Potential Analysis of Kinetic Energy Harvesting System from National Highways of Pakistan

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Abstract

Energy technology and management is one of the most challenging problems of today's world. Continuous use of natural reservoir increases global warming and earth's average temperature as world energy consumption will rise up to 50% by 2030. Currently, Pakistan has a short fall of approximately 4000 to 5000MW and the country urgently requires solution to ongoing energy problems, especially solutions which help to protect our environment. There are many techniques and approaches available to combat energy crisis; one relatively less explored approach is to exploit kinetic energy of vehicles on our road network. This paper presents an approach to exploiting kinetic energy of vehicles to generate useful energy. A model based on kinetic energy simulation is presented and discussed in this study; kinetic energy is extracted from speed breakers commonly found on our road network.

Key Words: Kinetic energy, Green energy, Highway potential

1. Introduction

The idea of converting speed breaker energy into electricity is discussed by Zhu and Beeby in [1] which was a new addition in renewable energy field. When a vehicle moves on a speed breaker, its energy is wasted by vehicle breaking mechanism. This wasted potential can be extracted by specially designed speed breakers which are called energy harvesting devices [2].

The world is facing energy and environment crises [3]. The current trends of producing energy from fossil fuels may increase ambient temperatures substantially. Energy harvesting through road speed breakers poses no environment threat with additional advantage of its non- dependence on seasons. This paper presents a method of extracting kinetic energy from speed humps on roads with a calculation of total energy potential on our road network. In this study, a specially designed metal slab is connected with a gearbox by means of shaft and mechanical arms in order to extract energy. As there are a lot vehicles moving on our roads, we can harvest a lot of energy which is otherwise lost [4]. The energy exploited this method is free of cost if harvesting mechanisms are placed on different points on our roads [5].

Figure 1 shows the arrangement of system. The figure explains how kinetic and potential energy is converted into electrical energy with speed breaker which works as a prime mover. When a vehicle passes over the ramp, it gets pressed by force exerted from vehicle, the breaker converts this energy into rotational energy and delivers it to generator; thus producing electricity. The charge generated through this mechanism is stored in battery for back up purpose, an inverter is used to convert power into AC and can subsequently be fed into national or local grid.

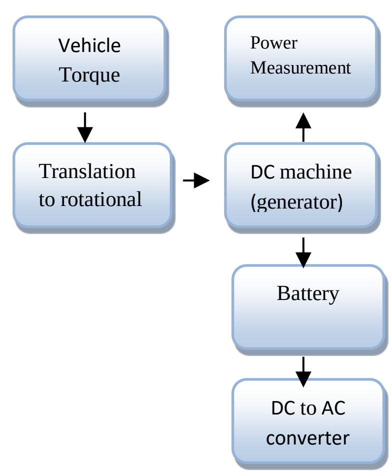

Figure 1: Block representation

2. Physical Model

The method of extracting kinetic energy is important as this study is attempting to exploit as much potential as possible. The proposed approach of kinetic energy harvesting (KEH) is shown in fig. 2.The slab is connected with the generator through gearbox and flywheel. The implementation of this approach can produce enough energy to power high way electric bulbs. A series of such energy harvesting devices placed on a road will add up to improve overall efficiency of the system. The following model developed in 3D CAD system shows the approach structure. The National highway authority (NHA) indicate that there can be as many as 99 toll plazas on our road network where this system can be applied [6].

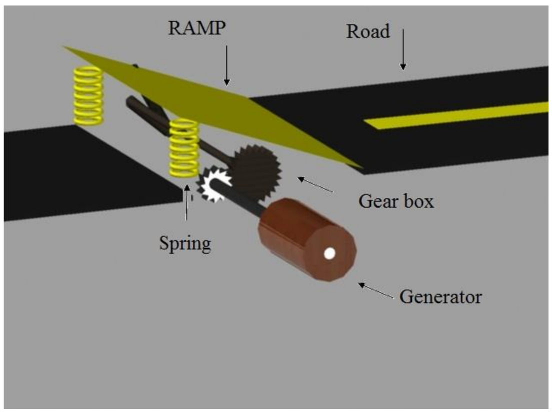

Figure 2: Physical model

3. Simulation

Model Simulation analysis is done by using different subsystem units in Simulink model of MATLAB software. Combination of all systems is shown in Figure (Fig: 3) different equations are drives and implement by math functions and predefined function block. We can input mass in Kg and movement arm in meter to calculate the power produce. The simulation is developed using SIMULINK model; power generated is simulated at different shaft speed values.

Input of a whole of system is vehicle weight. Torque produce is depending on tilt angle, applied force and movement of arm. First block convert the applied weight into torque T. After torque is found second task is to calculate the total velocity produce in a shaft which is connected to the gearbox also called driven shaft. 2nd Block calculates the velocity and torque of both shafts of gearbox. Gearbox ration define the difference in velocities

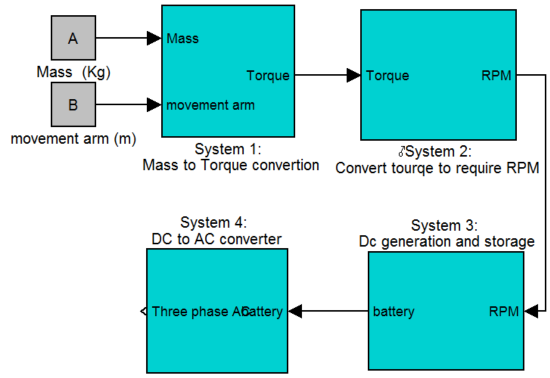

Figure 3: Simulink model

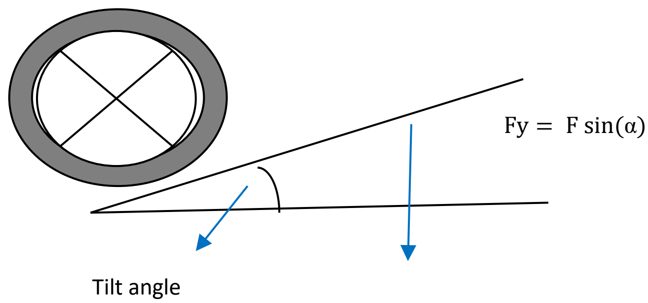

Figure 4: Ramp Inclined

$$T = r \times F \quad (1)$$

$$= r \times m \times g \times F.\sin(\alpha) \quad (2)$$

In 3rd block DC generators is used for power production. Output shaft of gearbox is connected to the DC generator which provides the mechanical power to generator. Electricity generated is proportional to the input velocity. Produced voltages are store in batteries by connecting charge controller and regulators. Final block four converts these DC voltages into AC voltage by inverter. Connecting batteries in series and parallel combination describe the AC voltage and power for three phase conversion three phase inverter is used and pulses are provide by pulse generator. It defines the frequency of three phase AC voltages which is set to 50 Hertz for Pakistan. Complete simulation is shown in figure (fig: 13). Result generated by each block is explained following.

To meet with require velocity gearbox is used having two shaft base and follower. Ratio between them decides the difference of input and output speed and torque. According to the gearbox kinematics following are the equations.

$$r_f \cdot \omega_f = r_b \cdot \omega_b \quad (3)$$

$$\sum T = r \times F = m\left(r \times \frac{dv}{dt} + \frac{dr}{dt} \times v\right) \quad (4)$$

Here, r and ω are radius and angular velocity. T is torque and f & b denotes base and follower of gear box. Suppose a vehicle of 1200kg is passing through the system then the velocity and torque produce is shown in following response,

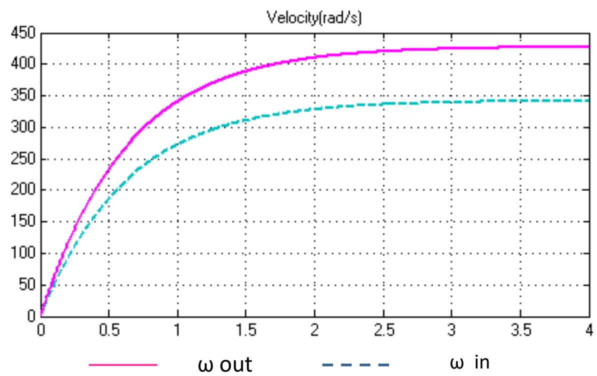

Figure5: Velocity response

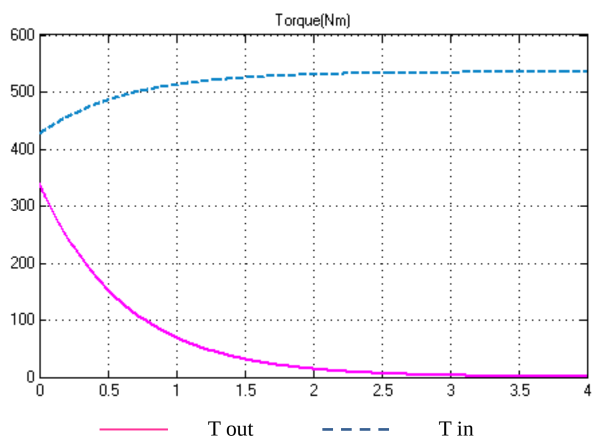

Figure 6: Torque response

When suitable velocity is received through gearbox second step is to generate power. DC generator is used for power generation. Separate 12V is providing for excitation. Velocity is provided into the input of Dc generator (fig. 5). Voltage produce is proportional to the input velocity. Current and voltage block are used to measure values and product block give us the final power generated. Dynamic states equations for DC machine are listed below.

$$Va = Ra.ia + La\frac{dia}{dt} + E \quad (5)$$

$$Vf = Rf.if + Lf\frac{dif}{dt} \quad (6)$$

I_a,$V_a$are armature current and voltage. I_f, V_f represent field. R, E, and L are referred to resistance, Back EMF and inductor of the Dc machine. When angular velocity is fed into generator then it start moving and generate electric power according to the above equations. Its power curve is shown in following figure (fig: 7).

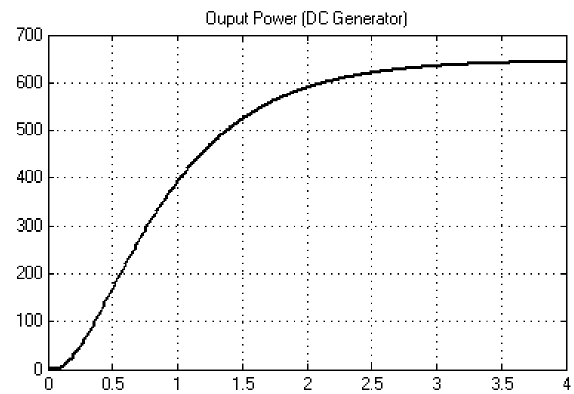

Figure 7: Generator power response (Watt)

DC generated power is stored in batteries according to demand of AC power then we can utilize it where we need [8]. Research shows the conversion of DC to three phase AC power. In MATLAB DC voltage source is used to describe voltage of battery and three phase pulse inverter is used for conversion. Pulses are provided from PWM generator.

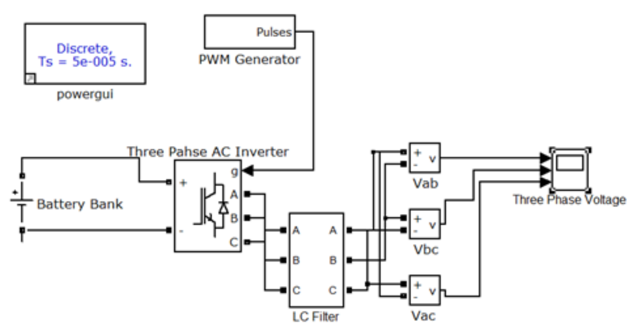

Figure 8: Three Phase inverter

V_{ab} ,V_{bc}, V_{ac} are three phase voltages. Scope draw the response of each voltage and simultaneous response is shown in figure (Fig: 9) different color represent three phase voltages. AC 220 V is obtained from three phase bridge inverter with pulse frequency 50Hz. Total power is depend on the battery capacity and rating.AC voltage across each phase and instantaneous time is calculated by following equations.

$$Vab = \sum_{n=1,3,5...}^{\infty} \frac{4Vin}{n\pi} \sin\frac{n\pi}{2} \sin\frac{n\pi}{3} \left(n\omega t + \frac{n\pi}{6}\right) \quad (7)$$

$$Vbc = \sum_{n=1,3,5,...}^{\infty} \frac{4Vin}{n\pi} \sin\frac{n\pi}{2} \sin\frac{n\pi}{3} \left(n\omega t - \frac{n\pi}{2}\right) \quad (8)$$

$$Vac = \sum_{n=1,3,5...}^{\infty} \frac{4Vin}{n\pi} \sin\frac{n\pi}{2} \sin\frac{n\pi}{3} \left(n\omega t - \frac{7n\pi}{6}\right) \quad (9)$$

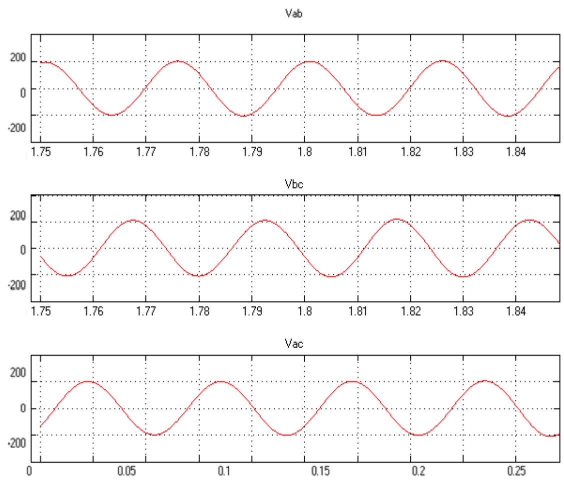

Figure 9: Three Phase voltages

Flywheel energy dissipation response can also be plot using MATLAB. By adjusting deceleration simulation can find the energy dissipation time. Following figure illustrate the flywheel response.

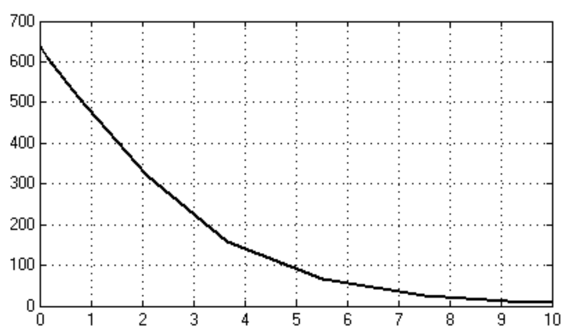

Figure 10: Energy dissipation (Watt/s)

4. National Highway Statistics

According to the survey report of National highway authority (NHA) Pakistan has 99 toll plazas which are located on motorways road and national highways. Toll plazas detail information is provided in table 1.

Toll plaza is the place where it is necessary for vehicle to reduce its speed. Important factor for kinetic energy harvesting is the frequency of vehicle. Power curve response shows that generator take two seconds for delivering maximum power and whole process need total five seconds. Following table shows the transportation statistics on national highway of Pakistan from each station.

Table 1: NHA Network Toll plaza detail

Sr. No	Network	No. of Toll Plazas
	Highways	
1	Balochistan	12
2	Punjab	34
3	KPK	7
4	Sindh	18
	Sub-total	71
	Expressways	
5	Pindi Bhattian –Faisalabad Motorway (M-3)	3
6	Lahore –Islamabad Motorway (M-2)	18
7	Islamabad –Peshawar Motorway (M-1)	7
	Sub-total	28
	Total	**99**

Table 2: Toll plaza average transportation in a day

Vehicle	Average transportation in a day
Cars	12,755
Vans & Suzuki's	3,580
Trailers	1,842
Trucks	3,934
Busses	2,377

5. Result and Calculations

Total power can be calculated by using following formula

$$p = \int_0^t P\,dt \quad (10)$$

= 380 + 590 + 630 + 640

= 2240 W

= 2.24 KW

And average power is calculated as,

$$p = \frac{1}{T}\int_0^t P\,dt \quad (11)$$

= ¼ (2240) W

= 560W

Continuous transportation can produce energy of 560Wh Daily maximum production can be found as,

= 560W x 24h

= 13.4KWh

Simulation give clear results regarding to power produce, velocity and torque response. One vehicle with weight of nearly 1200Kg produces power of 2.2KW. Vehicle front and back tires need approximately 2 second each and generator sustain it energy using flywheel Summarize total power produce by different vehicle weight is shown in figure.

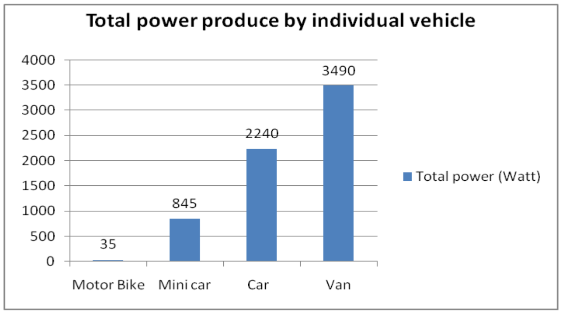

Figure 11: Power production from single vehicle

NHA have large transportation capacity as describe in table. Following figure shows the per day potential from single toll plaza. Research deal with the system design for car only. KEH method extract large amount of energy which can be comparable with wind turbine generation. It can also save the primary energy consumption and reduce global warming.

Average 13KWh electricity can be extracted from single unit in a day. By implementing this system on all over the toll plaza situated on NHA then approximately 3000MW electric power can be extracted in day.

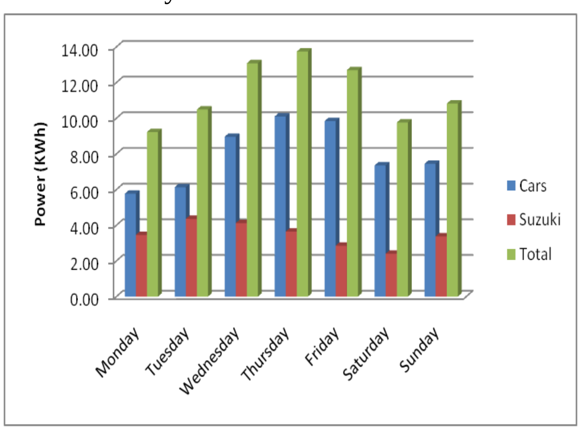

Figure 12: Daily production from single unit

Rotational kinetic energy can be found with the help of flywheel specification.

$$K.E = \frac{1}{2} I\omega^2 \qquad (12)$$

And

$$\text{Inertia}(I) = mr^2 \qquad (13)$$

Flywheel has a weight of 5kg with 20cm diameter (0.1m radius) putting the value in equation inertia become 0.5Kg m^2. Form figure (fig 5) output velocity is 450 rad/s putting these values to equation of K.E

I = 0.05Kg m^2

$$\text{Input } K.E = \frac{1}{2}(0.05)(450)^2 \quad = 5062 \text{ Joules}$$

Corresponding electrical power produce from DC generator is shown in figure (Fig: 7) which is 650W.

Output energy = Power × Time

= 650W × 1s

= 650 Joules

Efficiency of whole system is calculated as,

$$\text{Efficency } (\eta) = \frac{\text{ouput}}{\text{input}} \times 100 \qquad (14)$$

= 12.84%

6. Conclusion

Renewable energy utilization is one of the solutions of our ongoing energy crisis. Kinetic energy harvesting is comparatively less exploited area in renewable energy solutions. This paper has presented an approach to extract kinetic energy from moving vehicles on road by applying kinetic energy harvesting methodology on road humps. It is, however, pointed out that this mechanism should be applied carefully, especially site selection is the most important issue as less number of vehicles can not produce enough energy and may cause lower system efficiencies. This approach can produce a lot of energy if implemented on points where there is enough number of vehicles passing through the system applied.

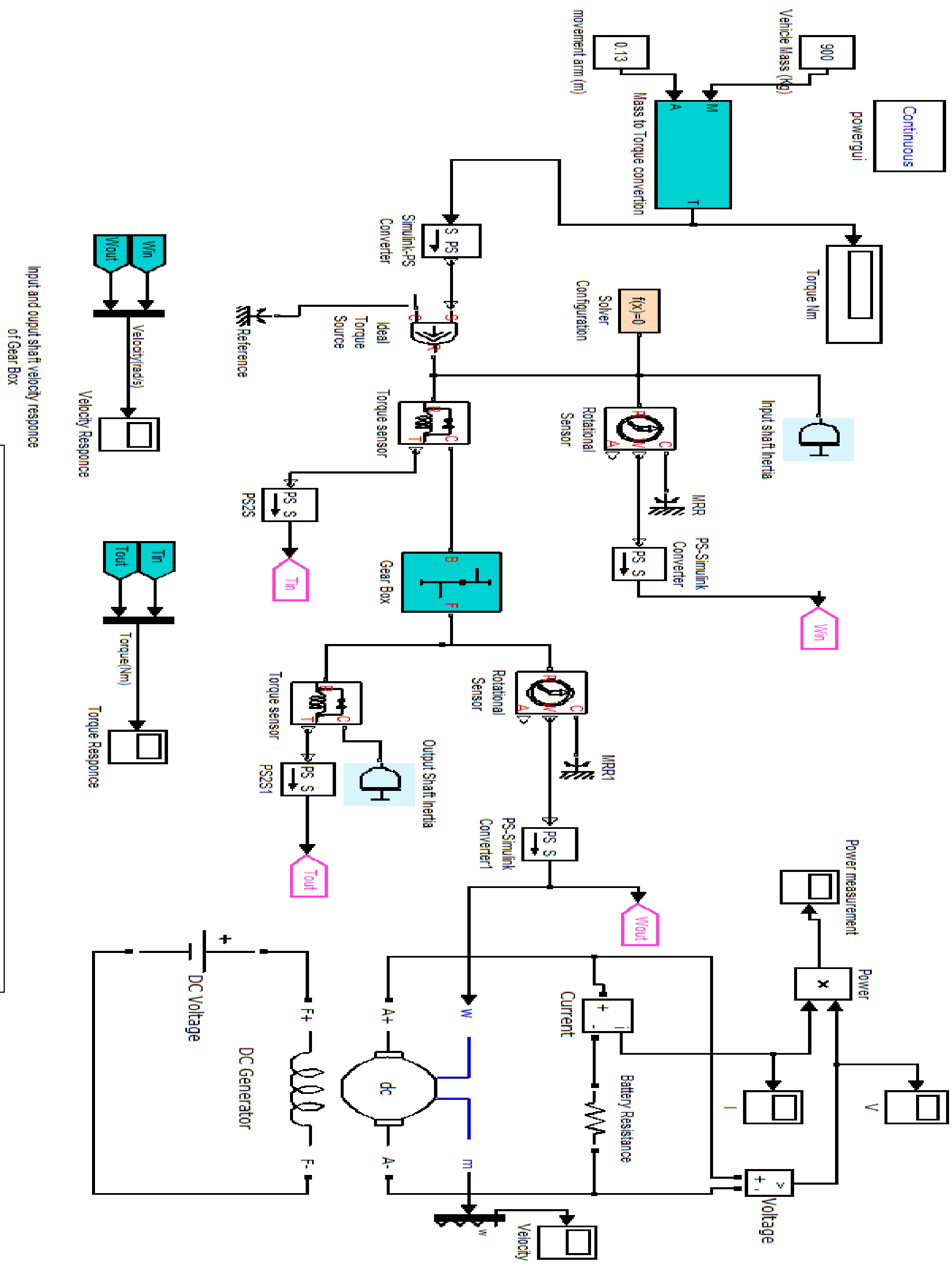

Figure 13: Simulation Model

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