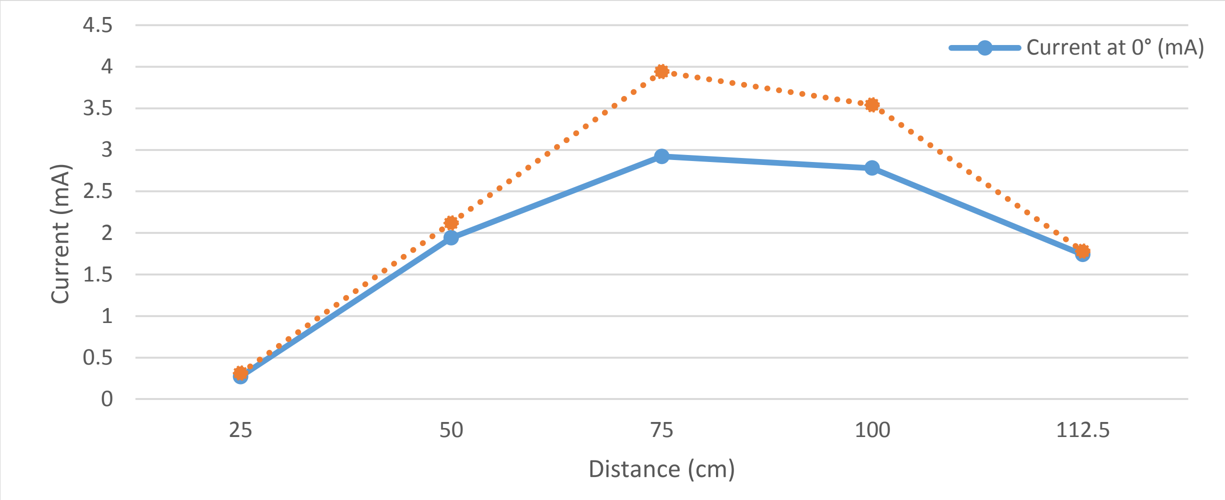


Figure 4.11: Variation of current at different distance of piezo-patch from the nozzle

Table 4.12 and figure 4.13 shows the variation in harvested power at different distances and two different angles of nozzle. In this chart, the maximum power output (46.843mW) for nozzle at 0° is at a distance of 100cm from the nozzle end. After that position the power goes on decreasing. The maximum power output (84.513 mW) for nozzle at 35° is at a distance of 75cm from the nozzle end. After that the power goes on decreasing.

Distance (cm)	25	50	75	100	112.5
Power at 0° (mW)	0.8775	19.0508	41.5516	46.843	34.6782
Power at 35° (mW)	0.9858	22.4296	84.513	73.9506	28.9072

Table 4.12: Power v/s Distance at two different angles

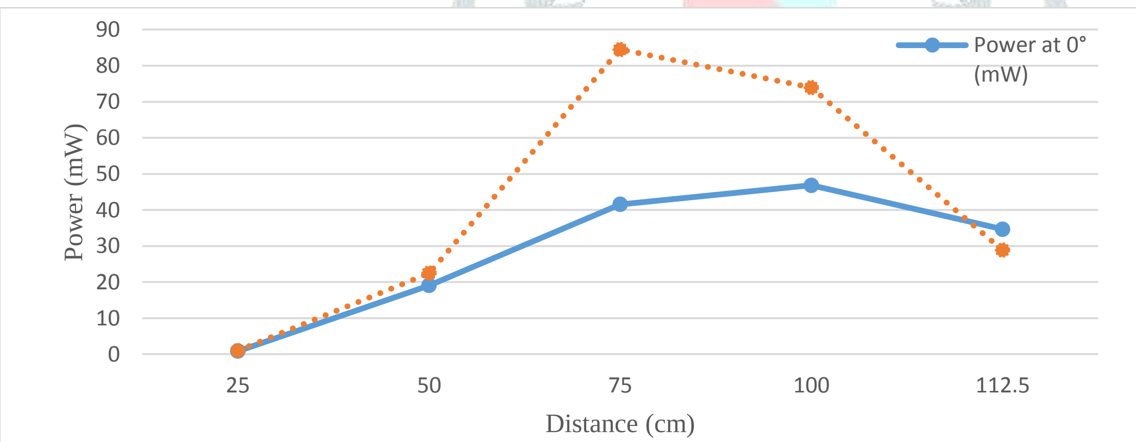


Figure 4.13: Variation of power at different distance of piezo-patch from the nozzle

4.5 POWER ANALYSIS AT DIFFERENT VELOCITY FOR DIFFERENT CONFIGURATIONS:

Two patches are connected in various configurations and output power has been analysed at different velocities of water striking the piezoelectric patches.Figure 4.14 shows the power analysis at different velocity for differentconfiguration of piezoelectric energy harvesting system at optimum distance and angle.

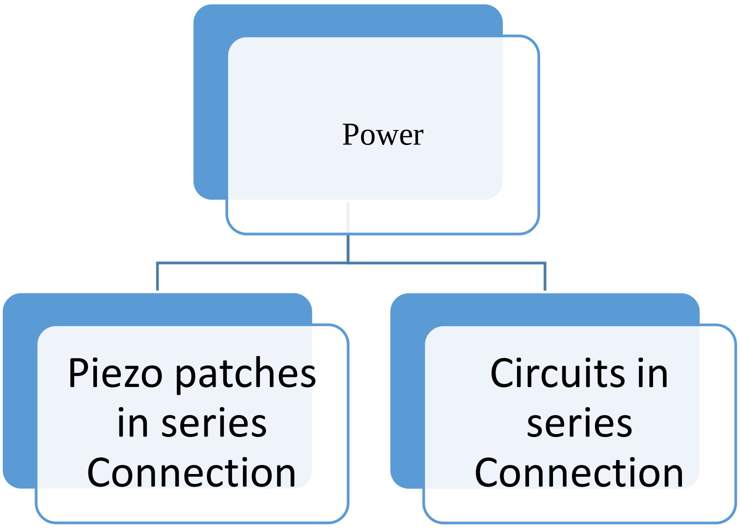


Figure 4.14: Power analysis at different velocity

4.5.1 Two Patches in Series Connection:

In this configuration, two piezo patches are joined in series and connected to the voltage doubler circuit are placed in front of two nozzles at a distance of 112.5cm. Power analysis of the system is done at 3 different velocities.

Table 4.15 and figure 4.16 shows the harvested power by the configuration at 3 different velocities at a distance of 112.5cmfrom the nozzle end.

Table 4.15: Power v/s Velocity

Velocity (m/s)	7.07	8.84	16.97
Power (mW)	1.1513	1.2832	3.0674

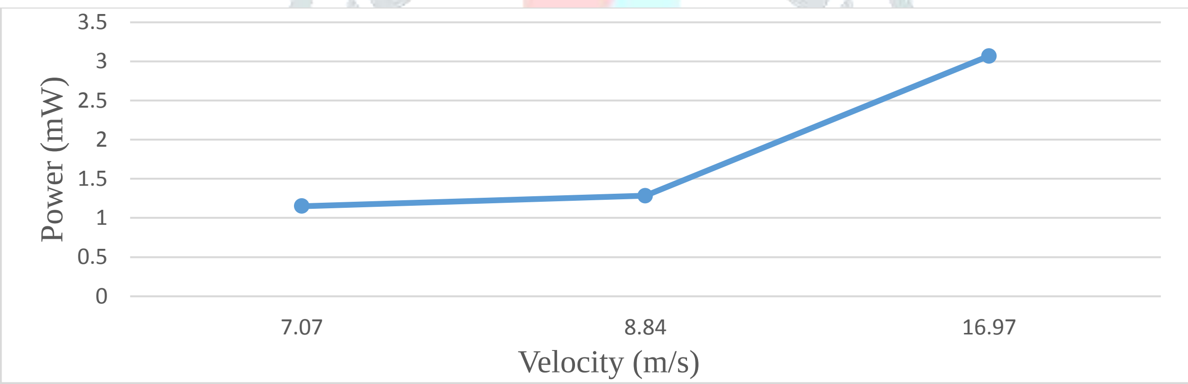


Figure 4.16: Power v/s Velocity

4.5.3 Series Connection of Two Voltage Doubler Circuits for Individual Piezo-patch:

Two patches are connected to two voltage doubler circuits individually and outputs of those circuits are connected in series. This configuration is placed in front of two nozzles at a distance of 75cm and power analysis of the system is done at 3 different velocities.

Table 4.17 and figure 4.18 shows the harvested power by the configuration at 3 different velocities at a distance of 75cm from the nozzle end.

Table 4.17: Power v/s Velocity

Velocity (m/s)	7.07	8.84	16.97
Power (mW)	25.8826	35.8512	84.513

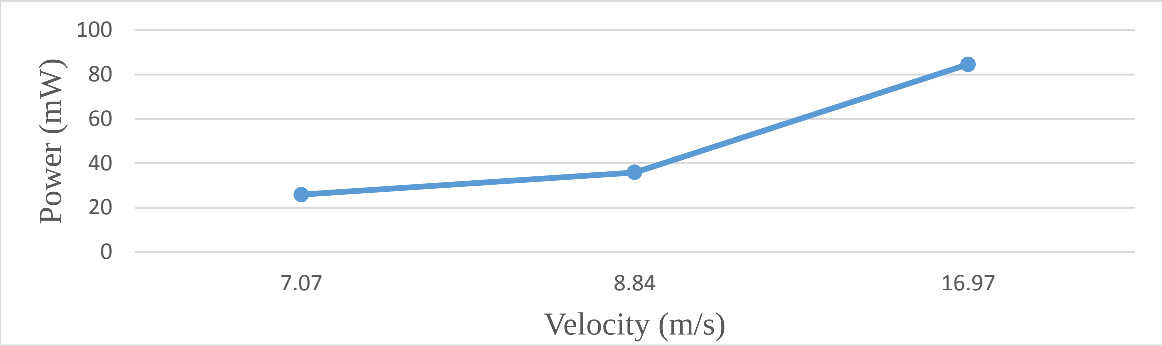


Figure 4.18: Power v/s Velocity

4.8 COMPARISON OF OUTPUTS OF SINGLE PATCH AND DOUBLE PATCHES IN SERIES:

Table 4.19 and figure 4.20 shows the comparison of voltage output of single patch and double patches in series. The result shows that output voltage of series and parallel connection of piezoelectric patches is lower than the output voltage of single patch due to parasitic capacitance as parasitic capacitance is an unavoidable and unwanted capacitance exists in an electric circuit, which decreases the output of a circuit.

Table 4.19: Voltage output v/s Distance for Single and Double Patches

Distance (cm)	25	50	75	100	112.5
Voltage(Single)	2.67	7.1	12.44	13.62	14.02
Voltage (Series)	1.18	3.7	5.8	5.3	6.26

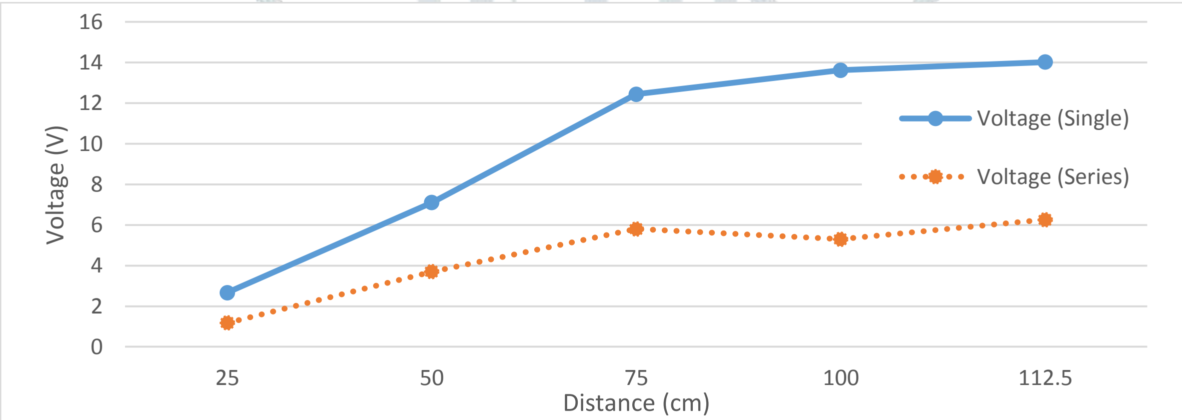


Figure 4.20: Voltage output v/s Distance for Single and Double Patches

Chapter - 5 Conclusion

5.1 CONCLUSIONS

Power generated using single patch and double patches of PZT in series configuration with voltage doubler circuit by using dynamic pressure of water. Voltages, current and power at different velocities, at different nozzle angle and at different distance of the patches from the nozzle end are measured. The comparison has been done using single and double patch piezoelectric elements under hydraulic dynamism. As we increase the number of piezoelectric patches the output in terms of voltage and current increases. It is observed that when two patches are connected to two voltage doubler circuit individually and output of those circuits is connected in series, the output voltage increase.

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