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Cognizance of Electric Vehicle Charging's Impacts on Distribution Transformers

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Abstract— In numerous countries worldwide, electric vehicles (EVs) have rapidly gained popularity, surpassing other transportation forms. The swift ascent of EV adoption in Bangladesh has exacerbated the prevailing energy crisis. In the midst of its growth, Bangladesh faces energy-related challenges stemming from excessive consumption. While electric vehicles offer benefits such as cost-effective transportation and reduced greenhouse gas emissions, the substantial energy demand for daily battery charging poses a formidable challenge. Despite the current lower EV count compared to conventional vehicles in Bangladesh, this equilibrium is projected to shift in the near future. The high energy consumption required for frequent battery recharging has significant ramifications for power grids and distribution networks due to the impending increase in EV numbers. This paper centers on comprehending the repercussions of EV charging on distribution transformers. The integration of a substantial number of EV chargers into the distribution grid engenders harmonics, which, in turn, influence voltage profiles, contribute to power losses, and ultimately impact electricity quality. This paper's contribution lies in its investigation of the challenges posed by the increasing adoption of electric vehicles in Bangladesh, particularly in relation to the energy demand for EV charging and its impact on the distribution grid, with a specific focus on the role of distribution transformers and harmonics. The paper aims to provide insights and potential solutions for mitigating these challenges in the context of EV adoption.

***Keywords*—Electric Vehicle (EV), Distribution Transformer, Power Quality, Harmonics, Hybrid EV Charging Station.**

I. Introduction

New technology known as electric vehicles (EVs) is acknowledged for reducing environmental pollution by emitting zero emissions when in operation. The transportation sector in Bangladesh makes a sizable contribution to the country's GHG emissions. The largest of these GHG emissions are made up of CO2. According to a research by the International Energy Agency, around 23% of the GHGs emitted into the environment are caused by transportation vehicles. In order to replace internal combustion engine vehicles, which are a major source of greenhouse emissions contributing to global warming, new technologies are being launched, including battery electric vehicles (BEV), plug-in hybrid electric vehicles (PHEV), and hybrid electric vehicles (HEV) [1].

Since 2017, almost 70% of the automobiles imported into Bangladesh are HEVs, whereas PHEV and BEV imports are much lower [2]. However, as they are battery-operated and require a connection to the grid for charging, Motorized rickshaws or "Easy-bikes" are examples of electric three-wheelers (ETWs), which can also be referred to as electric vehicles (EVs). The usage of electric three-wheelers is expected to increase, with 2 to 3 million Easy Bikes and 2.4 lakh motorized rickshaws likely to be in circulation by 2021 [3].

These electric cars have five different-sized batteries, all of which require a grid connection to recharge. Every year, lead-acid batteries around the country use about 1.9 million batteries as a source of energy storage. A battery-powered Easy-bike typically uses 8 to 12 kWh of power per day [4]. The majority of easy bikes are typically charged via 11 KV power connections' unauthorized outlets. The government calculates that it requires at least 800 to 900 MW of energy each day to charge those basic bikes [5]. Power electronic converters are used in EV interface systems, which are extremely nonlinear systems due to their working principles and the nature of their switching power semiconductor components [6]. Power quality, which is a key component of grid security and efficiency can be disturbed by high EV penetration. As EVs are non-linear loads, it hampers the power quality through harmonics, voltage disturbance and transformer loss.

This paper shows the power quality reduction by harmonic and voltage distortions in distribution transformer through MATLAB simulation which is caused by high EV penetration and also using HOMER Pro software, viability of solar-wind-based EVCS has been designed and proposed to reduce the EV pressure in grid.

II. Literature Review

There have been many studies published on the performance, economic effects, and other aspects of EVs, battery charging, and sustainable energy. As Example, M. Iqbal study has made an endeavor to illustrate the economic elements that ultimately have an impact on the remuneration of auto-rickshaw and motor rickshaw drivers [7]. In Rajshahi

S. Mandal developed a sheet-based techno-economic model to estimate the cost of PV based Easy-bike charging. The model also includes the calculation of reduction of GHG emissions [8]. Lead acid batteries used in electric vehicles have a history of exhibiting low efficiency and high loss. In order to encourage the utilization of electric vehicles, several researchers have recommended the rapid battery charging technique. The rapid charging techniques utilizing depolarization pulses and high current drop were also researched. Pamela researched several lead acid batteries charging techniques [9]. The researchers looked at the State of Charge (SOC), battery lifetime, and charging time in order to improve performance and efficiency. A Variable Frequency Pulse Charge System (VFPCS) has been proposed by Cheng S but is currently limited to tiny batteries [9].

On the social and economic implications of Easy-bike in specific Bangladeshi regions, not many studies have been published related to power quality problem due to electric vehicles. The charging systems for electric and hybrid vehicles, buses that employ Li-ion batteries and fast charging system for electric vehicles have been the subject of several studies. EV chargers shall be connected to low voltage or high voltage distribution network. It is uncommon to have huge number of power electronic converters or rectifiers as EV chargers in local distribution grid. But there are a few researches regarding the impact of EVs on local distribution transformers.

III. Problem Statement

About 2 million battery-powered electric vehicles (Easy-bikes) are currently on the road in our country. These electric cars have five different-sized batteries, all of which require a grid connection to recharge. Every year, lead-acid batteries around the country use about 1.9 million batteries as a source of energy storage. A battery-powered Easy-bike typically uses 8 to 12 kWh of power per day. The majority of easy bikes are typically charged via 11 KV power connections' unauthorized outlets. The government calculates that it requires at least 800 to 900 MW of energy each day to charge those basic bikes.

The high charging power requirements for EVs suggest that there has likely been a significant change in peak demand. These EVs are connected to the grid in an unregulated manner as active loads. The electrical power infrastructure conducts a large quantity of electricity when numerous EVs charge their batteries at once which adversely affecting the grid and the power demand. As these non-linear devices are increasing rapidly, distribution systems are forced to deal with issues of power quality.

IV. Methodology

Household loads, battery storage, EV charging stations, and general loads are all included in the distribution grid. The harmonic load-flow and instantaneous waveforms are used in the study for the EV loads. The distribution network system serves as the foundation for the MATLAB simulation model. To ascertain the effect on certain voltage and current harmonics, harmonic analysis is used. It entails taking measurements of the power quality at various locations along the low-voltage grid as well as on both sides of the distribution transformer. To ascertain whether there are any power quality breaches, the harmonic analysis is compared to the limitations established by standards. The suggestion of how to control power quality, including hybrid renewable charging stations, is made in terms of EV uptake. The suggested model was created using HOMER Pro software.

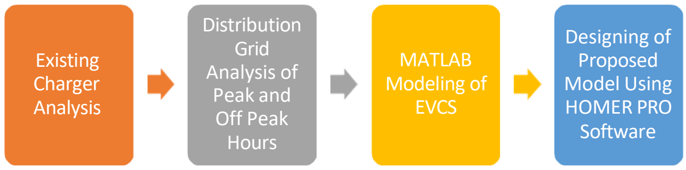


Fig 1. Methodological process explained in steps.

V. EV Charging and Impact Analysis

Easy-bikes have been much more popular due to their comfort as a mode of transportation, worries about the supply of sources of energy like gasoline, and volatilization inside the economy. The grid is concerned about how their power usage affects energy generation and the daily load profile.

Over a million vehicles have been registered, and that number is rising daily. Although recently several municipalities are issuing permits opening a route for the legality of these vehicles, BPDB is concerned that a lot of Easy-bikes operating on the street are not registered by BRTA. However, the government has not yet fully established control over and regulated these vehicles with regard to their use and pricing [12].Some positive and negative impacts of EV are described in the figure below:

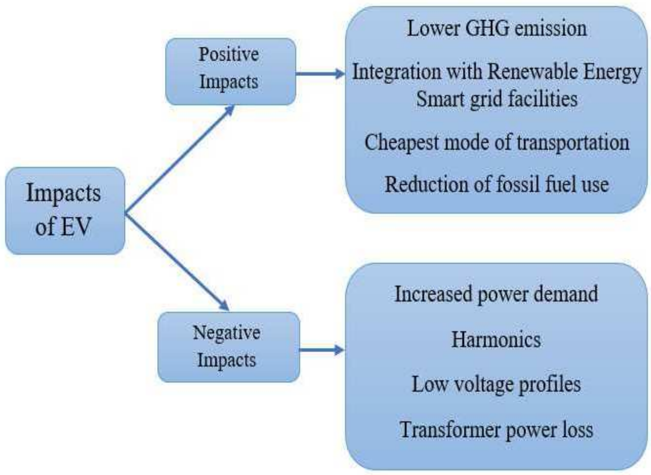


Fig. 2. Positive and negative impacts of EV.

A. Battery Analysis

Assuming batteries are changed once day, the majority of batteries have a life of fewer than 270 cycles. According to the study, most battery banks in Fig.3 required to be changed after only nine months. The easy-bike can often go 120 km on a single charge before the battery is completely depleted. Five lead acid batteries with a combined capacity of 180 Ah are utilized in each vehicle. Each car utilizes lead acid batteries with a 180h capacity. The Easy-bikes typically cover a distance of around 120 km on a single charge before the battery is completely discharged [13].

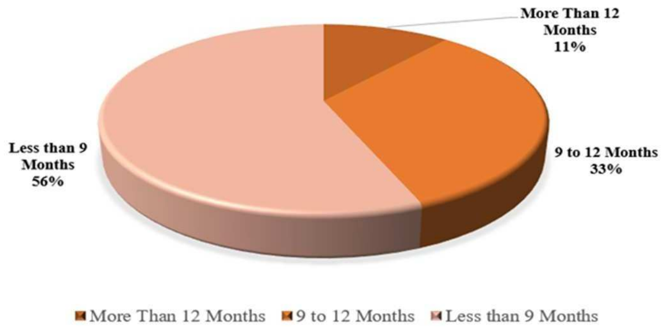


Fig. 3. Battery capacity of an Easy bike [13].

Dealers outside of Dhaka claim that certain Chinese manufacturers give warranties. According a survey, the majority of vehicles have battery warranties that last between 4 and 8 months. 55% or so of the sample's battery banks are not covered by a warranty [13].

B. Battery Charging and Chargers

Typically, Easy bike chargers are single phase chargers. 87% of Easy bikes, according to the report, are charged in garages, with 13% being charged at home and charging process in garages is influenced by elements like as vehicle security, parking, and the availability of individual power lines to charge the vehicles. From garage to garage, charging fees for the cars differ.

The technology used to charge three-wheeler nowadays is relatively basic and just uses some power electronic devices. For them, the charger needs to be extremely dependable and durable. Although this charger is fairly straightforward, it has a number of issues, including overheating from overcharging, energy waste, and environmental hazards. The fact that it takes this charger almost 10 hours to completely charge the Easy bike hampers both the plug-in and plug-out times [13].

C. Cycle life of batteries and environmental problem

The battery's lifespan is determined by how many cycles it can go through before losing its ability to store and transfer energy. Manufacturers of lead acid batteries claim that the battery has a cycle life of 400 to 550 cycles, although independent testing of four models by an anonymous manufacturer indicated a cycle life of 300–400 cycles. Most e-bike manufacturers only offer battery guarantees of one to five years, or around 110 to 170 cycles. The most obvious types of impact were acidification and global warming. Following the stage of product use, the stage of getting raw materials had the greatest influence on the environment. Production had the least amount of an influence, however recycling used batteries had a beneficial effect on the environment.

D. Impacts on the grid's energy

The most important problem with EV charging stations is that they significantly increase demand and unflatten the load profiles on various feeders.

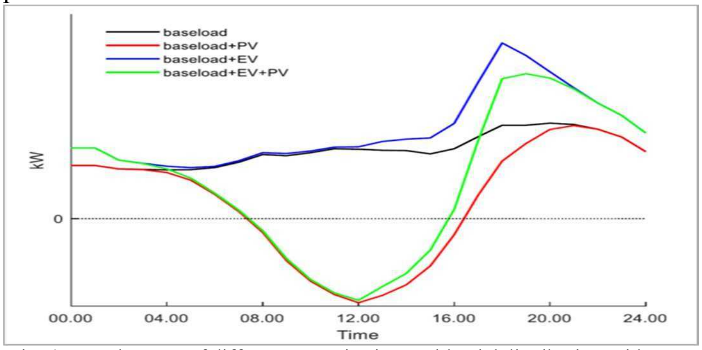


Fig. 4. Load curves of different scenarios in a residential distribution grid [13].

A representative daily load curve for the residential distribution grid in Fig.4 is shown, with significant percentages of PV and EVs. As seen, the curve in the scenario with only base load is the most flattened, whereas the peak can be moved to the largest amount by include EV. Furthermore, the peak will be lower when PVs and EVs are combined.

E. Impacts on Grid's Power Quality

EVs have a natural impact on the grid's e power quality, including harmonics, sag, swell, voltage, and phase imbalance, as a result of their dynamic properties. To avoid catastrophic effects on the grid, manufacturers of EVs adhere to requirements for power quality. According to the literature, harmonics and other grid power quality problems are caused by power electronics equipment. Therefore, harmonics are created when converting electricity since EV chargers use power electronics devices that comprise switching semiconductor-based parts.

VI. Result Analysis

Transformer power quality is an important factor to take into account when assessing the effects of EV charging because transformers are among the most expensive parts of the medium and low voltage distribution infrastructure. In order to produce a clean, noise-free, sinusoidal wave-shaped power supply that is within the permitted range of voltage and current harmonics, a power grid network must have a certain level of power quality.

A. Increased power demand in Bangladesh

The increased electricity demand causes by electric vehicles add an extra pressure to the grid. The normalized daily load curve of 2012 and 2021 for Bangladesh power sector is given in Fig. 5 According to the Bangladesh Power Development Board's (BPDB) most recent annual report, installed capacity increased by 8.1% to 22,031 MW in FY 2020–21. In addition, more power was produced in FY 2020–21 than in FY 2019–20, reaching 80,422.54 GWh [10].

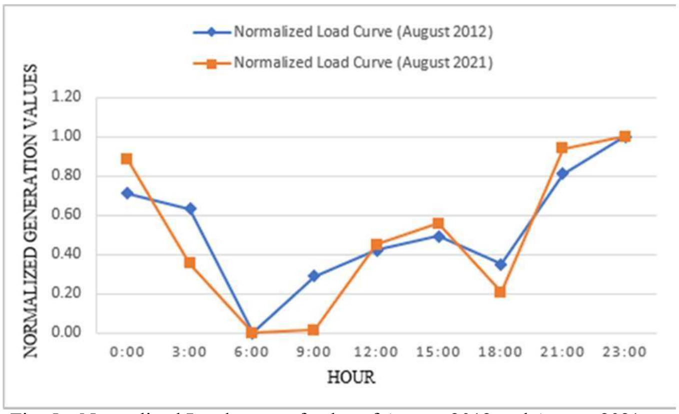


Fig. 5. Normalized Load curve of a day of August 2012 and August 2021.

From Fig. 5 above, it is clear that the load consumption for 2021 is much greater from 6 pm to 11 pm. Fig. 6 displays an EV charging profile in a charging station.

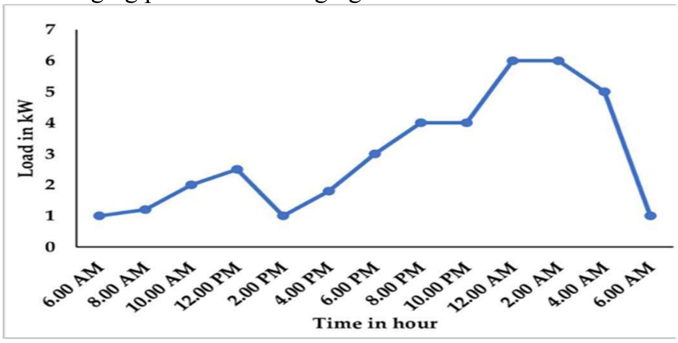


Fig. 6. Daily load curve of EVCS situated in Gazipur, Bangladesh [11].

This graph demonstrates that during peak hours, there is an increase in demand for EV charging. Due to the extensive use of EV, there is a high demand during peak hours throughout Bangladesh. Increased power usage, which also lowers the quality of the power, may lead to load-shedding.

B. MATLAB Simulink model

If larger number of EVs were connected to the electric distribution network to recharge their batteries, the power quality would suffer. The distribution transformer seen in Fig. 7 is utilized in this paper to assess the impacts of EV charging using the MATLAB Simulink model.

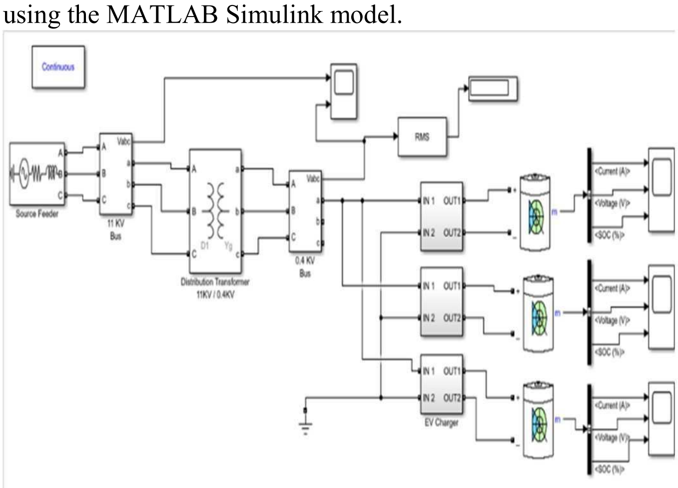
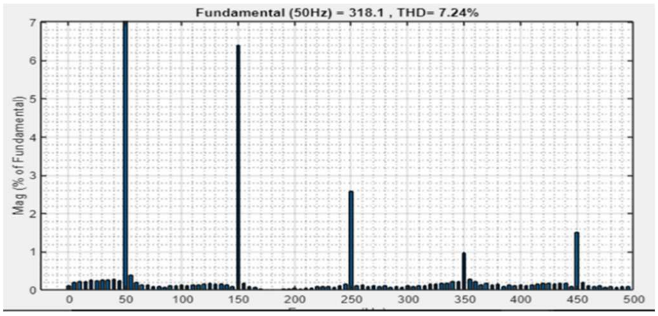


Fig. 7. MATLAB Simulink model for EV charging.

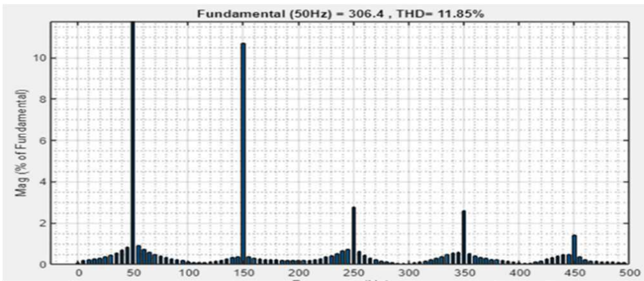
In this simulation, the three-phase source is used as the source feeder for the distribution grid, and the battery ratings are taken into account to be those of the EVs operating in Bangladesh. The model comprises of a 50 Hz three-phase source block operating at 33/11 KV distribution feeder, fed by an 11 KV/0.4 KV, 1 MVA delta/wye transformer. For measurement, there are instantaneous waveform scopes at the 11 kV and 0.4 kV buses. The simulation is done with a continuous solver and a 0 second simulation time.

C. Analysis of Total Harmonic Distortion

A power system's disruptions are called harmonics. Since an EV charger is a non-linear demand, harmonics are produced when it is connected to the electrical grid. The combined impacts of harmonics can pose a hazard to the whole power system because EV chargers are Harmonics are the sinusoidal component of periodic waveforms with frequencies that are multiples of the fundamental power frequency. Fig. 8 shows the MATLAB Simulink results of harmonics when EVs are connected to the transformer.



(a)



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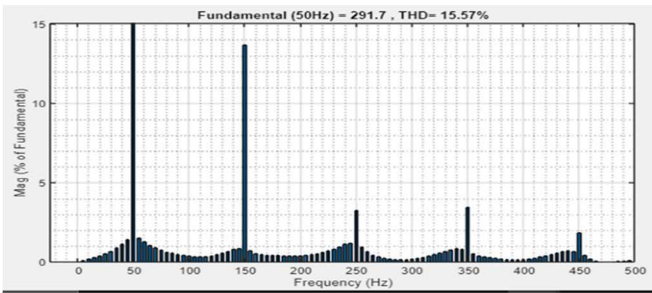

(c)

Fig. 8. Harmonic Distortion when (a) a single EV battery (b) 2 EV battery (c) 3 EV connected to single phase-a of the distribution transformer.

Fig. 8 clearly composed of odd harmonics, which has the distinctive feature of triple harmonics produced by the single-phase nonlinear load. Where, triple harmonics are the odd multiples of fundamental frequency. The higher the harmonic components of a quantity, the larger the distortions of this

quantity; in other words, the larger the deviations of this quantity from the sinusoidal fundamental frequency.
The value of THD should not be greater than 5%, as per the IEEE Standard for Harmonics Level, in order to maintain power quality. According to this investigation, the harmonics level exceeds the standard of good power quality.

D. Disturbance in voltage waveforms
When numerous EV chargers are connected, voltage drops occur at the transformer. The overload brought on by the enormous amount of EVs is the root of this issue. The voltage profile fluctuation before and after attaching an EV charger is seen in Fig. 9 and Fig. 10 .Comparing the voltage with and without the connection of EV chargers demonstrates how harmonic distortion affects the voltage.

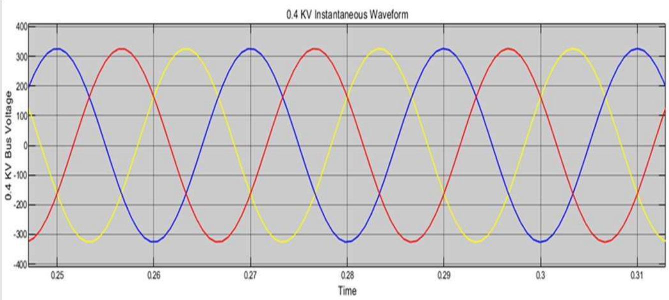

Fig. 9. Instantaneous Waveform of 0.4KV bus before connecting EV.

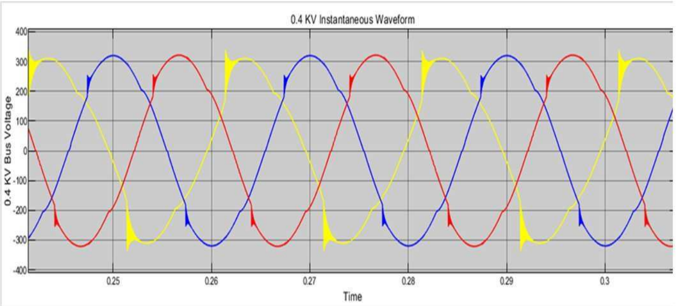

Fig. 10. Input waveforms of 0.4KV bus voltage when 5 EV connected to phase-a, phase-b and phase-c.

Above figures show the disturbance in the waveform of voltage due to the flow of EV charging or non-linear load. It can be seen that the voltage waveforms have notches. Voltage notching is a type of periodic waveform distortion produced by operation of power electronic devices. The notches in the voltage waveforms are caused by the commutating action of the rectifier as electric vehicle chargers have rectifiers.

E. Transformer power loss
Grouping EV charging might overload transformers and increase power loss. The copper and iron are the two types of losses that occur in the transformer. The copper loss relies on the current (ampere) flows through the windings of the transformer whereas the iron loss relies on the voltage (volts or kilovolts). The overloading scenario for a distribution transformer is shown in Table-1 based on simulation results from MATLAB with various EV loads.
Table-1: Measured transformer power for EV loads when 1, 2 and 3 EVs are connected respectively in phase-a.

TABLE I

Measured Transformer Power for EV Loads		
EV Loads (In Phase-a)	***Power (KVA) Measured at 11KV Bus***	***Power (KVA) Measured at .4KV Bus***
Single EV	191	220.8
Two EVs	183.5	214.3
Three EVs	177.4	208.3

As we know, the loss in a transformer compares the primary power to the secondary power. A step-down transformer decreases voltage but increase current. A transformer cannot increase the power. But from the above table, we can see a difference in power between the primary and secondary side of the bus which is occurring due to the non-liner load. The distribution transformer will experience greater losses as there are more EVs linked to it, which will reduce the system's efficiency.

F. Mitigation technique for power quality problem
Bangladesh currently lacks hybrid renewable energy-based electric charging stations. The number of electric vehicles on the road in the state is much higher. Setting up charging stations powered by renewable energy might be a reasonable solution to address this enormous demand.
The EVCS block diagram created by HOMER Pro program is shown in Fig. 11. This demonstration makes use of the PikaX3001 converter (8 kW), Trojan Sind 06 610 battery storage, LONGi LR6-72HV-350M solar PV module (0.350 kW), Generic Wind Turbine (10 kW), deferrable electrical load (1180 kWh/day), charging station load (431 kWh/day), and deferrable electrical load.

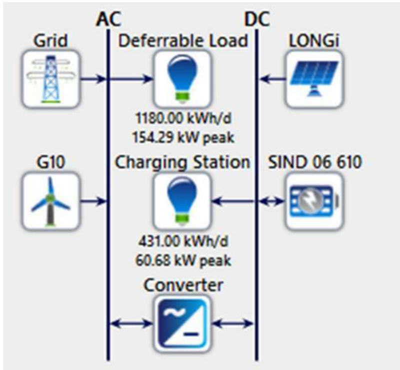

Fig. 11. Block diagram of EVCS designed by HOMER Pro software.

This model uses the solar irradiation from National Renewable Energy Lab and wind resources and temperature data from the NASA Surface Meteorology and Solar Energy. The load distribution of electric vehicles at the charging station is shown in Fig. 12.

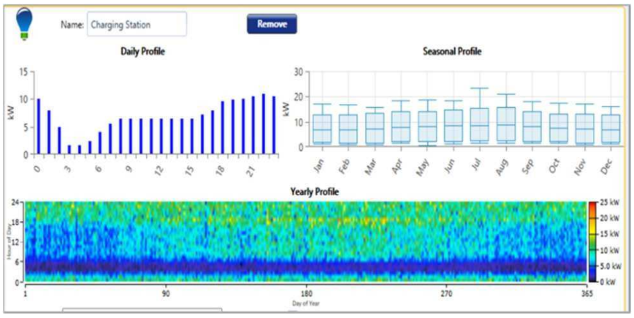

Fig. 12. Load curve of Hybrid Charging Station.

The station will be used to charge hybrid electrical automobiles in 2 hours, and one battery requires 4.4KW of electricity per hour to be fully charged. Therefore, assuming the station is completely utilized the total load that must be fulfilled is around 431 kWh and each day has a 60.68 kW peak.

VII. Conclusion

The market for EVs is more attractive to consumers due to its prominent qualities of lower environmental pollution and least expensive mode of transportation. Due to the shortage of charging stations in Bangladesh, household connections are where most electric vehicles are charged. Furthermore, the study focuses the impending shift in the equilibrium from conventional vehicles to EVs in Bangladesh. As this transition unfolds, it becomes evident that the high energy consumption required for frequent battery recharging carries significant implications for power grids and distribution networks. Of particular concern is the introduction of harmonics into the distribution grid resulting from the integration of numerous EV chargers. These harmonics, in turn, have the potential to disrupt voltage profiles, contribute to power losses, and affect the overall quality of electricity supply. However, the penetration of EVs degrades power quality and increases the vulnerability of the distribution transformers. In this study, MATLAB Simulink is used to analyze challenges with power quality such as harmonics, voltage fluctuations, and transformer power losses. The stability of the power system is threatened by these disturbances that were found in the MATLAB simulation. Therefore, it is important to reduce power quality issues to ensure energy supplies & effectiveness in the power sector. This study also discusses the mitigation strategy using easily obtainable renewable resources. Bangladesh has a lot of potential for renewable energy sources including solar and wind. In order to overcome these power quality obstacles, such resource integration for EV charging can be a great option. As electric vehicles continue to gain prominence globally, it is imperative to address the associated energy and grid-related issues, and this paper offers a foundation for further research and policy development in this domain.

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