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Experimental Study of Improvised Tesla Micro-Turbine

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ABSTRACT

The Tesla turbine has revolutionized conventional turbine technology by employing friction and viscous forces on stacked discs instead of blades. The Tesla turbine is still distinguished by its remarkable efficiency in capturing the fluid energy through the boundary layer adhesion and cohesion principle. While Tesla turbines can achieve impressive rotational speeds, they also have a limitation in torque, which becomes a substantial obstacle in its application. Hence, the main objective of this study is to improvise the design of the Tesla turbine and analyze the new design's rotational speed and voltage generation with different inlet pressures. To accomplish this, the new design of the Tesla turbine discs is developed and fabricated. The study is then proceeded with the experimental work by conducting the RPM and voltage generation tests, which are performed to gather quantitative data to assess the best disk spacing and test the performance and feasibility of the improvised Tesla turbine. In general, the initial result has shown that the smallest disc spacing of 0.2 cm produces the highest RPM compared to the other models. The effect of design where blades are attached to the upper part of the pure Tesla discs (model 4) is found to perform the best in terms of RPM, which is higher by three times of the original Tesla turbine at 20 psi. At the highest inlet pressure, which is 80 psi, model 4 shows the highest rotational speed and voltage production at 3881 rpm and 19 V, respectively, when compared to the other models. It can be concluded that the improvisation of the Tesla turbine has performed better than the original. By achieving high RPM and voltage, the power output is enhanced for energy harvesting applications.

Keywords: Tesla turbine, Bladeless micro-turbine, Turbine design, Voltage generation

I. INTRODUCTION

Today, increased public awareness on environmental issues have raised the interests on development of greener solutions, especially in using renewable energy sources [1]. These include harvesting energy from natural sources such as solar [2], ocean waves [3] and wind [4,5]. For the latter, which is of main interest in this study, many wind turbines have been designed and studied to harvest the wind energy. For instance, mini shrouded wind turbine design has been studied to power small wireless sensors [6]. Moreover, the design of wind turbine with the incorporation of rotating piezoelectric devices has also been analyzed for improved wind energy harvesting [7]. Furthermore, the design of the Magnus wind turbine has also been studied [8].

A unique type of turbines that has been considered to be used to harvest the wind energy is Tesla turbine. Unlike the traditional wind turbines, Tesla turbine is bladeless [9]. Its design features flat discs with side nozzles as illustrated in Figure 1. In principle, it operates by harnessing the fluid

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viscosity and surface adhesion in order to slow down the flowing fluid and transfer energy from the fluid to the discs as it spirals towards the central exhaust. Unlike traditional turbines, it relies on friction and also viscous forces, using the boundary layer of the fluid for the momentum transfer. Previous studies in turbine technology have shown that this Tesla turbine can be used as small, low-power turbine [10,11]. Among others, it can serve as the viable option for various energy recovery initiatives like in the applications of the low-capacity Organic Rankine Cycle (ORC) system [12], energy collection from various types of fluid sources [13,14] and utilization of the low-energy gasses or streams in micro-combined heat and power application [15]. It can be noted that despite its simplicity, the Tesla turbine faces challenges with operational efficiency compared to bladed turbines. In general, the effectiveness of bladeless turbine is influenced by various factors like pressure, temperature, velocity conditions, rotational speed of the rotor, quantity, size and spacing of the discs, condition of the disc surface and the number and configuration of the inlet nozzles [16].

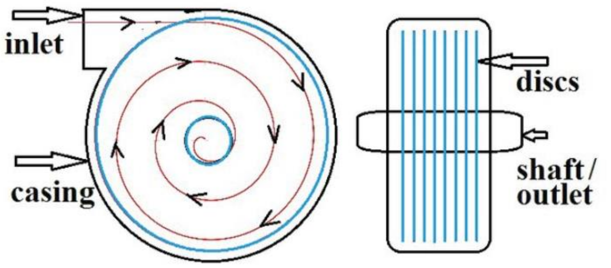


Figure 1 Schematic of a Tesla turbine [17]

To date, several experimental studies have been done on Tesla micro-turbine, considering its design parameters such as nozzle angle, inlet pressure and disc characteristics. However, it seems that rather limited attention is given on optimizing disc spacing and surface roughness of the Tesla turbines. In a conducted study of three inter-disc distance configurations of Tesla micro-turbines with a few different numbers of discs and also exit profiles for total of six rotor stacks, it has been found that increasing the disk spacing has resulted in greater generation of RPM due to the lower mass of the stacks of smaller discs [18]. It should be noted that in this study, the turbine size was kept unchanged for the different design configurations. The findings from this study have revealed intriguing characteristics of the flow parameters in the space between the turbine's rotating discs.

For the meantime, efficiency and output power have been often used as key parameters to describe and analyze the performance of turbines. One conducted study used the computational fluid dynamics (CFD) method to show the efficiency of the turbine as a function of the performance of different openings of the inlet nozzles [19]. The results have clearly indicated the effectiveness of the 4-inlet and 4-outlet (4i4o) pitot configuration, which has significantly increased the torque and power output 10 times compared to 4-inlet and 1-outlet (4i1o) setup. Furthermore, the 4i4o configuration has also demonstrated higher values for both thrust and efficiency, respectively with the improvements of 33.69% and 34.30% compared to the 4i1o configuration. Moreover, 4i4o configuration has an efficiency of 34.30% compared to the 4i1o with only 3.11%. In addition, studies have suggested that, to achieve a greater power generation, it is necessary to have a Tesla turbine design with enhanced revolutions per minute (RPM) capacity [20]. An increase in RPM of the Tesla turbine results in increase of voltage, current and power.

Based on the finding from a conducted study in Ref. [10], the top experimental power output for Tesla turbine was achieved using a 4 kW bench setup. These discoveries support the idea of using Tesla turbine as a small turbine and show that it is becoming more common to use it for capturing very low levels of energy. According to the reviewed literature, there's limited research that has experimentally investigated and improved upon the Tesla micro-turbine. In view of this notion, this study focuses mainly on disc spacing and disc design effects on RPM and voltage generation of the improvised Tesla turbine. The disc employed on the improvised Tesla turbine is fabricated using stereolithography (SLA) based 3D printer and it is tested with flowing air generated by a compressor. The performance of the improvised turbine is then compared to that of the original bladeless turbine.

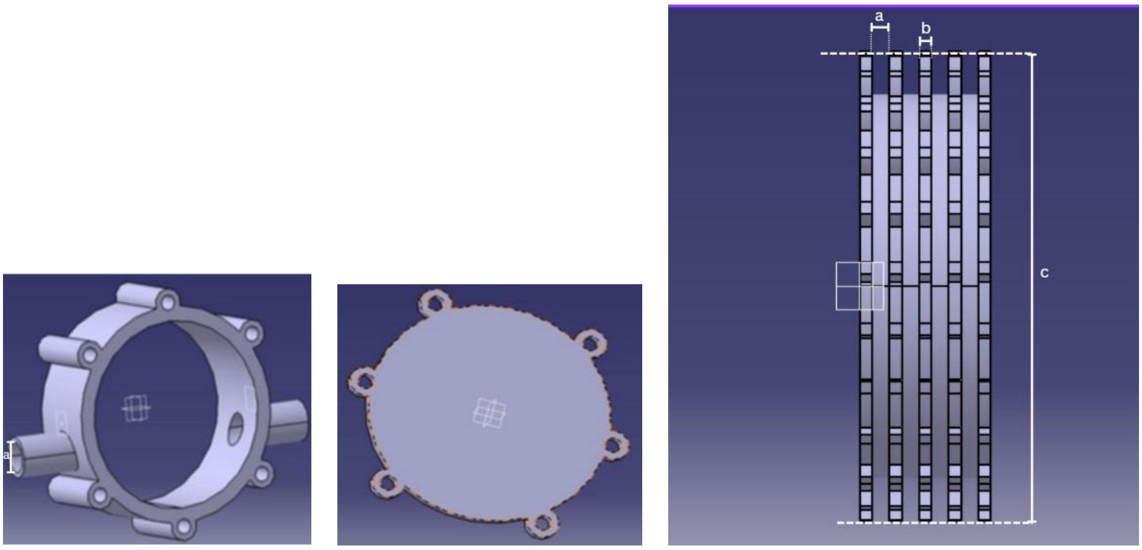
II. SETUP AND METHODOLOGY

A set of experiments is designed to identify the ideal disk spacing for the Tesla turbine. For this study, the disk spacing has been varied at five different values. The design parameters that are considered for the Tesla turbine design in this study are shown in Table 1.

Table 1 Parameters of Tesla turbine design

Parameters	**Value**
Disc Spacing (cm)	0.2, 0.4, 0.6, 0.8, 1.0
Disc Thickness (mm)	1.5
Disc Diameter (mm)	38
Number of Discs	5
Dimensions of Turbine Casing	71.5 mm x 21 mm x 53.8 mm
Size of Inlet Nozzle (mm)	7

Firstly, the computer-aided design (CAD) model for the Tesla turbine is constructed using CATIA V5 software. The CAD models are illustrated in Figure 2. Based on the CAD models, the rotor and turbine are fabricated through the three-dimensional (3D) printing method. 3D printing has been used in various engineering research studies since it has a high versatility to produce complex design shapes. For instances, 3D printing has been applied to fabricate the test model for the study of flapping wing mechanism [21,22], flow control devices [23], unconventional designs of aircraft wing [24] and propeller blade [25-27]. In this study, the 3D printing is done using Creality HALOT-ONE resin 3D printer for its high-quality results. Using the fabricated model, experimental testing of the Tesla turbine is then conducted to measure the resultant RPM at five different disc spacing settings. In brief, the experimental setup used is depicted in Figure 3, where the Tesla turbine is connected to the air compressor that is supplying compressed air. As can be seen, a pressure gauge has been placed between them to monitor the input pressure. On the other hand, a tachometer is also placed in perpendicular to the turbine to measure the resultant RPM of the rotor.



(a) Body casing a: inlet size

(b) Top casing

(c) Tesla Turbine a: disk spacing, b: disk thickness, c ; diameter

Figure 2 CAD models of Tesla turbine

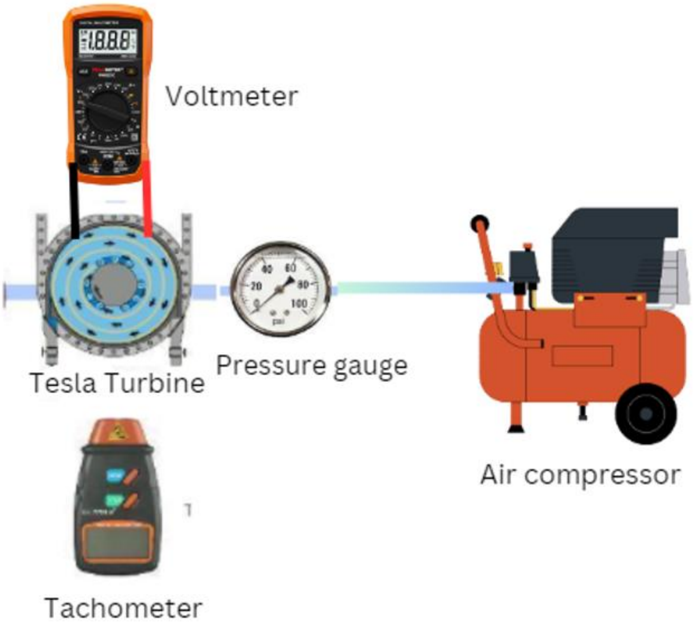
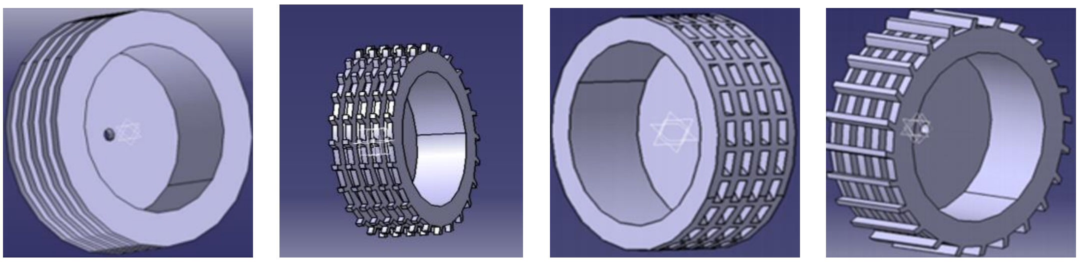


Figure 3 Schematic of the experimental setup

Based on the experimental results, ideal disc spacing is determined. With this ideal disc spacing, four different Tesla turbine models are designed to determine the optimal design for RPM and voltage generation. These designs are illustrated in Figure 4. It should be noted that one of these designs is simply a pure Tesla turbine while the other three designs are improvised from this basic design. In this case, Model 1 is the pure Tesla turbine design. On the other hand, Model 2 consists of blade patterns attached on the Tesla discs where the gap between those discs is still maintained. This design fully uses the boundary layer effects between those discs such that viscous force will be created to rotate the turbines. Moreover, additional design is added in terms of the discs, which will efficiently capture kinetic energy from the pressurized air. Meanwhile, Model 3 consists of inner blade patterns that are attached in between the disc gaps where it has multiple hole-like structures. This design combination aims to harness the kinetic energy of the high-velocity fluid flow through the bladed patterns and utilize the boundary layer adhesion principle of the Tesla turbine. Furthermore, Model 4 is the combination of Model 1 and Model 2 in which the blades are attached to the upper part of the pure Tesla discs. This design is made to increase the force imposed toward the turbine blades by allowing more gaps for the air path to flow and therefore drive the turbine.



(a) Model 1 (b) Model 2 (c) Model 3 (d) Model 4

Figure 4 Considered designs of Tesla turbine rotor

Figure 5 to Figure 7 present the subsequent stages of this research work after the design modelling process. The 3D models are prepared using Chitubox slicing software before printing as shown in Figure 5. The material used for printing is water-washable resin that is Magma 8K Water Washable Photopolymer UV Resin. Figure 6 depicts all of the printed models after the curing process (the models are exposed to sunlight for four hours). Next, in Figure 7, the RPM of the turbine is measured using a tachometer when the compressed air has been passed through the inlet. The generated voltage is measured using a voltmeter.

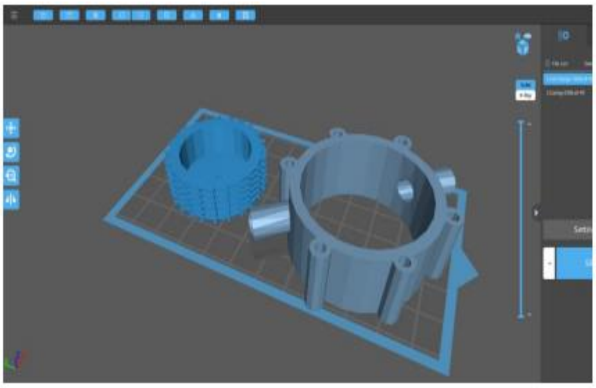


Figure 5 Slicing of Tesla Turbine in Chitubox

Figure 6 3D printed parts of modified Tesla turbines

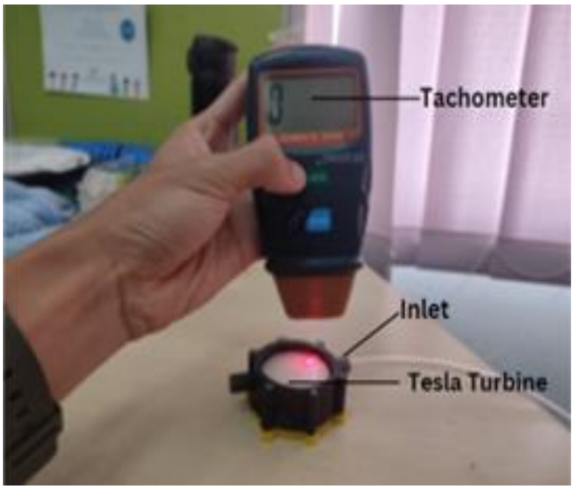


Figure 7 Measuring the RPM of the Tesla turbine.

III. RESULTS AND DISCUSSION

The results for the different disk spacing are plotted in Figure 8. In this case, the initial inlet pressure is 14 psi with the maximum inlet pressure being 24 psi. This is because the observation will be focused in the low inlet pressure range first for the disk spacing test before being continued to higher inlet pressure. This test aims to observe how altering the spacing between the disks impacts the turbine's ability to capture air for rotation. The highest RPM recorded is 250.8 at the lowest pressure whereas the lowest RPM reached is 95.2. Conversely, at the maximum pressure, the highest RPM is measured as 659.5 while the lowest is 418.8. It can be observed that the turbine with a disc spacing of 0.2 cm consistently produced the highest RPM at both pressure levels. On the other hand, the turbine with disc spacing of 1.0 cm consistently yielded the lowest RPM at both pressure settings. It can be noted that when the pressure is increased, the turbine speed also increases. However, when the spacing between the jet and the disc is widening, the rate of speed change slows down. This is because, as the gap between the jet and the disc decreases, the friction and shear forces between them also increase, resulting in the formation of a boundary layer around the revolving disc and the jet. This boundary layer will exert a pulling force on the discs.

In the meantime, Figure 9 presents the results for the different designs of the Tesla turbine. In general, it can be observed that the higher the inlet pressure, the higher the RPM for all of the models. The highest RPM is achieved by Model 4, which is 3881 RPM at 80 psi compared to the other two models, which is 2869 and 2407 for Model 2 and Model 3, respectively. The efficiency of the turbine affects its RPM. A more efficient turbine could essentially convert a larger proportion of available fluid energy into rotational motion, resulting in a higher RPM for a given fluid input. Furthermore, attaching the blades at the upper part of the pure Tesla discs augments the total surface area accessible for interaction with the working fluid. This, in turn, leads to greater surface for the boundary layer to adhere to, thus boosting the efficiency in energy transfer from the fluid to the discs.

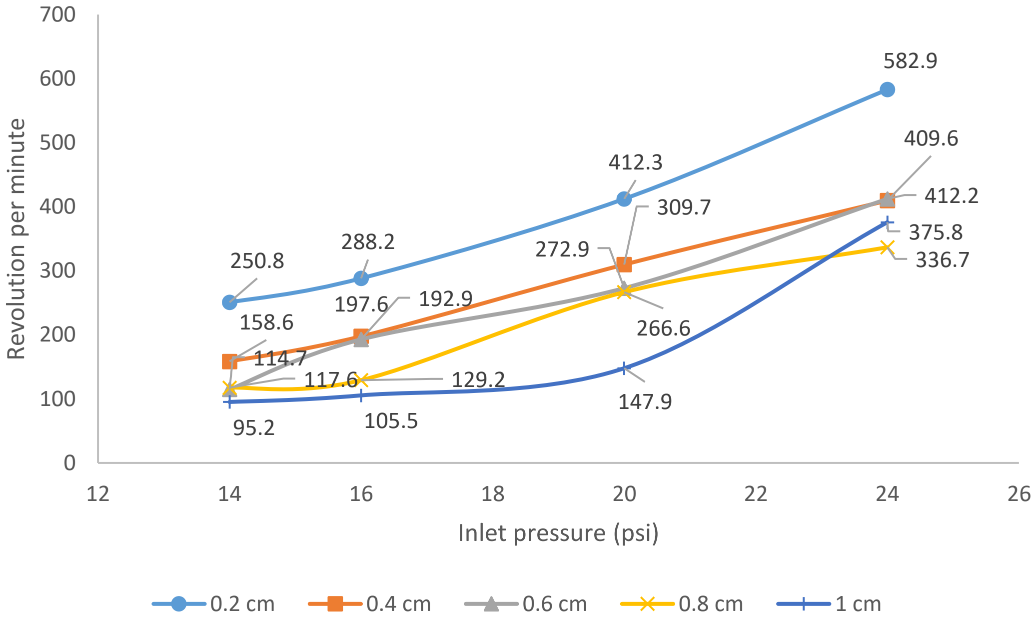


Figure 8 RPM versus inlet pressure for different disc spacing

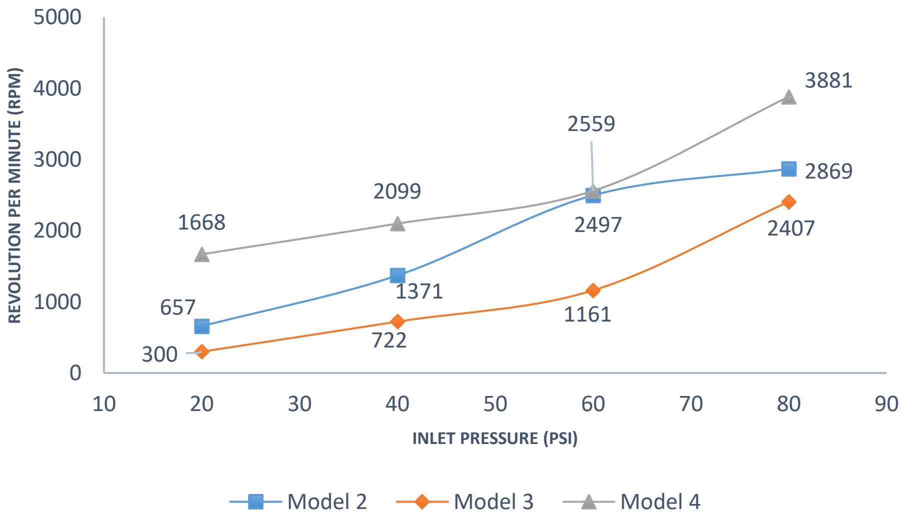


Figure 9 RPM versus inlet pressure for all three improvised Tesla turbine models

The results are summarized in Table 2. It can be seen that the highest RPM difference in comparison to the pure Tesla turbine is achieved by the improvised Tesla turbine Model 4, which is 1256 RPM. In contrast, Model 3 has an even lower RPM compared to the original Turbine by 27%. Model 4 has achieved about three times higher RPM than the original Tesla turbine at 20 psi. Moreover, Model 2 also has shown good performance by achieving 59% increment in RPM compared to the original turbine. This data proves that two out of the three modified Tesla turbine models can achieve higher RPM at low inlet pressure.

Table 2 RPM comparison between considered Tesla turbine designs at low pressure (20 psi)

Model	RPM	RPM Difference to Model 1	RPM Increment Percentage
Model 1	412	-	-
Model 2	657	245	59%
Model 3	300	-112	-27%
Model 4	1668	1256	304%

Therefore, this proves that the modified model has more torque compared to the original turbine. Model 4 design can boost the power directed at the turbine blades by adding more air openings, which ultimately results in a stronger driving force for the turbine. In addition, the design takes into consideration the spacing of the discs, ensuring that principles of adhesion and cohesion are not overlooked. This aids to maintain the unique identity of Tesla turbine that enables it to operate at higher RPM.

Figure 10 presents the experimental results in terms of the voltage output. It is evident that, in general, higher inlet pressures lead to increased voltage output across all three improvised Tesla turbine models. As can be seen from the figure, Model 4 has achieved the highest voltage output, reaching 19 V at 80 psi. Both Model 2 and Model 3 have also managed to produce their highest voltage output at the same pressure of 80 psi, registering 14.6 V and 16.5 V for Model 2 and Model 3, respectively. This trend could be attributed to the turbine's accelerated rotational speed that is causing the rotor's magnets to move speedily past the stationary coils in the stator. This motion induces changes in the magnetic field, subsequently generating an electric current in the coils. This electric current is then harnessed to generate electrical voltage, with higher turbine speeds resulting in more rapid fluctuations in the magnetic field and, consequently, greater induced voltage. In essence, the outcome reveals that even at the lowest inlet pressure of 20 psi, the 12 V voltage generated by Model 4 can serve a practical purpose such as charging a 3s battery employed in a quadcopter.

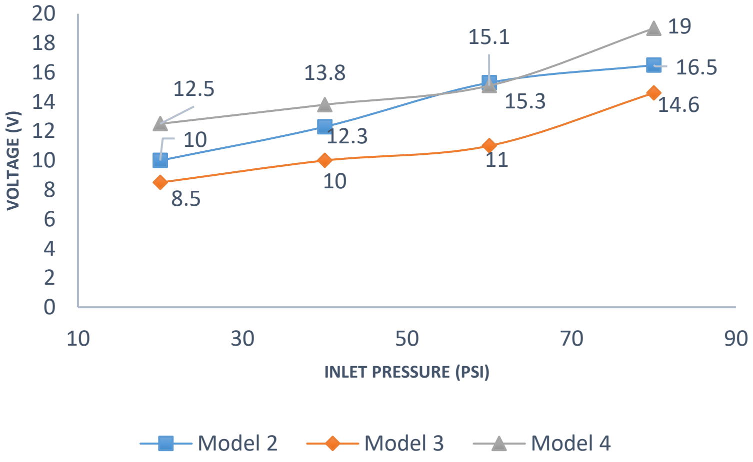


Figure 10 Voltage output versus inlet pressure for all three improvised Tesla turbine models

IV. CONCLUSIONS

In conclusion, the results from this study indicate that the smallest disc spacing of 0.2 cm yields the highest RPM when compared to other spacing configurations. Moreover, Model 4 of the improvised Tesla turbine outperforms the original Tesla turbine (Model 1) by a substantial threefold improvement in RPM, particularly at the inlet pressure of 20 psi. The results prove that the improvised Tesla turbine has a higher torque than the original turbine. Even at the highest inlet pressure of 80 psi, Model 4 continues to demonstrate superior performance, boasting a rotational speed of 3881 RPM and also voltage production of 19 V, surpassing the capabilities of both Model 2 and Model 3. Model 4 also demonstrated 304% increment compared to original model. To summarize, Model 4 of the improvised Tesla turbine is the most ideal design in terms of torque, RPM and voltage production among the considered Tesla turbine designs in this study. In conjunction with this finding, this modified Tesla turbine could be applied in a variety of applications, especially for higher torque usage where the original Tesla turbine has limited capabilities.

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