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Article

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

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Abstract: Bangladesh's railway system mostly uses typical manual railway crossing techniques or boom gates through its 2955.53 km rail route all over the country. Accidents frequently happen at railway crossings due to the lack of quickly operating gate systems, and to fewer safety measures at the railway crossing as well. Currently, there are very few automatic railway crossing systems available (without obstacle detectors). Additionally, all of them are dependent on the national power grid, without a backup plan for any emergency cases. Bangladesh is still running a bit behind in generating enough power for its consumption; hence, it is not possible to have a continuous power supply at all times all over the countryside. We aim to design and develop a smart railway crossing system with an obstacle detector to prevent common types of accidents at railway crossing points. We use two infrared (IR) sensors to operate the railway crossing systems, which are controlled by an Arduino Uno. This newly designed level crossing system is run with the help of sustainable renewable energy, which is cost-effective and eco-friendly, and applied under the national green energy policy towards achieving sustainable development in Bangladesh as a part of the global sustainable goal to face climate change challenges. We have summarized the simulated the results of several renewable energy sources, including a hybrid system, and optimized the Levelized Cost of Energy (LCOE) and the payback periods.

Keywords: railway crossing; obstacle detection; renewable energy; hybrid system; sustainable development

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1. Introduction

The railway system is one of the largest parts of the transportation network in Bangladesh. The length of the railway route in Bangladesh is more than 2955 km, and soon it will increase after the completion of new train track constructions. Currently, the railway network needs to maintain 1540 level crossings (where over 207 level crossings are on the highways) to confirm the safe operation of mass transport. There are 2541 level crossings across the country, of which only 1400 are well maintained. Out of those 1400 level crossings, around 500 are operated with the help of a properly trained operator. More than 70% of authorized level crossings do not have any dedicated operator/manpower. In addition, there are 1141 unauthorized level crossings as well, which can be considered open death traps [1]. However, there are electronically controlled level crossings (i.e., available mostly in the city areas), but all of them are dependent on the national power grid, and there is no alternative backup for any kind of power disruption. More than 85% of the level crossings in Bangladesh are not safe, and about 89% of the casualties of rail accidents mainly happen due to unprotected rail crossings and the rate is increasing day by day [1,2]. Railway level crossings' traffic is maintained by a trained person. Busy level crossings are operated by lifting barriers. Railway safety is one of the most crucial aspects in Bangladesh, and the government is also very active and taking on new projects to reduce the number of unwanted accidents by developing a secure transportation system, including train tracks, and safe level crossings. Many people have died in level crossing accidents of various types that happen frequently in Bangladesh, as it is not possible to stop the train instantly due to the mechanism of the train engine [2]. So, an automatic railway level crossing technology system is greatly needed to reduce accidents [2–6]. There are some relevant studies conducted related to railway level crossing and safety measures worldwide, including smart level crossing designs, surveys, and case studies, as well as the advantages and disadvantages of having automatic railway level crossings available in the literature [7–18]. A research group in Florida, USA has dedicated time and effort to conduct diverse research on highway-rail grade crossings (HRGCs) in the state of Florida. They have studied and reported different areas related to the HRGCs, including the holistic analysis of train-vehicle accidents at HRGCs, accident-hazard prediction models to identify the most hazardous HRGCs that require safety improvements, deployment of autonomous trains (AT) in rail transportation, and the ways of reducing traffic delays at HRGCs towards improving the sustainability of rail transportation systems [7–10]. Other studies are found to report the possible ways HRGCs' safety can be improved for the US highway and railway transportation network. Those reports focused on the multi-criteria methodology for prioritizing highway-rail grade crossings for grade separation or other major improvements, as well as multi-objective resource allocation [11,12]. Arduino and ultrasonic sensors-based automated railway gate control systems have been reported for the Indian railway system [13,14], whilst another work has been conducted for the Indian railway system based on the global positioning system (GPS). However, the drawback of this proposed system is its need for continuous internet availability [15]. Dent, M. et al. have reported on introducing automated obstacle detection to British railway level crossings. They have mentioned that obstacle detection can simultaneously help to improve the safety of level crossings and reduce the costs associated with level crossing operators, lowering the waiting times for road vehicles and pedestrians [16]. A recent study developed an optimization method (a numerical algorithm optimization) to reduce the time lost at the railway level crossing per train trip. The study claimed that at least 50% of the time lost at railroad level crossings can be reduced and higher safety and capacity can be ensured at railway level crossings [17]. Very few works have been conducted theoretically and concept-wise only to improve the railway level crossing safety measure in Bangladesh [19–21]. However, more comprehensive research and practically employable prototype development are still required to find the feasibility of implementing the real-life auto-detectable and smart level crossing to reduce unwanted calamities in Bangladesh. From that point of view, our work significantly carries merit for future sustainable transportation systems, as this proposed model is self-site energy generated driven and eco-friendly. Internet of Things (IoT) based technology such as ultrasonic sensors, vibration sensors, programmable logic control, and infrared sensor automatic railway crossing systems have been reported to be commonly used in these types of automatic railway level crossings [7,18,21–27]. The Digital Twins (DT) concept (that works based on data derived from different sources to develop a digital representation of products, processes, machines, or components), has recently become an attractive alternative for various applications, such as industrial management, supply chain, production control, smart manufacturing, and internal transport system [28–32]. It is worth noting that DT, along with the Internet of Things (IoT), are an interesting option to manage the data processing for automatic railway level crossings, which will be explored in the near future with the scope of our research project. Though some research considers using solar energy, most of them do not care about power source management to confirm continuous power supply to the level crossing points.

The production of electricity in Bangladesh is mainly dependent on fossil fuels, though there are some renewable energy resources in operation to mitigate the power supply demand. According to the Power Development Board's (PDB) reports, in 2019–2020 Bangladesh installed power plants of different types at these proportions: 0.19% renewable energy (solar), hydro (1.13%), gas (53.86%), furnace oil (27.18%), diesel (6.33%), coal (5.62%), and power import (5.69%). Total net energy generation in the fiscal year 2019–2020 from renewable energy was only about 0.07% [33]. However, the current power scenario in Bangladesh is different. Bangladesh is experiencing a severe power crisis every day [34]. In this current circumstance, renewable energy sources are needed most to overcome the power shortage problem. It is time to develop self-sustained, smart, advanced, and automatic railway crossing systems powered by renewable power generation, of either solar or hybrid systems. In this research, we designed an automatic railway crossing system to be operated by the energy which is generated from a combination of multiple energy resources such as solar, generator, and wind turbine. As it is a 24 h running system, we used batteries as the main power source of the control system. The generator is used for the non-sunny winter season or on a rainy day, or also in natural disasters where there is no option to use solar and wind energy. We have used an infrared (IR) sensor for fast-detecting response to the main circuit board to operate the functionality of railway level crossings' gates. Section 2 of the paper presents the methodology part that describes circuit simulation where a microcontroller has been used to control the boom barrier's raising and lowering system through programming. Section 3 describes the energy generation system components and results in a different combination system (i.e., hybrid power generation). Section 4 presents the cost analysis followed by a conclusion in Section 5.

2. Automatic Level Crossing System Architecture and Components

2.1. Architecture of the Automatic Level Crossing System

We have designed an automatic level crossing system to prevent accidents, which is operated by renewable energy sources or a combination of renewable energy sources, and the required energy to operate the system can be produced on-site (i.e., close to the crossing level based on the landscape). Figure 1 shows a schematic diagram of the proposed obstacle-detectable automatic railway crossing level along with the circuit diagram of the automatic boom barrier. It can be seen that (Figure 1) the infrared proximity (IR) sensor is placed near the train track at a certain distance from the level crossing. The lithium-ion battery is used as the power source for the IR sensor and boom barrier. The required power to recharge the battery is sourced from renewable energy sources (either single or a combination of multiple sources).

We have used an IR proximity sensor to detect the entry and exit of trains while an Arduino Uno microcontroller has been used to automate the process by using input code. The light-emitting diode (LED) and buzzer were added to the system to provide an indication and activate the alarm when the train is incoming and passing to the level crossing, as can be seen in Figure 1b. In Bangladesh, the maximum speed limit for trains is approximately 83 m/s. Based on the fastest speed limit, the distance between the boom gate and IR sensor should be around 50 m as the IR sensor output is in a millisecond. Here, two IR sensors for incoming and outgoing were considered for the single track, while for the two tracks line four IR systems could be implemented. Figure 2 shows the flowchart of the algorithms that control the indication of trains' arrivals and departures, and this process is continuous. Detailed information about the size of the motor required (how to determine the required motor size) to operate the level crossing systems is provided in the Supplementary Materials.

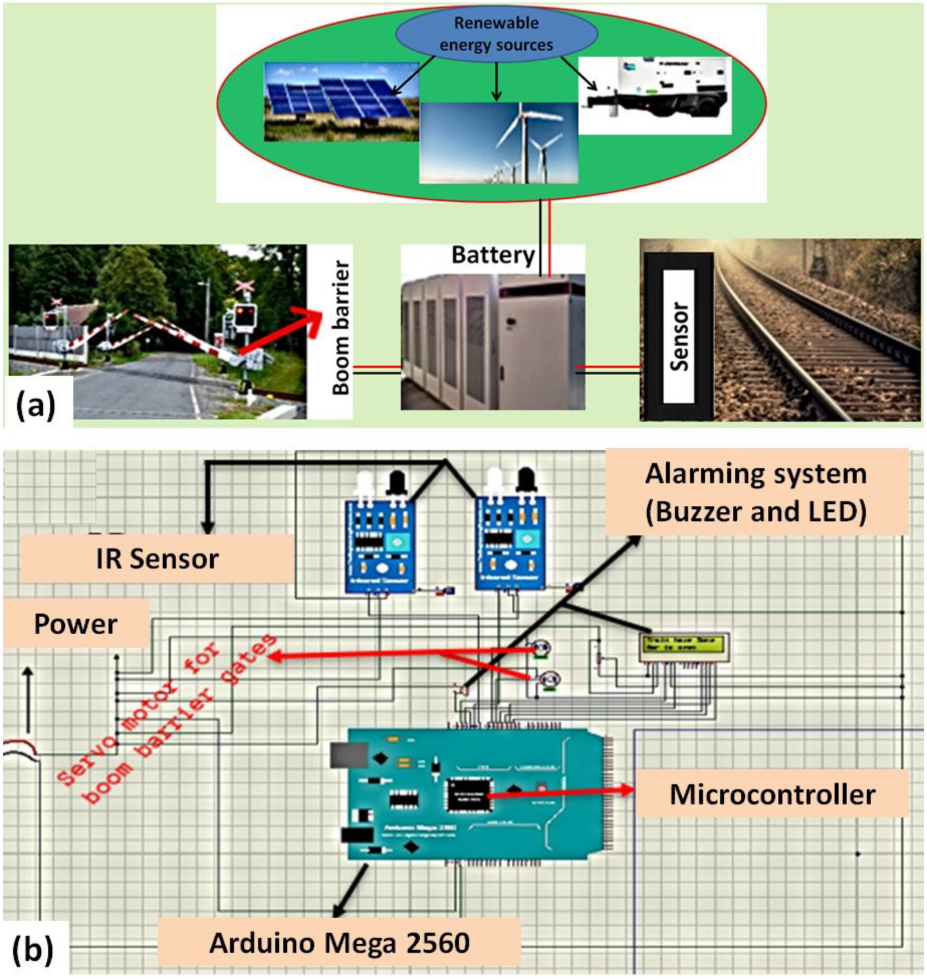

Figure 1. Schematic diagram of the automatic level crossing system with the possible renewable energy sources (**a**), and the circuit diagram (**b**) of the automatic boom barrier.

In this work, we have used Proteus circuit simulation-based software to complete the main circuit design, Hybrid Optimization of Multiple Energy Resources (HOMER, developed by National Renewable Energy Limited (NREL, Boulder, CO, USA)) Pro software for renewable energy, load consumption, etc., and Arduino IDE software for microcontroller coding. We have performed the simulation process using the Homer Pro software with a Photovoltaic (PV) panel, Wind turbine, and Generator. The battery is kept as a power source for the automatic boom barrier and IR sensor because that is necessary to run the system for 24 h continuously. The load consumption of IR sensors is 0.0036 kWh/day, and the boom barrier is 7.2 kWh/day (i.e., 0.300 Kw per hour). Therefore, it is very important to keep a power backup plan to run the system continuously for 24 h.

2.2. Sensor

The sensor is the most important part of this project. At present many proximity sensors are available in the market and infrared proximity (IR) sensor or IR obstacle sensor is one of them. There are two types of infrared (IR) sensors such as active and passive sensors [35]. Active IR sensors act as proximity sensors, and they are commonly used in obstacle-detection systems, while passive infrared (PIR) sensors only detect infrared radiation [36]. The infrared sensors mainly work according to three different laws such as Planck's radiation law, Stephan Boltzmann's Law, and Wein's Displacement Law [37]. Planck's radiation law states that all objects with a temperature above absolute zero emit energy in the form of electromagnetic radiation. IR radiant energy is determined by the temperature and surface condition of an object [38].

$$E_\lambda = \frac{2hc^2}{\lambda^5\left(e^{\frac{hc}{\lambda kT}} - 1\right)} \tag{1}$$

Here, E_λ = energy radiated per unit volume, h = Plank's constant, c = speed of light in vacuum, k = Boltzmann's constant.

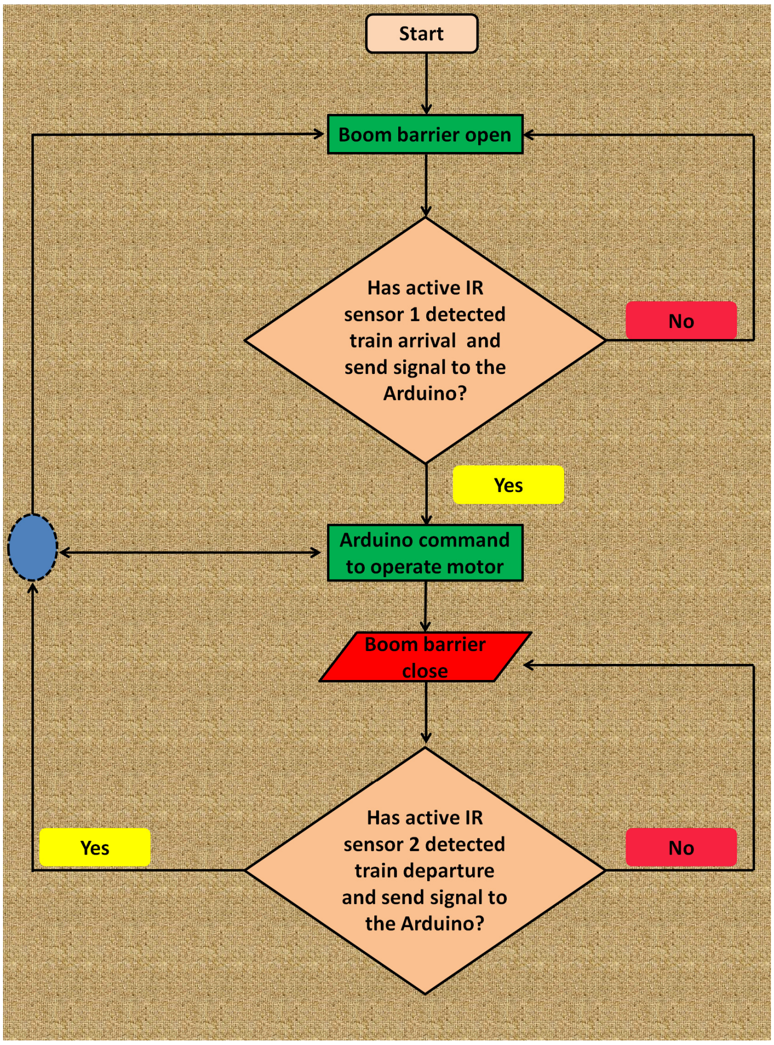

Figure 2. Schematic diagram of the flowchart of the algorithms used to control the automatic level crossing system.

Stephen Boltzmann's equation states that the radiation energy per unit of time from a black body is proportional to the fourth power of the absolute temperature [39].

$$H = \sigma T^4 \tag{2}$$

Here, H = irradiance existence from the surface, σ = Stefan Boltzmann constant, T = temperature.

Wein's Displacement Law states that the wavelength of thermal radiation most copiously emitted by a blackbody is inversely proportional to the absolute temperature of the body [40].

$$\lambda_{max} = \frac{k}{T} = \frac{2898}{T} \tag{3}$$

Here, λ_{max} = maximum wavelength, k = constant, T = temperature. IR sensors are used to detect infrared radiation of 0.75 to 1000 µm. Infrared radiation wavelength is divided into three regions: Near Infrared (NIR) 0.74–1.4 µm, Mid Infrared (MID) 1.4–3 µm, and Far Infrared (FIR) 3–1000 µm [41]. The detection procedure of this technology follows the concept of the blackbody theory to collect the emitting infrared spectrum [42]. The concept of an IR sensor which is used as a proximity sensor or obstacle detector is presented schematically together with the basic operational circuit diagram of the IR proximity sensor (as shown in Figure 3).

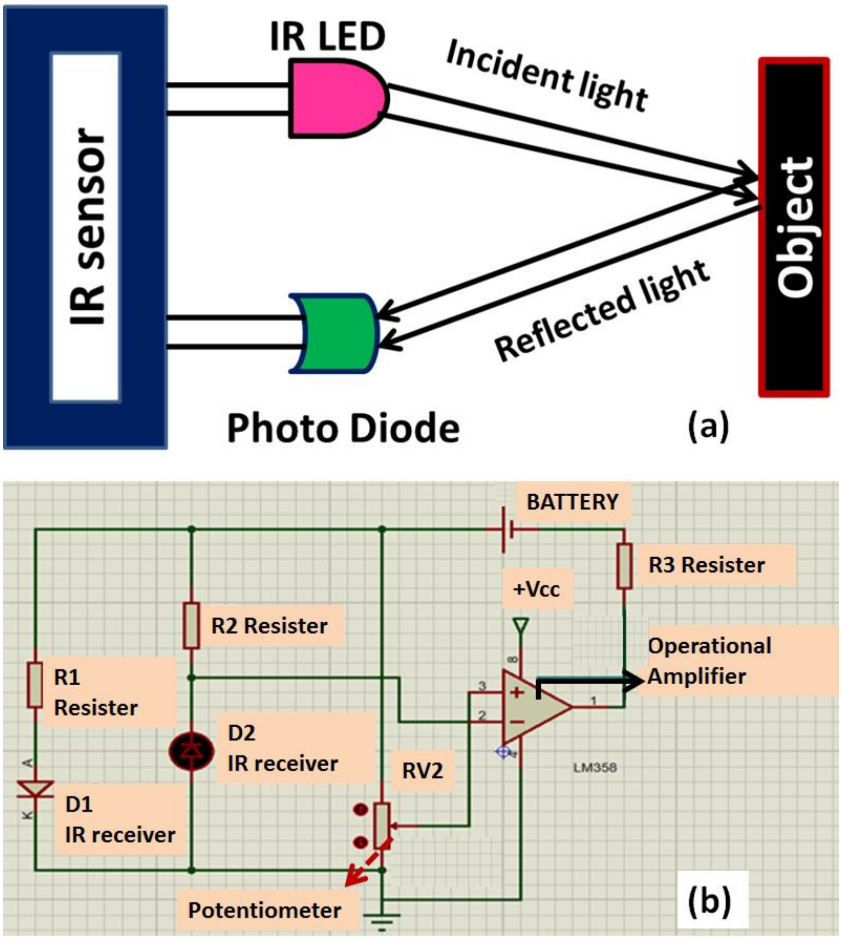

Figure 3. Schematic diagram of basic working principle (**a**), and the circuit diagram (**b**) of an Infrared proximity sensor.

In the IR proximity sensor, a laser or LED is used as an infrared source and the photodiode is used as an IR receiver (also known as an optocoupler). The signal processing is performed by the operational amplifier. There is an analog-to-digital (ADC) converter used to convert the signal [43]. The potentiometer is used to calibrate the output of the sensor according to requirements. We have selected the SHARP IR sensor from the Acroname sensor manufacturer company. As per manufacturer information, the total input and output time are about 25 to 30 ms when performing the objective detection by the sensor. More details about the SHARP sensor are also available in Ref. [44].

2.3. Battery

Lithium-ion batteries are used as a power source for the sensor and boom barrier throughout the project. The capital and replacement cost of the battery is USD 550, with a lifetime of 15 years. Operating and maintenance cost is USD 10 per year and the throughput of the battery is 3000 kWh. The lifetime throughput calculation of the battery is given below [45–49].

$$Q_{lifetime,i} = f_i d_i \left(\frac{q_{max} V_{nom}}{1000W/Kw} \right) \quad (4)$$

Here, $Q_{lifetime,i}$ = lifetime throughput (Kwh); f_i = number of cycles to failure; d_i = depth of discharge (%); q_{max} = maximum capacity of storage (Ah); V_{nom} = nominal voltage of the storage (V).

3. Power Generation System Components and Simulation Results

3.1. PV Panel

Below are the Homer Pro-collected solar radiation data from the National Aeronautics and Space Administration (NASA). Figure 4 shows the monthly average solar radiation data and clearness index profile in Dhaka city of Bangladesh. Solar radiation data are combined with daily radiation data and clearness index.

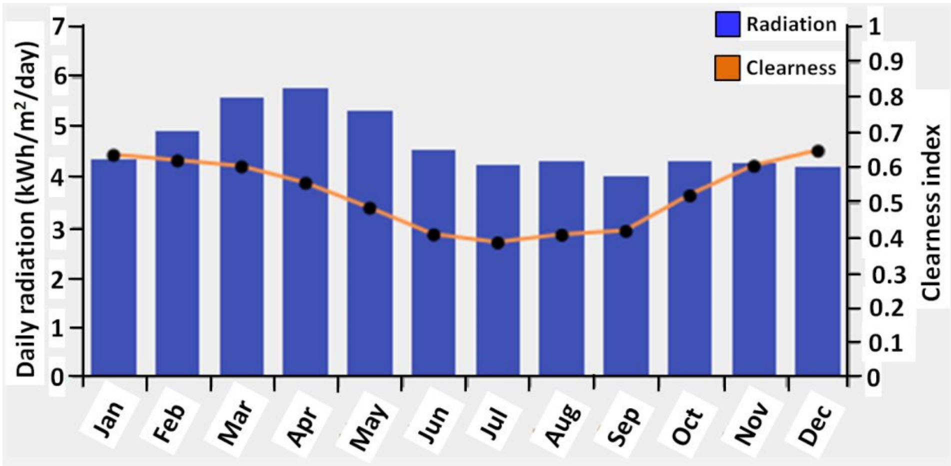

Figure 4. Average Solar radiation data Dhaka, Bangladesh.

The Homer Pro software uses the equations given below to calculate average solar radiation data and power output [50–54]:

Monthly average clearness index:

$$K_t = \frac{H_{ave}}{H_{0,ave}} \quad (5)$$

where H_{ave} = monthly average radiation (kWh/m^2/day) and $H_{0,ave}$ = extraterrestrial horizontal radiation (kWh/m^2/day). The clearness index K_t is a dimensionless number between 0 and 1. Average values are from 0.25 (cloudy month) to 0.75 (sunny month). The following equation is to calculate the output of the PV array:

$$P_{pv} = Y_{pv} f_{pv} \left(\frac{G_T}{G_{T,STC}} \right) [1 + \propto_p (T_c - T_{c,STC})] \quad (6)$$

Here, Y_{pv} = rated capacity of the PV array under standard test condition (kW), f_{pv} = PV derating factor (%), G_T = solar radiation incident on the PV array (kW/m^2), $G_{T,STC}$ = incident radiation at standard test condition (1 kW/m^2), $\propto_p$ = temperature coefficient of power (%/°C), T_c = PV cell temperature (°C), and $T_{c,STC}$ = PV cell temperature under standard test conditions (25 °C). For this study, we have considered using a 1 kW generic flat-plate PV panel. The initial capital for a generic flat-plate PV panel is around USD 1280/kW and the replacement cost is USD 1280/kW. The operating and maintenance cost is USD 10/year with a lifetime of 25 years and 80% derating factor. The Levelized Cost of Energy (LCOE) is 0.0736 USD/kWh. The output power of the PV panel (24 h a day all year round) is shown in Figure 5.

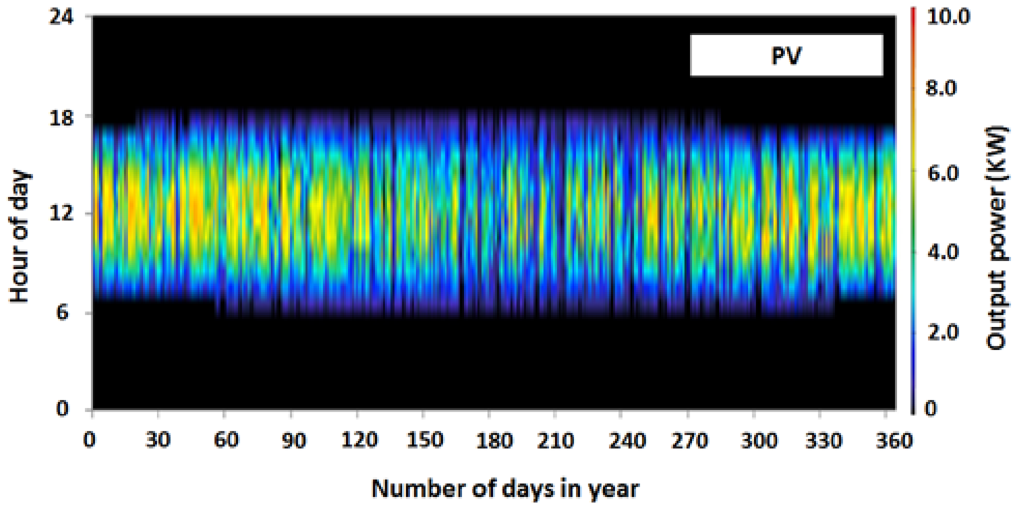

Figure 5. Power output for PV.

3.2. Wind Turbine

Nowadays, many developed countries such as China, USA, and Germany are producing wind energy. In Bangladesh, there is also a possibility to produce wind power; however, proper action, including investment and policymaking, needs to be taken to establish wind energy production sites on a large scale. Wind speed resources are downloaded from the National Aeronautics and Space Administration (NASA) by the resources option in the Homer pro software automatically. For this study, we have selected Bangladesh's average wind speed as shown in Figure 6. The ideal months with the highest wind speed in Bangladesh for maximum power output are April to September.

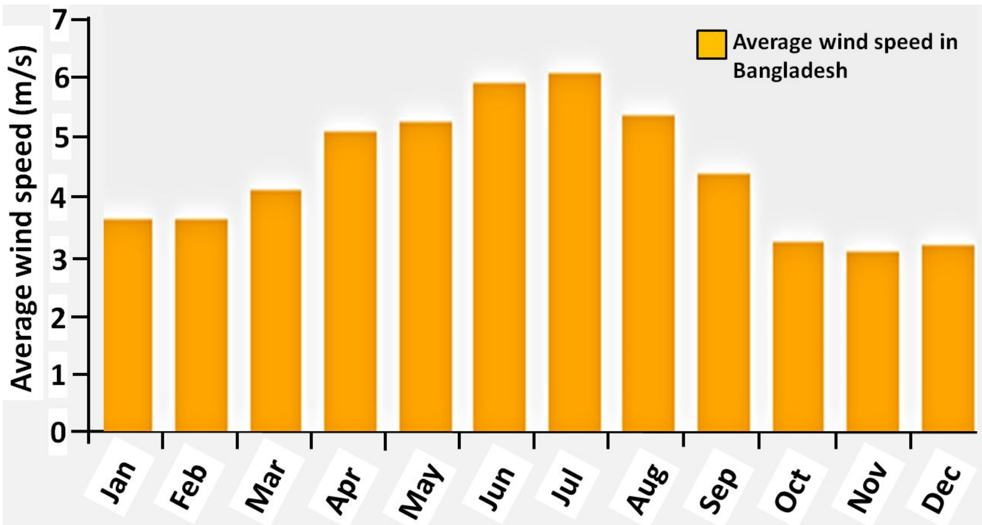

Figure 6. Average wind speed in Bangladesh.

In the simulation process, we considered a 3 kW wind turbine with a lifetime of 20 years, with a hub height of 17 m. The capital and replacement cost of the 3 kW generic wind turbine is USD 18,000, and operating and maintenance costs are USD 180/year. There are many calculation steps Homer Pro followed to produce the output. Generally, an anemometer is placed at 10 m height for meteorological measurements.

Hub height of the wind turbine:

$$U_{hub} = U_{anem} \times \frac{\ln(Z_{hub}/Z_0)}{\ln(Z_{anem}/Z_0)} \tag{7}$$

Here, U_{hub} = turbine hub height wind speed (m/s), U_{anem} = anemometer wind speed (m/s), Z_{hub} = turbine hub height, Z_{anem} = anemometer height (m), and Z_0 = surface roughness length (m).

The power output of the wind turbine:

$$P_{WTG} = \left(\frac{\rho}{\rho_0}\right) \times P_{WTG,STP} \tag{8}$$

where P_{WTG} = power output of the turbine (kW), $P_{WTG,STP}$ = wind turbine power output at standard temperature and pressure (kW), ρ = actual air density (Kg/m^3), and ρ_0 = air density at standard temperature and pressure (1.225 kg/m^3).

3.3. Generator

Normally, the generator is used mainly for backup in the event of a natural disaster, in the winter season, or for cloudy days. The initial capital and replacement cost of the generator is USD 500, while the fuel price is USD 0.760 per liter according to the Bangladesh market. Its lifetime is 15,000 h with a minimum load ratio of 25%. Emissions and fuel properties are given in Table 1.

Table 1. Emission and fuel properties.

Emissions		
Name	**Unit**	**Value**
Carbon Monoxide (CO)	g/L	16.5
Unburned Hydrocarbons (HC)	g/L	0.72
Particulate Matter (PM)	g/L	0.1
Fuel Sulfur converted to PM	%	2.2
Nitrogen Oxides (NOx)	g/L	15.5
Fuel properties		
Lower heating value	MJ/Kg	43.2
Density	Kg/m^3	820
Carbon content	%	88
Sulfur content	%	0.4

The Homer Pro software calculates fuel consumption according to the following calculations:

$$F = F_0 \times Y_{gen} + F_1 \times P_{gen} \tag{9}$$

Here, F = fuel consumption (L/hr), F_0 = generator fuel curve intercept coefficient (L/hr/Kw_{rated}), F_1 = generator fuel curve slope (L/hr/kW_{output}), Y_{gen} = rated capacity of the generator (kW), and P_{gen} = electrical output of the generator (kW). The data map of the output power of the generator per day in a year in different types of hybrid combination systems is provided in the Supplementary Materials. As the generator is a backup for our proposed system, it is fully optional and can be used only if it is necessary. However, there is a drawback to running a generator, as the generator produces pollutant gases into the environment, mainly carbon dioxide, and is a cause of sound pollution. Carbon dioxide is emitted by burning fossil fuels. It is the main cause of greenhouse gas that affects the Earth's radiative balance.

3.4. Converter

The converter consists of an inverter and a rectifier. The inverter converts Direct Current (DC) to Alternating Current (AC) electricity and the rectifier converts AC to DC electricity. The inverter's power output is in AC and the rectifier is in DC. In this project, we run both AC and DC components such as the PV array and battery connected to the load, and wind power and the generator are connected to the AC circuit of the load. Both the installation and replacement cost of the converter is USD 300/kW with 95% efficiency as described in Ref. [55].

3.5. Hybrid Power Generation Systems

PV systems are commonly used as the best renewable energy resource worldwide, though power generation is fully dependent on the availability of sunlight. A PV module can be used only during the daytime with a clear sunny sky. Due to this, a storage device such as a battery can help to provide power to the operating system from its saved power during any emergency case. However, alternatives are always welcome, to find how to be more sustainable depending on only the possible renewable energy sources. We have used Homer Pro software to investigate different hybrid power systems. We have performed techno-economic analyses for different energy systems, including a suitable combination of a hybrid energy system to understand the feasibility of developing a sustainable off-grid or grid-tied energy generation system that can provide an uninterrupted power supply to maintain the level crossing operation. Figure 7 presents an example of the Homer Pro software that scopes the components through an optimization process for different types of systems.

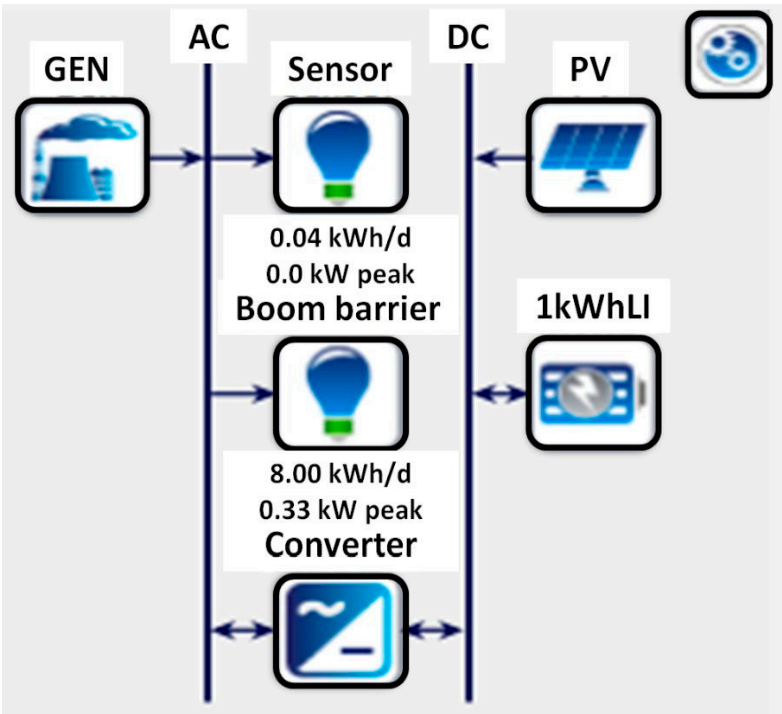

Figure 7. Schematic presentation of Homer Pro software operation module to realize the components through an optimization process for different types of systems.

A summary of the system components' requirements is given in Table 2. As shown in the table, component items are expressed in power (kW). The most PV used was in PV, battery systems (8.61 kW), and the most Li-ion batteries used were 12 for both PV and wind, PV systems.

Table 2. Basic components required for different types of combinations of PV, generator, and wind.

	Quantity of Components				
Combinations	**PV (kW)**	**Wind (3 kW)**	**Generator (kW)**	**Battery (kWh)**	**Converter (kW)**
PV, generator	1.30	null	0.380	1	0.372
Generator	Null	Null	0.380	1	0.00671
PV	8.61	Null	Null	12	0.382
PV, generator, wind	0.187	1	0.380	1	0.0208
Wind, PV	6.75	1	Null	12	0.583
Generator, wind	Null	2	0.380	2	0.0677

It is noticeable that in the winter season, Bangladesh experiences foggy days (less sunlight) and sometimes natural disasters such as cold waves (Soitto Probaho) and rain, where PV or wind power are not enough to run any electrical equipment. In these cases, the generator is the only option that needs to be in action. We have performed some sensitivity analyses for December to March (the winter season in Bangladesh), which is given in Table 3, and for the rest of the months the generator remains turned off.

Table 3. Components' quantity and fuel consumption of generator for the winter season (December to March).

	Generator (0.380 kw)		
	Battery	**Converter**	**Fuel Consumption**
System combinations			
PV, generator	12	0.382	217
PV, generator, wind	12	0.583	195
Wind, generator	55	2.35	194

In addition, each subsystem has a particular control unit that requires specific tasks that need to be in action during the energy generation period, and requires a power management strategy to ensure the optimal use of generated power and smooth operation. Several approaches to power converter control and power management strategies have been theoretically studied and published in the literature [56–60]. In our work, we have used a bidirectional converter that can act as a rectifier and an inverter as detailed in Ref. [61]. However, within the scope of the research, we studied and conducted experimental work to compare and find the best approach of power management (possibly having the lowest system loss) for our described hybrid power system to ensure (twenty-four hours, seven days) uninterrupted power supply for the railway level crossings.

4. Cost Analysis

We have performed a cost analysis for different systems' architectures as shown in Figure 8. From the cost analysis, it is seen that the operation and maintenance cost is very low for every system. Capital cost is highest for generator, wind systems because the cost of a wind turbine is very high, whereas the cost of PV, generator systems is the lowest.

We also performed Levelized Cost of Energy (LCOE) for the different systems. The LCOE is the lowest for the PV, generator system and highest for the generator, wind system. Though the PV, generator, and generator systems are almost the same, PV, generator is more feasible than a generator system. Other systems are also feasible in different circumstances. We categorized every system according to years and cost by the Homer Pro sensitivity optimization. We conducted this sensitivity to examine each system's feasibility in different years, i.e., to find the payback time of the investment. It can be seen that the PV, generator system has the lowest payback time (5, 10, and 15 years). However, the PV panel has a lifetime of 25 years, which should be considered by the decision maker or policymakers.

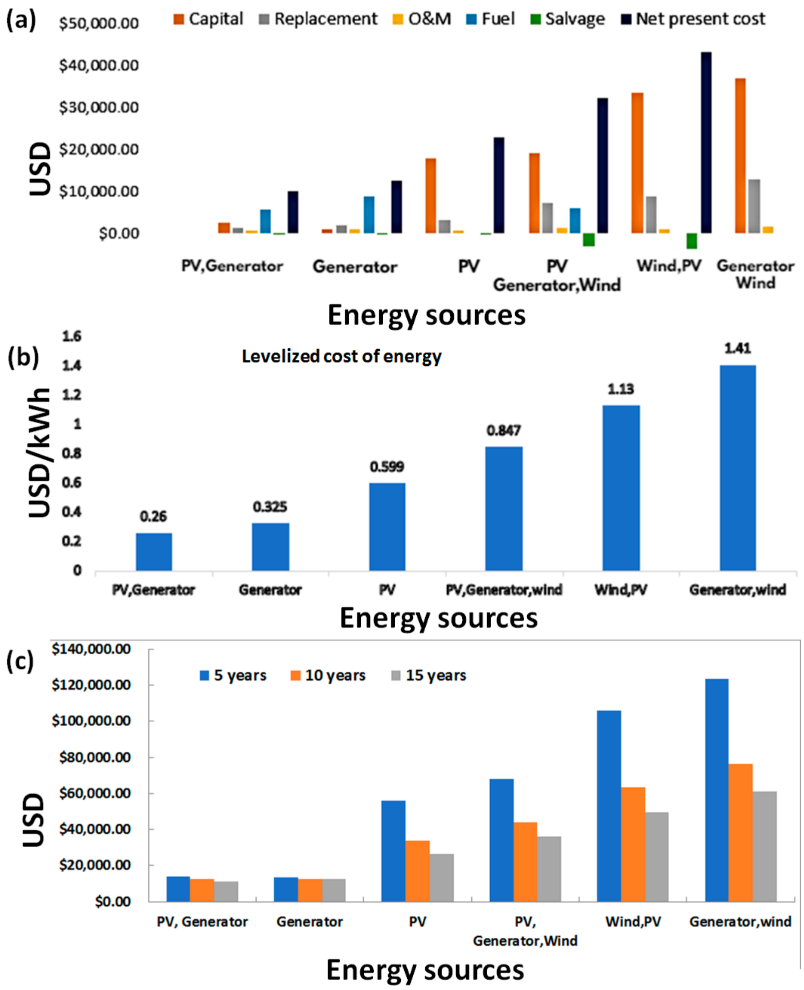

Figure 8. Cost analysis for different types of energy generation systems (**a**), LCOE for different systems (**b**), and cost effectiveness in different types of systems (**c**).

5. Discussion

From the simulation results, it is clear that renewable energy-based (i.e., either single power generation component or hybrid energy generation systems) automatic railway crossing systems are feasible and will reduce accidents in level crossings. As it is a 24 h continuous system, generator or battery backup has been considered as an alternating source of power during national or environmental disasters. The obtained result shows the possibility of using renewable energy in this type of project from both economic and environmental views. Additionally, this type of automation system can reduce accidents in railway level crossings. Importantly, the off-grid power generation systems have low transmission losses (i.e., almost zero loss), which can provide electricity continuously anywhere, including remote areas as well. Therefore, we recommend that either PV or a suitable combination of hybrid power generation systems be made major contributors in the energy supply line to operate the automatic railway level crossings and help reduce the number of accidents in Bangladesh. Now, if renewable energy sources or any hybrid system is considered for this kind of work, the question of where to and how to install these power generation components may arise, as in Bangladesh open space is limited. To the best of our knowledge, our recommendations are to use only PV systems with battery backups in developed or urban areas, and to use a hybrid (i.e., PV, wind) system where there is open space available close to the boom gates. The advantage of using wind turbines beside the PV panels is that the wind turbines can generate power at any time when it is windy (either day or night). Once again, it can raise the issue that wind turbines require large open spaces; however, a miniature version of a wind turbine (as shown in Figure 9) can be used together with the PV panels for this type of project, where a minimum but continuous power supply is required.

Figure 9. A miniature version of a wind turbine installed together with conventional PV panels to power the streetlight.

However, the installation of large-scale wind power generation where it is possible (such as in the coastal areas of Bangladesh or Cox's Bazar, Kuakata, Vashanchor, etc.) would be beneficial not only for Bangladesh's railway, but also for the national power grid as well. In summary, it is worth noting that the focus of this research project is not only to develop renewable energy-based automatic railway crossings, but also to achieve the following goals as stated below [62]:

(i) Development of automatic railway crossing systems all over the country to reduce unexpected accidents;
(ii) Generate enough renewable energy for the railway crossing systems and store the excess energy generated from the site for emergency cases;
(iii) To reduce pressure on the national grid to help the country to deliver the energy demanded in other sectors;
(iv) Ensure the harvesting of renewable energy for sustainable development.

This is an ongoing research project, and we wish to continue our research work further to make a pilot project to implement the proposed idea, to realize our work if funding (government or private) opportunities are available.

6. Conclusions

We performed the HOMER Pro simulation and demonstrated the possibilities of developing a smart railway level crossing system that can be operated by either a single energy generation system or a hybrid energy system. The use of solar or hybrid energy generation can provide the required power to operate a low-voltage smart level crossing system, and can ensure a forward-looking initiative to reduce the number of accidents at railway crossings in Bangladesh. In addition, the use of on-site generated power (from renewable energy sources) reduces the pressure on the national grid and serves the purpose of the nation's sustainable development goal by lowering carbon emissions as well. To the best of our knowledge, this is the first work to design a renewable energy-based auto-detectable railway level crossing system in Bangladesh.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/futuretransp3010005/s1, Figure S1: Boom gate structure and cross section area of boom gate. Figure S2: Rotational speed vs acceleration timing diagram. Figure S3: Trapezoidal motion profile. Figure S4: Comparison of power output for PV and PV based hybrid power generation systems. 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. Figure S6: Generator output power and fuel consumption in the different hybrid systems; PV, Generator, and Wind (a), and PV, and Generator (b). Figure S7: Generator scheduled for the winter season. Figure S8: Pollutant gas emission in a different system. Figure S9: Schematic of power converter control and power management process by using a bidirectional converter system. Reference [63] is cited in the supplementary materials.

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References

1. Railway Information Book 2018. Bangladesh Railway. Available online: http://railway.portal.gov.bd/sites/default/files/files/railway.portal.gov.bd/page/3951d3b2_dcc8_463d_9657_4e3cc6e49b8b/Information%20Book%202018%20(3).pdf (accessed on 5 October 2021).
2. Azzacy, M.B. Analysis of rail accidents due to collision and their preventive measures in Bangladesh. Ph.D. Thesis, Bangladesh University of Engineering and Technology, 2012. Available online: http://lib.buet.ac.bd:8080/xmlui/handle/123456789/454 (accessed on 9 November 2022).
3. Selvan, T.A.; Viswanathan, A.; Madhankumar, S.; Dhanush Kumar, R. Design and Development of an Automatic Unmanned Railway Level Crossing Gate. *IOP Conf. Ser. Mater. Sci. Eng.* **2021**, *1059*, 012005. [CrossRef]
4. Balamurugan, C.R.; Vijayshankarganth, P.; Alagarraja, R.; Subramanian, V.E.; Ragupathy, R. Automatic Railway Gate Control System Using 8051micro Controller. *Int. J. ChemTech Res.* **2018**, *11*, 63–70. [CrossRef]
5. Babylatha, M.; Pranitha, K.; Jhansidevi, P.; Shilpa, T. Automatic railroad level crossing systems using AGM technologies. *Indian J. Comput. Sci. Eng. IJCSE* **2015**, *8*, 558–563.
6. Moorthy, P.; Vishnupriya, P.; Poornima, N.; Priyadarshini, R.; Kharche, S. Automatic Railway Level Crossing Using LoR. *Int. J. Res. Anal. Rev. IJRAR* **2020**, *7*, 421–424.

7. Singh, P.; Pasha, J.; Khorram-Manesh, A.; Goniewicz, K.; Roshani, A.; Dulebenets, M.A. A Holistic Analysis of Train-Vehicle Accidents at Highway-Rail Grade Crossings in Florida. *Sustainability* **2021**, *13*, 8842. [CrossRef]
8. Abioye, O.F.; Dulebenets, M.A.; Pasha, J.; Kavoosi, M.; Moses, R.; Sobanjo, J.; Ozguven, E.E. Accident and hazard prediction models for high-rail grade crossing: A state-of-the-practice review for the USA. *Rail. Eng. Sci.* **2020**, *28*, 251–274. [CrossRef]
9. Singh, P.; Dulebenets, M.A.; Pasha, J.; Gonzalez, E.D.R.S.; Lau, Y.-Y.; Kampmann, R. Deployment of autonomous trains in rail transportation: Current trends and existing challenges. *IEEE Access* **2021**, *9*, 91427–91461. [CrossRef]
10. Pasha, J.; Dulebenets, M.A.; Singh, P.; Moses, R.; Sobanjo, J.; Ozguven, E.E. Towards improving sustainability of rail transport by reducing traffic delays at level crossings: A case study for the state of Florida. Clean. Logist. *Supply Chain.* **2021**, *1*, 100001. [CrossRef]
11. Mathew, J.; Benekohai, R.F.; Berndt, M.; Beckett, J.; McKerrow, J. Multi-critieria prioritization of highway-rail grade crossings for improvements: A case study. *Urban Plan. Transp. Res.* **2021**, *9*, 479–518. [CrossRef]
12. Pasha, J.; Dulebenets, M.A.; Singh, P.; Moses, R.; Sobanjo, J.; Ozguven, E.E. Safety and delays at level crossings in the United States: Addressing the need for multi-objective resource allocation. In *Sustainable Rail Transport 4. Lecture Notes in Mobility*; Marinov, M., Piip, J., Eds.; Springer: Cham, Switzerland, 2020. [CrossRef]
13. Ilampiray, P.; Deepak, K.; Santhosh, M.G.D.; Kishore, S. Automated railway gate control system using Arduino and ultrasonic sensors. *J. Phys. Conf. Ser.* **2021**, *1916*, 0120081. [CrossRef]
14. Shetty, R.; Patel, P.; Sampat, A.; Shukla, S.; Singh, A.K.; Deshmukh, P. Automated railway crossing and obstacle detection. In Proceedings of the 2nd International Conference on Advances in Science & Technology (ICAST-2019) K.J. Somaiya Institute of Engineering & Information Technology, University of Mumbai, Maharashtra, India, 8–9 April 2019.
15. Banerjee, S.; Mondal, S.; Chakraborty, A.; Chattaraj, S. Global Positioning System Based Automated Railway Level Crossing. Available online: https://www.researchgate.net/publication/344789112 (accessed on 9 November 2022).
16. Dent, M.; Marinov, M. Introducing Automated Obstacle Detection to British Level Crossings. In *Sustainable Rail Transport Lecture Notes in Mobility*; Fraszczyk, A., Marinov, M., Eds.; Springer: Cham, Switzerland, 2019. [CrossRef]
17. Tshaai, D.C.; Mishra, A.K.; Pidanic, J. Demonstration of smart railway level crossing design and validtioa using data from metro rail South Africa. *J. Adv. Transp.* **2022**, *2022*, 6614242. [CrossRef]
18. Liyanage, T.D.; Jayathilake, M.V.M.; Abeysinghe, D. Secure Based Railway Crossing and Controller Room Management System Using IoT. In Proceedings of the CSRS 2021, Colombo, Sri Lanka, 26 November 2021; Available online: https://www.researchgate.net/publication/356556856 (accessed on 9 November 2022).
19. Bhuyan, M.H.; Rahman, S.M.M.; Tarek, M.T. Design and simulation of a PLC and IoT-based railway level crossing gate control and track monitoring system using LOGO. *IOSR J. Electr. Electron. Eng. IOSR-JEEE* **2022**, *17*, 13–23.
20. Mahfuz, M.B.; Ali, Z.M.; Hossain, M.S.; Das, A. Development of a smart railway system for Bangladesh. In Proceedings of the 2017 IEEE Region 10 Conference (TENCON), Penang, Malaysia, 5–8 November 2017.
21. Shikder, K. Intelligent system for train engine with automatic gate controlling using wireless technology in Bangladesh. *Int. J. Sci. Res. IJSR* **2014**, *3*, 745–748.
22. Anila, S.; Saranya, B.; Kiruthikamani, G.; Devi, P. Intelligent system for automatic railway gate controlling and obstacle detection. *Int. J. Curr. Eng. Sci. Res. IJCESR* **2017**, *8*, 24–30.
23. Ebrahim, E.A. Bacteria-foraging based-control of high-performance railway level crossing safety drives fed from photovoltaic array. *J. Electr. Syst. Inf. Technol.* **2016**, *3*, 485–512. [CrossRef]
24. Rehman, A.; Latif, S.; Zafar, N. Automata Based Railway Gate Control System at Level Crossing. In Proceedings of the 2019 International Conference on Communication Technologies (ComTech) IEEE, Rawalpindi, Pakistan, 20–21 March 2019; pp. 30–35. [CrossRef]
25. Reddy, E.A.; Kavati, I.; Rao, K.S.; Kumar, G.K. A secure railway crossing system using IoT. In Proceedings of the 2017 International Conference of Electronics, Communication and Aerospace Technology (ICECA), Coimbatore, India, 20–22 April 2017; pp. 196–199. [CrossRef]
26. Cho, B.; Jung, J.-I. A Study on Intelligent Railway Level Crossing System for Accident Prevention. *Int. J. Railw.* **2010**, *3*, 106–112.
27. Soppimath, V.M.; Hudedmani, M.G. An Intelligent Controller For Unmanned Railway Gate Control Systems. *Int. J. Electr. Electron. Eng.* **2016**, *8*, 137–144.
28. Kosacka-Olejnik, M.; Kostrzewski, M.; Marczewska, M.; Mrówczyńska, B.; Pawlewski, P. How Digital Twin Concept Supports Internal Transport Systems?—Literature Review. *Energies* **2021**, *14*, 4919. [CrossRef]
29. Errandonea, I.; Beltrán, S.; Arrizabalaga, S. Digital Twin for Maintenance: A Literature Review. *Comput. Ind.* **2020**, *123*, 103–316. [CrossRef]
30. Chen, Z.; Huang, L. Digital Twins for Information-Sharing in Remanufacturing Supply Chain: A Review. *Energy* **2021**, *220*, 119–712. [CrossRef]
31. Negri, E.; Fumagalli, L.; Macchi, M. A Review of the Roles of Digital Twin in CPS-Based Production Systems. *Procedia Manuf.* **2017**, *11*, 939–948. [CrossRef]
32. Cimino, C.; Negri, E.; Fumagalli, L. Review of Digital Twin Applications in Manufacturing. *Comput. Ind.* **2019**, *113*, 103–130. [CrossRef]
33. Available online. Available online: https://www.bpdb.gov.bd/bpdb_new/index.php/site/new_annual_reports (accessed on 10 November 2021).

34. Nur-E-Alam, M.; Basher, M.K.; Iftekharuzzaman; Mostofa, K.Z.; Islam, M.A.; Haque, A.H.M.A.; Das, N. Rooftop PV or Hybrid Systems and Retrofitted Low-E Coated Windows for Energywise and Self-Sustainable School Buildings in Bangladesh. *Solar* **2022**, *2*, 540–558. [CrossRef]
35. Yeong, D.J.; Velasco-Hernandez, G.; Barry, J.; Walsh, J. Sensor and Sensor Fusion Technology in Autonomous Vehicles: A Review. *Sensors* **2021**, *21*, 2140. [CrossRef] [PubMed]
36. Available online: https://www.fierceelectronics.com/sensors/what-ir-sensor (accessed on 11 May 2021).
37. Chilton, A. The Working Principle and Key Applications of Infrared Sensors. Available online: https://www.azosensors.com/article.aspx?ArticleID=339 (accessed on 9 November 2022).
38. Meyers, R.A. Radiometry and Photometry. In *Encyclopedia of Physical Science and Technology*, 3rd ed.; McCluney, R., Ed.; Academic Press: Cambridge, MA, USA, 2003; pp. 731–758, ISBN 9780122274107. [CrossRef]
39. Kingston, R.H. Chapter 1-Blackbody Radiation, Image Plane Intensity, and Units. In *Optics and Photonics, Optical Sources, Detectors, and Systems*; Kingston, R.H., Ed.; Academic Press: Cambridge, MA, USA, 1995; pp. 1–32, ISSN 15575837. ISBN 9780124086555. [CrossRef]
40. Chaulya, S.K.; Prasad, G.M. Chapter 2-Mine Transport Surveillance and Production Management System. In *Sensing and Monitoring Technologies for Mines and Hazardous Areas*; Chaulya, S.K., Prasad, G.M., Eds.; Elsevier: Amsterdam, The Netherlands, 2016; pp. 87–160, ISBN 9780128031940. [CrossRef]
41. Jun, S.; Krishnamurthy, K.; Irudayaraj, J.; Demirci, A.; Pan, Z.; Atungulu, G.G. Fundamentals and theory of infrared radiation. In *Infrared Heating for Food and Agricultural Processing*; Pan, Z., Atungulu, G.G., Eds.; CRC Press: Boca Raton, FL, USA, 2010; pp. 1–18.
42. Cabuz, C.; Shoji, S.; Fukatsu, K.; Cabuz, E.; Minami, K.; Esashi, M. Fabrication and packaging of a resonant infrared sensor integrated in silicon. *Sens. Actuators A Phys.* **1994**, *43*, 92–99. [CrossRef]
43. Grout, I. Chapter 8-Interfacing Digital Logic to the Real World: A/D Conversion, D/A Conversion, and Power Electronics. In *Digital Systems Design with FPGAs and CPLDs*; Grout, I., Ed.; Newnes: London, UK, 2008; pp. 537–614, ISBN 9780750683975. [CrossRef]
44. Available online: Acroname.com/store/long-range-distance-sensor-r316-gp2y0a710yk#features (accessed on 22 October 2021).
45. Available online: https://acroname.com/sites/default/files/assets/sharp-app-note_4.pdf (accessed on 6 November 2021).
46. Manwell, J.F.; McGowan, J.G. Lead acid storage model for hybrid energy systems. *Sol. Energy* **1993**, *50*, 399–405. [CrossRef]
47. Neubauer, J. Battery Lifetime Analysis and Simulation Tool (BLAST) Documentation, NREL/TP-5400-63246. 2014. Available online: http://www.nrel.gov/docs/fy15osti/63246.pdf (accessed on 9 November 2022).
48. Smith, K.; Earleywine, M.; Wood, E.; Neubauer, J.; Pesaran, A. Comparison of Plug-In Hybrid Electric Vehicle Battery Life Across Geographies and Drive Cycles. In Proceedings of the SAE World Congress and Exhibition, Detroit, MI, USA, 24–26 April 2012.
49. *ASTM E1049-85(2011) e1*; Standard Practices for Cycle Counting in Fatigue Analysis, ASTM International: West Conshohocken, PA, USA, 2011; Available online: www.astm.org (accessed on 9 November 2022).
50. Manwell, J.F.; McGowan, J.G.; Abdulwahid, U.; Wu, K. Improvements to the hybrid2 battery model. In Proceedings of the Windpower 2005 Conference, American Wind Energy Association, Denver, CO, USA, 15–18 May 2005.
51. Duffie, J.A.; Beckman, W.A. *Solar Engineering of Thermal Processes*, 2nd ed.; Wiley: New York, NY, USA, 1991.
52. Erbs, D.G.; Klein, S.A.; Duffie, J.A. Estimation of the diffuse radiation fraction for hourly, daily, and monthly-average global radiation. *Sol. Energy* **1982**, *28*, 293. [CrossRef]
53. Graham, V.A.; Hollands, K.G.T. A method to generate synthetic hourly solar radiation globally. *Sol. Energy* **1990**, *44*, 333–341. [CrossRef]
54. Graham, V.A.; Hollands, K.G.T.; Unny, T.E. A time series model for Kt with application to global synthetic weather generation. *Sol. Energy* **1988**, *40*, 83–92. [CrossRef]
55. Nur-E-Alam, M.; Hoque, M.N.; Ahmed, S.M.; Basher, M.K.; Das, N. Energy Engineering Approach for Rural Areas Cattle Farmers in Bangladesh to Reduce COVID-19 Impact on Food Safety. *Sustainability* **2020**, *12*, 8609. [CrossRef]
56. Uddin, N.; Nahian, S.A.; Islam, M.S.; Joy, J.S. Optimization and energy management of hybrid renewable power generation using HOMER and FLC. In Proceedings of the Advances in Sciences, Engineering and Robotics Technology (ICASERT 2019), Dhaka, Bangladesh, 3–5 May 2019.
57. Nureddin, A.A.M.; Rahebi, J.; Ab-Belkhair, A. Power Management Controller for Microgrid Integration of Hybrid PV/Fuel Cell System Based on Artificial Deep Neural Network. *Int. J. Photoenergy* **2020**, *2020*, 8896412. [CrossRef]
58. Yasin, A.; Alsyed, M. Optimization with excess electricity management of a PV, energy storage and diesel generator hybrid system using HOMER Pro software. *Int. J. Appl. Power Eng. IJAPE* **2020**, *9*, 267–283. [CrossRef]
59. Tribioli, L.; Cozzolino, R.; Evangelisti, L.; Bella, G. Energy Management of an Off-Grid Hybrid Power Plant with Multiple Energy Storage Systems. *Energies* **2016**, *9*, 661. [CrossRef]
60. Kotb, K.M.; Elkadeem, M.R.; Elmorshedy, M.F.; Dan, A. Coordinated power management and optimized techno-enviro-economic design of an autonomous hybrid renewable microgrid: A case study in Egypt. *Energy Convers. Manag.* **2020**, *221*, 113185. [CrossRef]
61. 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. [CrossRef]

62. Rifat, I.; Ghosh, S.; Basher, M.K.; Islam, M.A.; Das, N.; Nur-E-Alam, A.M. Visualization of Renewable Energy Powered Automatic Railway Crossing Systems in Bangladesh. *Preprints* **2022**, 2022020060. [CrossRef]
63. Voss, W. *A Comprehensible Guide to Servo Motor Sizing*; Copperhill Media: New York, NY, USA, 2007; Chapter 2; p. 4, ISBN 978-0-9765116-1-8.