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Generating Electrical Energy from Tyne and Wear Metro

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Abstract

High-speed wind formation is created in "Tyne and Wear," which is the metro in the northeast of the UK. The study is focused on generating electricity from that wind formation with the help of both horizontal and vertical wind turbines. The idea is to assemble wind turbines on metro tunnels and generate electricity to use on lighting, cooling, and so on. There are similar studies in the literature on which is to install vertical wind turbines on the train rails. Another one is to use turbines at stations. Two scenarios have been thought theoretically for the study. The first one is assembling horizontal wind turbines, and the second one is vertical wind turbines. The first scenario consists of 9 horizontal-axis wind turbines used while 3 vertical-axis wind turbines installed in the second scenario. Tyne and wear metro have two metro lines, yellow and green. Metro cars can go up to 80 km/h at maximum speed. The potential energy that can be generated theoretically is calculated. The financial value of electricity production is determined using the UK's current industrial average price of electrical energy. 462,291 kWh from the first scenario and 398,536 kWh of electrical energy from the second scenario are calculated to produce per annum from a set of turbines.

Keywords — *Generate energy, horizontal wind turbine, vertical wind turbine.*

I. INTRODUCTION

According to the UK's energy forecast, the key energy sources for electricity production in 2019 were coal with 72 TWh, oil with 864 TWh, and natural gas with 789 TWh, with renewable energy responsible for 300 TWh or 14% of overall electricity generation [1]–[3]. To address the high use of fossil fuels, new approaches may be employed. This theoretical investigation focuses on the application of a novel approach that has been developed but has yet to be implemented in the industry. The concept is to generate electricity by moving trains. The study's main goals are to uncover hidden potentials and raise global awareness [4].

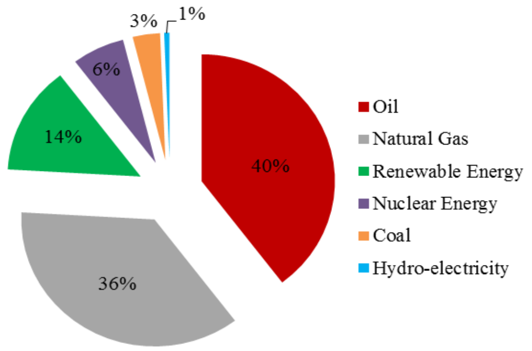


Figure 1.1. Primary energy consumption of the UK in 2019 [1].

II. MATERIALS AND METHODS

A. Materials

a) Tyne and Wear Metro and metro lines

Tyne and the Wear Metro is a light rail system located in Newcastle, UK. Tyne and Wear metro opened on the 11th of August, 1980 [5]. The system is 77.5 km long and has 2 lines (green and yellow) and 60 stations. The manufacturer's website has more details on the metro lines [6]–[9]. Figure 2.1. contains information on the Tyne and Wear Metro lines. There are a total number of 89 metro cars which have a top speed of 80 km/h. The Green and Yellow Line's route can be seen in Figure 2.1. and Figure 2.2.

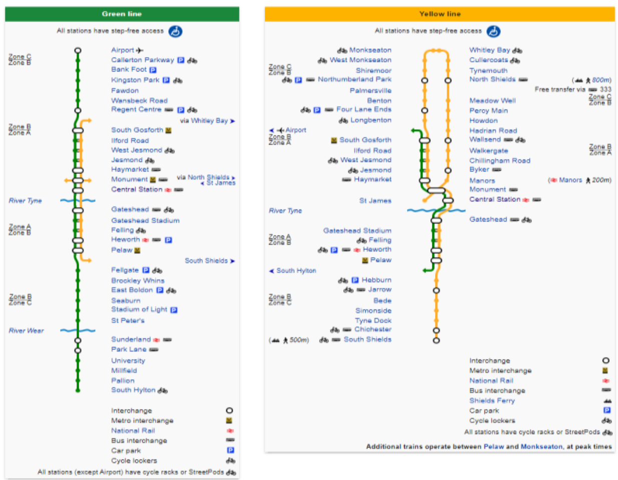


Figure 2.1. Details of the Tyne and Wear Metro [9], [10].

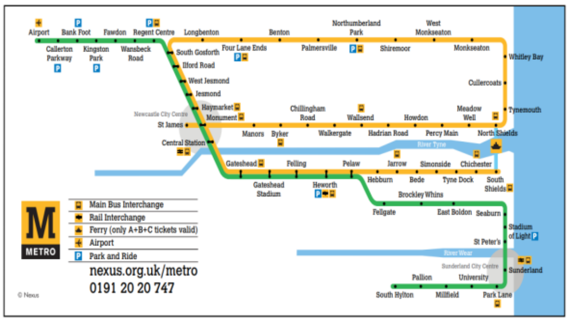


Figure 2.2. Tyne and Wear Metro Network [11].

The length of the deep tube, annual train count, and station number have been taken into account. The manufacturer also opened the dimensions of Tyne and Wear Metro's rolling stock to the public. (see Figure 2.3.).

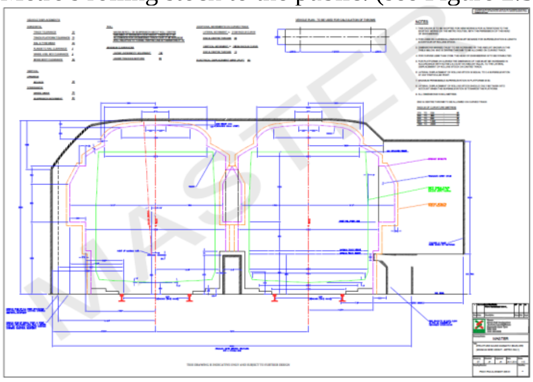
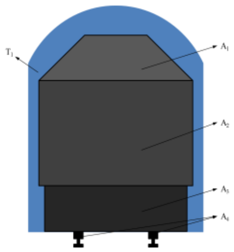


Figure 2.3. Tyne and Wear Metro cars and tunnel cross-section [12].

b) Geometrical suitability approach

The geometrical suitability method begins with calculating train and tunnel geometries by reducing their components to calculable geometrical bits. Two methods have been used to evaluate the cross-sectional areas. When it is compared to the second method, the first method is less sensitive. Table 2.1 divides the cross-sectional area into various geometrical configurations. The geometrical proportions and areas were then estimated and calculated [13]. The equations for the geometrical suitability approach as seen in Table 2.1. The technical drawing and scaling method can be seen in Figure 2.4.

Table 2.1. Geometrical suitability approach demonstration.



Geometrical Part	Area of the Geometrical Part (m^2)
T_1	14.544
A_1	1.5275
A_2	6.51
A_3	1.881
A_4	0.0208

c) Solid Works scaling approach

The second method entails the use of Solid Works, a production software program. A train model and a tunnel were built as part of the program. A technical drawing of the train and tunnel was created and used in Solid Works to approximate missing dimensions. As a result, Solid Works derived data was used in additional calculations to provide more accurate results. Figure 2.2 shows the scaling process. Measurements of the train and tunnel are placed on the technical drawing. The training form is then developed based on the measurements given.

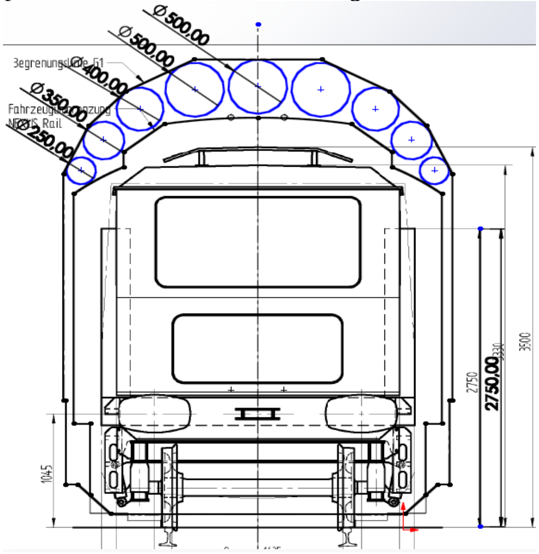


Figure 2.4. The technical drawing and scaling process [12].

The software calculates the cross-sectional areas of the entire tube, rail, and the distance between them. The areas are given in Figure 2.5.

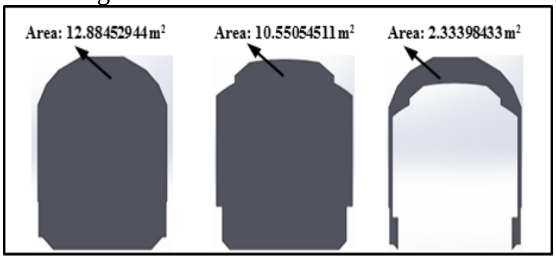


Figure 2.5. Train and tunnel's cross-sectional areas.

In the equations, the flow velocity in the space between the tube and the train was used. The differences in statistics between the two approaches are summarized in Table 2.2. The Solid Works Scaling Method is more effective, despite the limited error percentage. The error rate between the two methods is around %50 in terms of the air gap. As a result, the data obtained from Solid Works is used in subsequent measurements.

Table 2.2. 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	9.93	10.55
Cross-sectional Area of the Tunnel	m^2	14.54	12.88
Substracted Area	m^2	4.60	2.33

d) Theoretical approach and calculations

When a metro car enters a tube, high-velocity air is generated as a result of the train's movement. There have been calculations in the form of those values. The flow velocity was calculated using the continuity equation, assuming that the volume of air is equal to the volume of the train and that the flow velocity is perpendicular to and opposite the train's travel direction. The distance between the train and the tunnel can be used to escape from where the wind turbines are installed since the airflow generated is in the opposite direction of the train. The airflow discharged by the train is expected to be equal to the airflow trying to exit from the train in the opposite direction since friction losses are presumed to be negligible. The airflow created by the train's insertion into the tunnel is often equal to the airflow created by the train's passage between the tunnel and the train. It is assumed that there are no pressure losses due to air currents. The flow velocity used to determine the power generation of the turbines between the train and the tunnel can be calculated using the continuity equation [14].

e) Defining the wind turbines

The wind turbine models have been chosen as new generation wind jet concept turbines. Aeolos and FloDesign-branded wind turbines are expected to outperform traditional wind turbines. Furthermore, during the construction phase, it is anticipated that installing and disassembling wind turbines of the wind jet type would be easier. The overall productivity of many wind turbines is 60%. The problem is that 40% of the wind passes through the blades of a wind turbine without triggering the generator and producing electricity. To change these properties, FloDesign's horizontal axis wind turbines and Aelos Brand's vertical axis wind turbines are used. By steering the wind over the blades, significantly improves efficiency. They generate the same amount of energy as a windmill, double their size [15], [16]. This also means that more wind turbines will be placed closely together, increasing wind farm output.

The turbines were theoretically placed using a technical drawing that was then scaled in using the required tunnel. Figure 2.6. shows the configuration of horizontal axis wind turbines. Nine wind turbines are included in the first scenario:

- 500 mm x 3
- 400 mm x 2
- 350 mm x 2
- 250 mm x 2

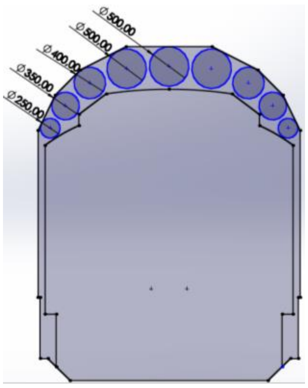


Figure 2.6. The layout of the horizontal axis wind turbines, train, and tunnel.

The second scenario includes 3 vertical wind turbines:

- 250 mm height, 900 mm rotor diameter x 2
- 350 mm height, 1500 mm rotor diameter x 1

The layout for the second scenario with vertical axis wind turbines is shown in Figure 2.7.

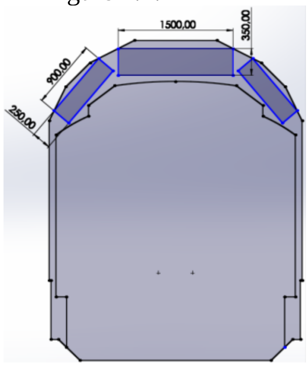


Figure 2.7. The layout of the vertical axis wind turbines, train, and tunnel.

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 approximately 100 m/s once the train exceeds 80 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 [13]. 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, 9 wind turbines with four different diameters were installed, while for the second scenario, three wind turbines were installed (see Figure 2.4.). The unique feature of the model is that 462,291 kWh from the first scenario and 398,536 kWh of electrical energy from the second 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 [13]. Furthermore, the off-grid system's overall cost is less risky and costly than the battery-based alternative. The Betz Limit or Betz's Law has been used to measure the production of electricity [14], [17].

B. Financial results

The annual revenue was measured using the calculated amount of energy (462,291 kWh and 398,536 kWh) based on the commercial power tariff in the United Kingdom. The industrial price of energy per unit has been set at 0.144 British Pound (GBP), but the first scenario involves 66,570 British Pounds (GBP), and the second scenario includes 57,389 British Pounds (GBP) [18].

The train finishes its acceleration at 17.1 and maintains the same pace until the 51st second. Deceleration begins just after the 51st second, and the train begins to slow down. The train begins to exit the tunnel at the 56th second.

Table 3.1. Generated electricity calculation charts for the first and second scenario, respectively [19].

Total Power (Wh/1 pass)	3,210	15 Turbines/set
Total Power (Wh)	64,207	A train in three minutes
Total Power (kWh/day)	1,541	24 Hours
Total Power (kWh/annum)	462,291	300 days/year

Total Power (Wh/1 pass)	2,768	3 Turbines/set
Total Power (Wh)	55,352	A train in three minutes
Total Power (kWh/day)	1,328	24 Hours
Total Power (kWh/annum)	398,536	300 days/year

C. Recommendations

- A prototype of one of the metro turbines should be created in order to measure and define the potential of electrical energy generation in a real-world application.
- For undergrounds, the capacity of airflow to generate electrical energy is beneficial.
- There is a lot of scope for producing electrical energy from off-shore and on-shore applications around the world, including in the United Kingdom.
- Testing and defining the exact performance and suitability of next-generation jet-style turbines is critical.

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