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Electricity Generation Using Wind Formation in Delhi Metro

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Abstract

Using a wind formation observed in "Delhi Metro," which is formed by the motion of the metro cars. Besides existing technological developments in wind energy applications, an unusual method of generating electricity is thought to apply to metro tunnels. There are similar studies in the literature that differentiates from this study in the case of installation spots, turbine types, and technique. Two types of wind turbines are thought to be installed in 2 scenarios. They are installed at spots where have the highest wind parameters, such as airflow and flow velocity. The desired wind turbines are thought to be installed on the metro tunnels. For the first scenario, horizontal axis wind turbines were used and 15 turbines installed. The second scenario is using vertical axis wind turbines. 3 wind turbines are desired to be installed on the metro walls. A reference metro line is needed to be chosen. Delhi Metro's 8th Line, which is also known as the Magenta Line, has been chosen as the reference line. The energy that can be produced theoretically has been calculated. The financial value of electricity production has been determined using India's current industrial average price of electrical energy. 115,265 kWh from the 1st scenario and 75,634 kWh of electrical energy from the 2nd scenario are calculated to produce per year from one set of turbines.

Keywords — *Energy, metro, wind.*

I. INTRODUCTION

According to India's energy outlook; coal with 5,172,222.22 GWh, oil with 2,844,444.44 GWh, and natural gas with 597,222.22 GWh were the main energy sources for electricity generation in 2019, with renewable energy accounting for just 336,111,11 GWh with a percentage of 4% of total electricity generation [1]–[3]. New possible methods may be used to resolve the high use of fossil fuels. This theoretical study focuses on the use of a new method that exists but is not industrially used. The idea is to produce electricity from train movement. The study's key objectives are to discover latent potentials and increase awareness all over the world [4].

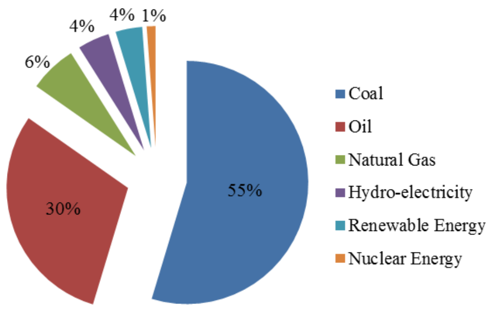


Figure 1.1. Primary energy consumption of India in 2019 [1].

II. MATERIALS AND METHODS

A. *Materials*

a) Delhi Metro and defining the pilot line

The pilot line was chosen based on a variety of factors that could have a positive or negative impact on the efficiency of energy production. The 8th Line has been selected. The details about the 8th Line can be found on the manufacturer's website [5]. Some details about Delhi Metro lines and also the Magenta Line have been given in Table 2.1. The rolling stock of the Magenta Line is Hyundai Rotem which can speed up to 100 km/h. The Magenta Line's route can be seen in Figure 2.1.

Table 2.1. Details of the Delhi Metro lines and 8th Line, the Magenta Line [6].

Delhi Metro: present network				
Line No.	**Line Name**	**First operational**	**Last extension**	**Stations**
1	**Red Line**	24.12.2002	08.03.2019	29
2	**Yellow Line**	20.12.2004	10.11.2015	37
3	**Blue Line**	31.12.2005	09.03.2019	50
4		07.01.2010	14.07.2011	8
5	**Green Line**	03.04.2010	24.06.2018	21
		27.08.2011	—	2
6	**Violet Line**	03.10.2010	19.11.2018	34
7	**Pink Line**	14.03.2018	31.12.2018	23
				15
8	**Magenta Line**	24.12.2017	29.05.2018	25
9	**Grey Line**	04.10.2019	04.10.2019	3
Airport Express	**Orange Line**	23.02.2011	—	6
		24.12.2002	**04.10.2019**	**253**

Figure 2.1. Delhi Metro Network [6].

The length of the deep tube, annual train count, station number, and the "Magenta Line," which has the highest energy-generating potential within, have all been taken into account. Table 2.1. indicates that the Magenta Line has a deep tube with a length of 38.235 km and 25 stations [7], [8]. Furthermore, Magenta Line rolling stock dimensions are available from its manufacturer (see Figure 2.2.).

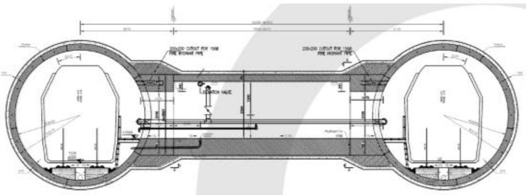
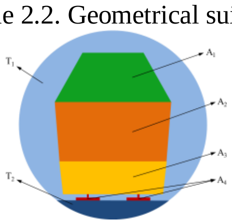


Figure 2.2. Delhi Metro and tunnel cross-section [5].

b) Geometrical suitability approach

The first step of the geometrical suitability approach is to calculate train and tunnel geometries by reducing their parts into calculable geometrical parts. In order to assess the cross-sectional regions, two approaches have been used. When it is compared to the second method, the first method is less sensitive. The cross-sectional area is divided into multiple rectangular geometries in Table 2.2. The dimensions and area of the shapes were then approximated and measured. Table 2.2. demonstrates the calculations made for the geometrical suitability approach [9]. In Figure 2.3. the technical drawing and the scaling process can be seen.

Table 2.2. Geometrical suitability approach demonstration.



Geometrical Part	Area of the Geometrical Part (m^2)
T_1	26.42
T_2	1.44
A_1	4.10
A_2	6.21
A_3	3.20
A_4	0.14

c) Solid Works scaling approach

The second approach involves the use of a designing software called Solid Works. On the program, a training model and a tunnel were constructed. A technical drawing of the train and tunnel was taken, and it was used on Solid Works to estimate measurements that were not provided. Therefore, Solid Works derived data was used in further calculations in order to provide more detailed performance. The scaling method is depicted in Figure 2.2. Tunnel diameter known as 5.8 meters and placed a circle on the given photo. Then, the train shape is created depending on the tunnel diameter.

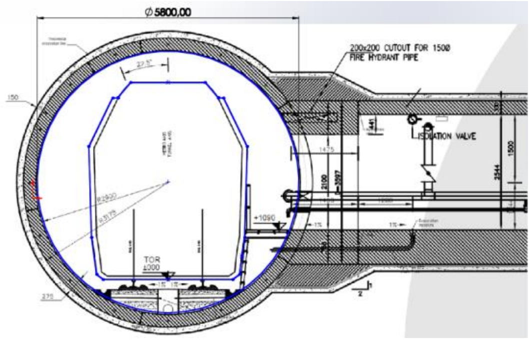


Figure 2.3. The technical drawing and scaling process [5].

The cross-sectional areas of the whole tunnel, train, and the gap between them are calculated using the program. The areas are given in Figure 2.4.

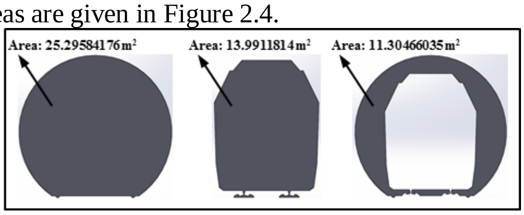


Figure 2.4. Train and tunnel's cross-sectional areas.

The flow velocity that exists in the distance between the tunnel and the train was used in the calculations. Table 2.3. summarises the improvements in the statistics between the two methods. Even though the error percentage is small, the Solid Works Scaling Method is more reliable. Therefore, Solid Works derived data are used in subsequent calculations.

Table 2.3. Geometrical suitability and Solid Works are scaling approach comparisons.

Comparison Parameters	Unit	Geometrical Suitability Approach	Solid Works Scaling Approach
Cross-sectional Area of the Train	m^2	13.65	13.99
Cross-sectional Area of the Tunnel	m^2	24.97	25.29
Substracted Area	m^2	11.33	11.30

d) Theoretical approach and calculations

Any time a metro car gets in a tunnel; high-velocity air is formed as a result of the train's motion in the tunnel. Calculations in the direction of certain values have been made. The flow velocity was determined using the continuity equation, with the assumption that the volume of the air is the same as the volume of the train and that the flow velocity is perpendicular and opposite to the train's movement direction. As the airflow produced travels in the opposite direction to the train, the gap between the train and the tunnel will be used to escape from where wind turbines are mounted. Since friction losses have been assumed to be minimal, the airflow discharged by the train is assumed to be equivalent to the airflow attempting to escape through the train in the opposite direction. The airflow induced by the insertion of the train into the tunnel is often equal to the airflow that happens during the train's movement between the tunnel and the train. It is presumed that the friction losses due to air flows are not present. Using the continuity equation, we can find the flow velocity required to measure the power generation of the turbines between the train and the tunnel [10].

e) Defining the wind turbines

The wind turbine types have been selected as turbines of the new generation wind jet design. The performance of Aeolos and FloDesign branded wind turbines are expected to be greater than conventional ones. What is more, it is expected that assembling and disassembling wind turbines of the wind jet type would be simpler during the installation process. Many wind turbines have a maximum efficiency of 60%. The issue is 40% of the wind goes through the wind turbine blades without activating the generator and also generating electricity. The horizontal axis wind turbines from FloDesign and vertical axis wind turbines from Aelos Brand alter these properties. It greatly increases performance by directing the wind over the blades. They produce the same amount of energy as a typical windmill that is twice the size [11], [12]. This also implies that it is possible to position more wind turbines closer together, raising production on a wind farm.

Theoretical placement of the turbines was initially modeled on a technical drawing which is scaled in using the appropriate tunnel. The horizontal axis wind turbine layout can be seen in Figure 2.5. The first scenario consists of 15 wind turbines:

- 1100 mm x 2
- 900 mm x 4
- 750 mm x 2
- 650 mm x 1
- 600 mm x 2
- 550 mm x 2
- 500 mm x 2

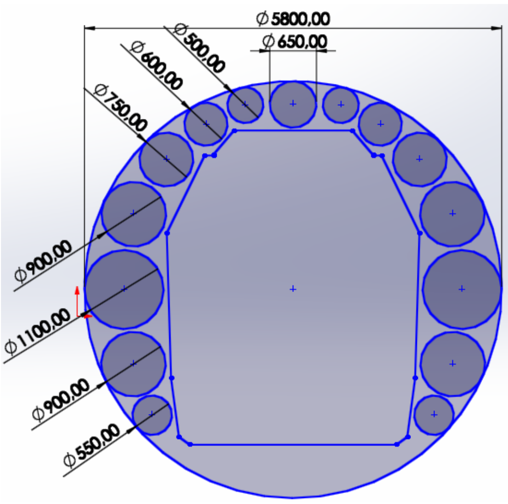


Figure 2.5. The layout of the horizontal axis wind turbines, train, and tunnel.

The second scenario includes 3 vertical wind turbines:

- 350 mm height, 2500 mm rotor diameter x 1
- 2700 mm height, 700 mm rotor diameter x 2

The layout for the second scenario with vertical axis wind turbines is shown in Figure 2.6.

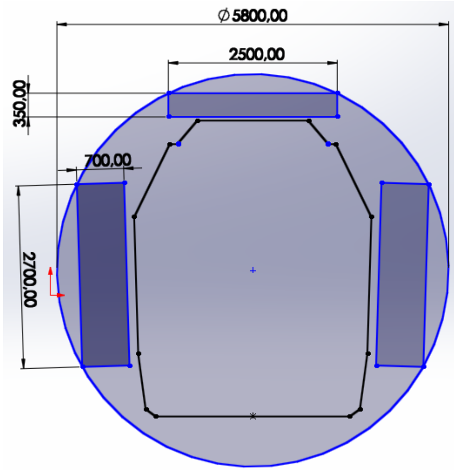


Figure 2.6. The layout of the vertical axis wind turbines, train, and tunnel.

III.RESULTS, CONCLUSIONS, AND RECOMMENDATIONS

A. Technical results and applicability

With the intensive movement of the train (a train in 3 minutes) and the speed of the train, taking into account the reference line's data, it can be stated from the velocity measurements that there is a high volume of airflow. When all train losses are neglected, the airflow velocity is estimated to increase to 40.1 m/s once the train exceeds 100 km/h. That speed could surpass the upper limit of the working condition of traditional wind turbines, which are Aelos and FloDesign wind turbines have been selected in the study. Furthermore, these wind turbines are more powerful than traditional turbines. The efficiency gap between the traditional and wind jet turbines significant: traditional turbines have a 35 percent efficiency, whereas wind jet style turbines have a 45 percent efficiency [9]. Horizontal axis wind turbines mostly match the project idea, so it is assumed that horizontal axis wind turbines are mounted in the gap between the train and the tunnel. Using Solid Works engineering design software, the distance between the train and the tunnel, the dimensions of the train and the tunnel, and other found dimensions were scaled up in a technical drawing, and the not-found dimensions were attempted to be calculated. For the first scenario, 13 wind turbines with four different diameters were installed, while for the second scenario, three wind turbines with two different diameters were installed (see Figure 2.4.). The unique feature of the model is that 115,265 kWh from the 1st scenario and 75,634 kWh of electrical energy from the 2nd scenario can be produced per year from one set of turbines. In the figures, in the event of malfunctions and repairs, the period of operation of the wind turbines was 300 days instead of 365 days. However, the generated energy can be stored in batteries; another alternative, called the off-grid system, is also possible. The electrical energy stored does not need an off-grid device. It uses the generated energy directly, so the energy is thought to be used in metro station lighting and ventilation systems [9]. Furthermore, the off-grid system's overall cost is less risky and costly than the battery-based alternative. The Betz Limit or Betz 'Law has been used to measure the production of electricity [10].

B. Financial results

The annual income has been determined using the calculated sum of energy (115,265 kWh and 75,634 kWh) based on the expense of India's industrial electricity tariff. The industrial price of electricity per unit has been taken as 5.94 Indian Rupees (INR), and the annual income has been estimated as 15,480 QR; however, this scenario includes 684,674 Rupees (INR) for the first and 449,268 (INR) Rupees for the second [14].

At 17.1, the train completes its acceleration, and until 51st second, the train keeps the same speed. Just after 51st second, the deceleration starts, and the train slows down. At 56th second, the train starts to leave the tunnel.

Table 3.3. Generated electricity calculation chart for 1st and 2nd scenario, respectively [15].

Total Power (Wh/1 pass)	800.45	15 Turbines/set
Total Power (Wh)	16009.02	A train in three minutes
Total Power (kWh/day)	384.22	24 Hours
Total Power (kWh/annum)	115,264.98	300 days/year
Total Power (Wh/1 pass)	525.24	3 Turbines/set
Total Power (Wh)	10504.77	A train in three minutes
Total Power (kWh/day)	252.11	24 Hours
Total Power (kWh/annum)	75,634.37	300 days/year

C. Recommendations

- In the world and in India, it is expected there is much potential for generating electrical energy from off-shore and on-shore applications.
- The ability of airflow to create electrical energy tends to be advantageous for undergrounds.
- One of the metro turbines should be simulated as a prototype in order to calculate and identify the capacity of electrical energy generation as a real-life application.
- It is important to test and define the precise efficiency and suitability of the new generation jet-type turbines.

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