Design and Concept of Renewable Energy Driven Auto-Detectable Railway Crossing Systems in Bangladesh

Iftekharuzzaman[1], Susmita Ghosh[1], Mohammad Khairul Basher[2], Mohammad Aminul Islam[3], Narottam Das[4, 5], and Mohammad Nur-E-Alam[2*]

[1]American International University-Bangladesh, 408/1, Kuratoli, Dhaka 1229, Bangladesh
[2]School of Science, Edith Cowan University, 270 Joondalup Drive, Joondalup, WA 6027, Australia
[3]Department of Electrical Engineering, Faculty of Engineering, University of Malaya, 50603 Kuala Lumpur, Malaysia
[4]School of Engineering and Technology, Central Queensland University Australia, Melbourne, VIC 3000, Australia
[5]Centre for Intelligent Systems, School of Engineering and Technology, Central Queensland University, Brisbane, QLD 4000, Australia
* Corresponding: m.nur-e-alam@ecu.edu.au

Supplementary information

Servo Motor size: Inertia is the most important factors in sizing a servo motor. Servo motor inertia is used as a measure of how well the motor is capable to control the acceleration and deceleration of the load (boom gate). The performance of the motor and also the operational cost is totally dependent on proper servo motor sizing. In the Ref [1] it is given that about 96% cost of the servo motor is electricity.

Fundamental equation of Inertia(J)

$$J=\iiint \rho(x,y,z)(x^2+y^2)dxdydz \text{ - } (1)$$

Where, ϱ (X, Y, Z) is the mass density at the point of (X, Y, Z). The boom gate structure and cross section area is drawn in Figure S1:

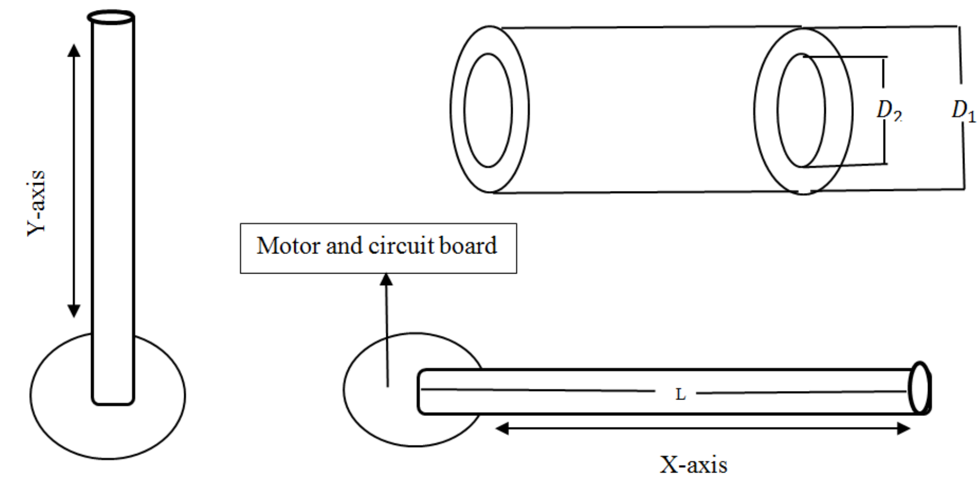

Figure S1: Boom gate structure and cross section area of boom gate.

Wight of the boom gate is = Volume(v) × material density (ϱ) and Mass (m)= weight(w) / gravity(g)

Boom gate will be hollow cylindrical made by aluminium metal. Density of aluminium is = 2800 kg/m^3

Motor inertia in x axis and y axis for boom gate, $J_{(x,y)}$= J_w is

$$J_x = \frac{1}{8}m\left({D_1}^2 + {D_2}^2\right) \text{ and } J_y = \frac{1}{4}m\left(\frac{{D_1}^2+{D_2}^2}{4} + \frac{L^2}{3}\right) \text{- - - - - - - - - - - - - - - - (2)}$$

Here, boom barrier mass = m, inner diameter =D_1, outer diameter =D_2 length=L, Density = ϱ,

Inertia of load (boom gate) value converted to motor shaft,

$$J_L = J_1 + G^2 + (J_2 + J_w)(Kg - m^2) \text{- (3)}$$

Here, J_L = motor shaft conversion load inertia, J_1 =Gear inertia on motor side, G=gear ratio Z_1/Z_2, Z_1= number of gear teeth on motor side, Z_2=number of gear teeth on load side, J_2=Gear inertia on load side, J_w= load inertia.

Load Torque, when external force rotating load,

$$T_w = F.\frac{D}{2} \times 10^{-3} \text{ N-m - (4)}$$

Here, T_w= torque due to external forces, F= external forces, D = diameter

Torque of a load value converted to Motor shaft,

$$T_L = T_w \times \frac{G}{\eta} \text{ N-m - (5)}$$

T_L= motor shaft conversion load torque, T_w= load torque, G= gear ratio Z_1/Z_2, η = gear transmission efficiency. Rotational speed vs acceleration timing diagram is shown in Figure S2.

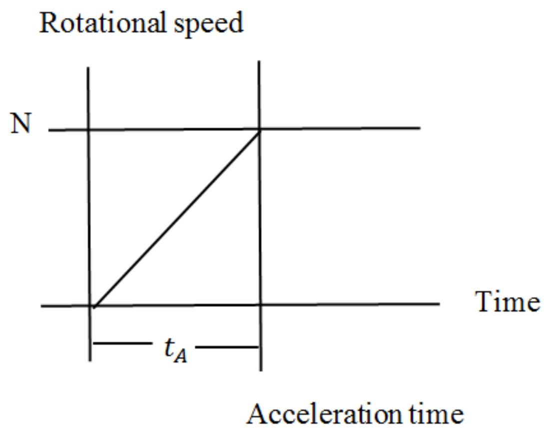

Figure S2 : Rotational speed vs acceleration timing diagram.

Acceleration/Deceleration torque,

$$T_A = \frac{2\pi N}{60 t_A}\left(J_M + \frac{J_l}{\eta}\right) \text{ (N-m)} \text{-----------------------------} (6)$$

N= rotational speed (r/min),t_A= Acceleration/Deceleration time, J_M= Motor inertia, J_l= load inertia, η = Gear transmission efficiency. Figure S3 presents the trapezoidal motion profile.

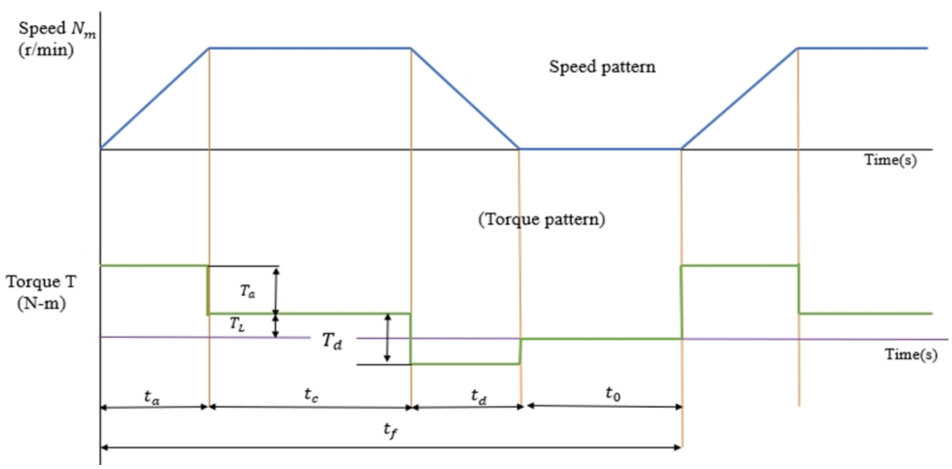

Figure S3: Trapezoidal motion profile.

Effective load torque

$$T_{rms} = \sqrt{\frac{(T_a+T_L)^2 \times t_a + {T_L}^2 \times t_c + (T_d+T_L)^2 \times t_d}{t_f}} \text{ --------------------} (8)$$

Here, T_A= acceleration torque, T_L= load torque, t_a= acceleration time, t_c=constant time, t_d= deceleration time, t_f= positioning time, T_d = total torque during decceleration

The motor's RMS current is given below,

$$I_{RMS} = \frac{T_{RMS}}{K_T} \text{ - } (9)$$

I_{RMS}= RMS current, K_T= torque constant, T_{RMS}= RMS torque

The motor's power dissipation is given by the following equation:

$$P_D = {I_{RMS}}^2 \times R_T \text{ - } (10)$$

Where, P_D= power dissipation, ${I_{RMS}}^2$ = RMS current, R_T = motor terminal resistance.

As it is a capstone project, a 12V PV panel is used to charge enough the battery and all equipment to run with maximum 5V only. There is no need to take any extra precaution during night time as the IR sensor is capable to work properly work at dark or night. The distance from gate to IR sensors should be around 50 m because the fastest train in Bangladesh is approximately 83 m/s. IR sensor output is in millisecond (ms). Here, there are two IR sensors for incoming and outgoing. The proposed model for single track. For two track four IR system can be implemented.

Hybrid power generation combination possibilities

In this section, we have provided more simulated results of various combination of hybrid power generation systems obtained using Homer Pro package. These combinatorial approach of desiging multi-power generating components based power system will enable to design and build self-sustainable and even off grid connected railway level crossing or small area susbstation for Bangladesh railway.

i) PV and combination

The output power of the PV panel (24 hours a day all year round) and several possible hybrid power generation systems are ploted in Figure S4. From the output results (simulated by HOMER Pro) it can seen that it is possible to avoid complete dependency on PV system, which opens the possibility of having pover from other source like wind turbine while the sunlight is not available.

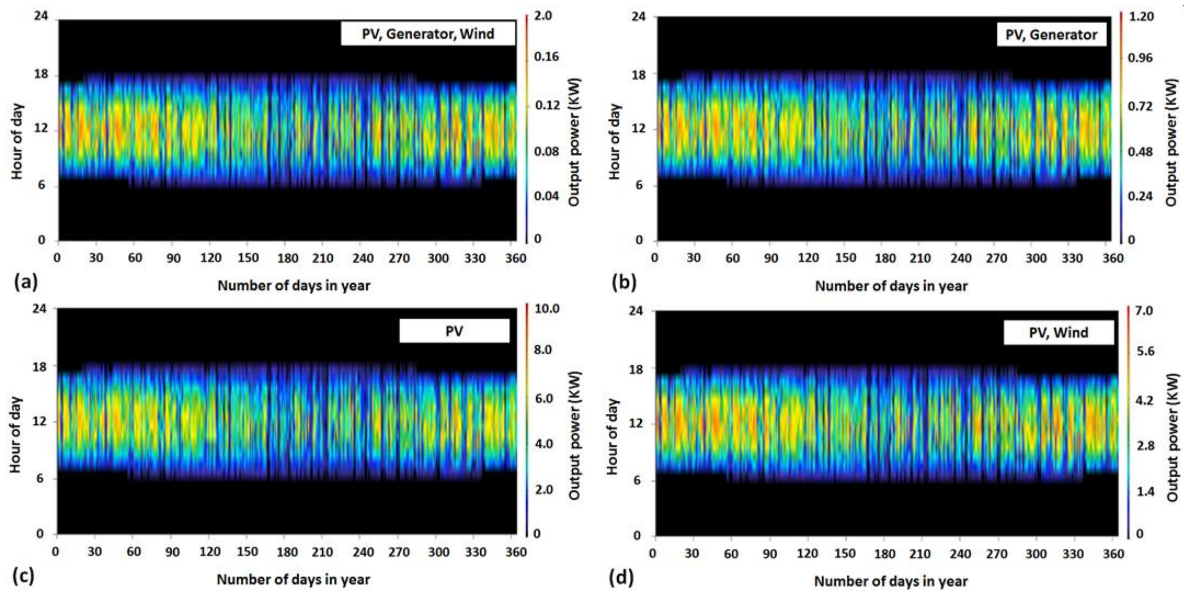

Figure S4: Comparison of power output for PV and PV based hybrid power generation systems.

ii) Wind and combination

From the figure S5 it can be seen that wind turbine power output (kW) is against the specific range of wind speed (m/s). In this calculation, we have considered Generic 3 kW wind turbine.

PV, Generator, and Wind (a) = 1

Wind, and Generator (b) = 2

Number of turbine is also given in Table 2.

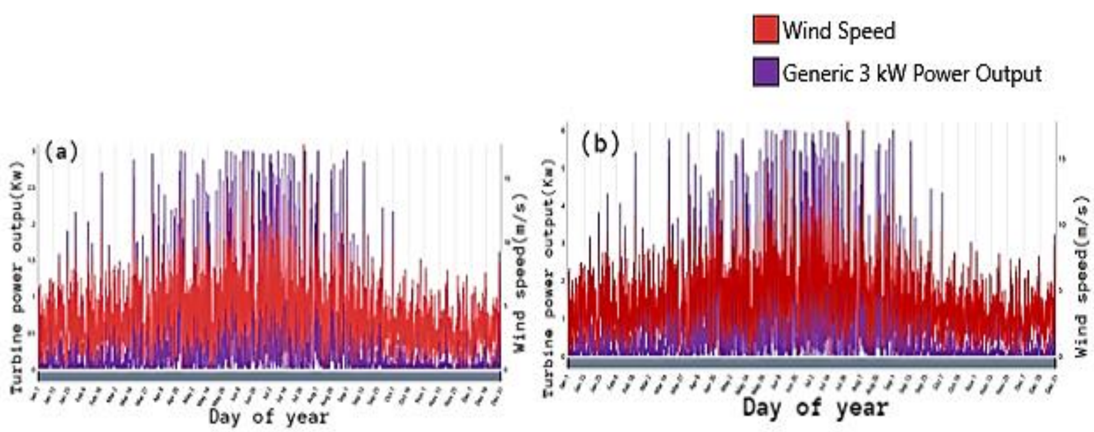

Figure S5: Power output of hybrid generation systems which is mainly ploted based on the wind speed; (a) PV, Generator, and Wind and (b)Wind, and Generator systems

iii) Generator and combination

In this section, we have presented the possible obtainable power out in the systems if combines with dissel generator. Note that to use a generator for power, we have to always keep in mind about the cost of the fuel and also the amount of pollutant gas emission like Carbon dioxide (CO_2).

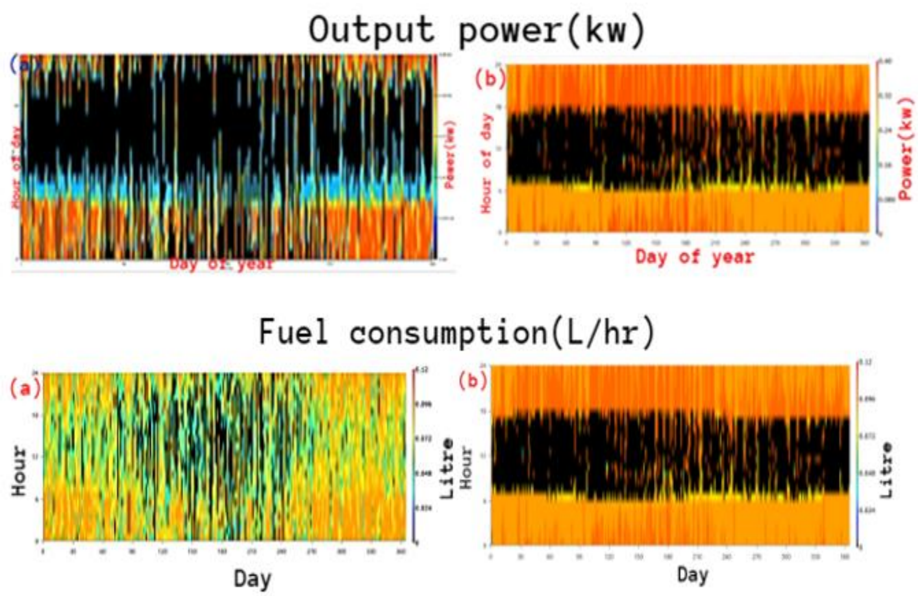

Figure S6: Generator output power and fuel consumption in the different hybrid systems; PV, Generator, and Wind (a), and PV, and Generator (b).

We have performed the scheduled for sensitivity analysis of the winter season shown in Figure S7.

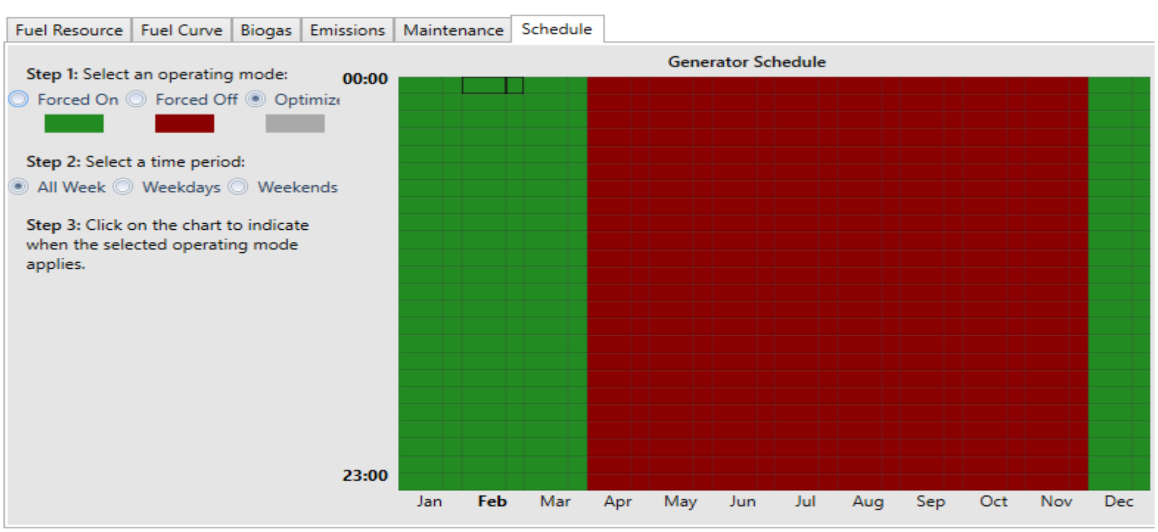

Figure S7: Generator scheduled for the winter season

We have analyzed gas emissions to the environment by the generator. Figure S8 is shown gas emission to the environment in kg/year.

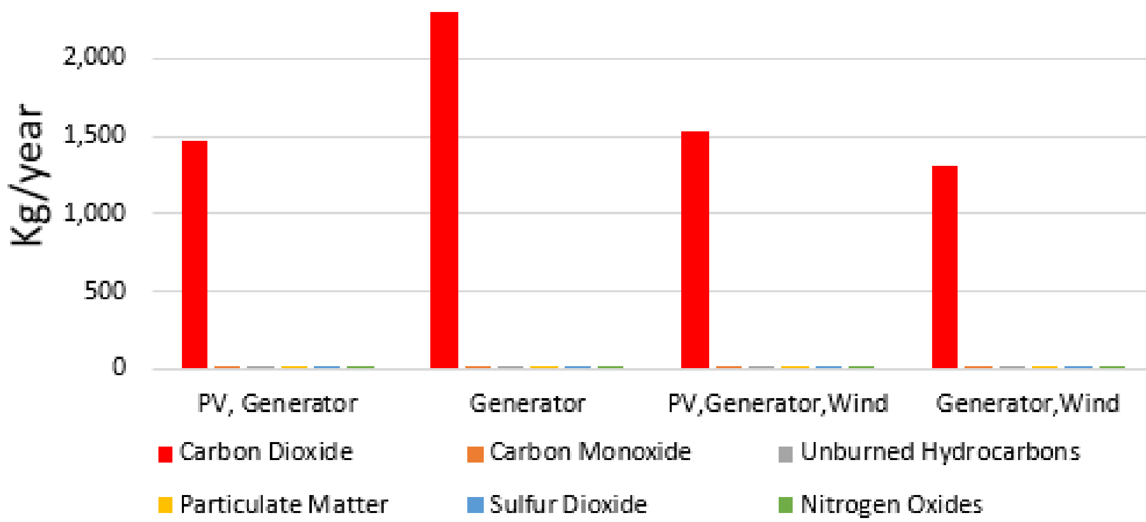

Figure S8: Pollutant gas emission in a different system.

From the overall investigation we always like to avoid the use of dissel generator in our hybrid power generation systems for this project.

Power converter control and power management strategy

A bidirectional converter system has been used to perform the power converter control and power management process, as detailed in the Refs [2].

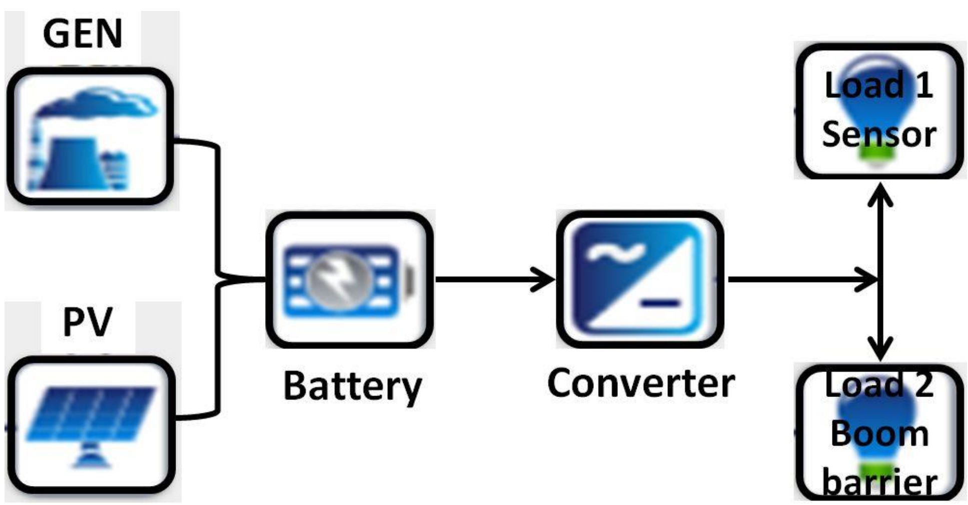

Figure S9: Schematic of power converter control and power management process by using a bidirectional converter system.

PV is the main power source for our level crossing system. However, if in any unforeseen reason, PV system is failed to provide enough power to the battery then generator will be started automatically to feed in the battery. The converter will convert the DC to AC power and provide the power to the load 1 and 2 (sensor and boom barrier). In this system generator is used mainly as a back-up power supply and support.

References

1. Wilfried Voss, “A Comprehensible Guide to Servo Motor Sizing”, Chapter 2, Page 4, (2007). ISBN: 978-0-9765116-1-8.

2. Podder, A.K.; Supti, S.A.; Islam, S.; Malvoni, M.; Jayakumar, A.; Deb, S.; Kumar, N.M. Feasibility Assessment of Hybrid Solar Photovoltaic-Biogas Generator Based Charging Station: A Case of Easy Bike and Auto Rickshaw Scenario in a Developing Nation. *Sustainability* **2022**, *14*, 166. https://doi.org/10.3390/su14010166.