Optimized Sizing and Analysis of Grid-Tied Renewable Energy based EV Charging System

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Abstract: The transport sector is one of the major emitters of greenhouse gases GHG, which pollutes the atmosphere system and affects the respiration system in living organisms. It also produces extreme heat and a noisy environment. On the other hand, due to increasing prices and the depletion of fossil fuels, there is an increased focus on transforming fossil fuel-based automobiles into green and clean sources of energy; this is possible only to work on renewable energy-based electric vehicles (EVs) and AI-based EVs charging station, Pakistan is also facing stressed climate change in the context of the warned situation of the worst air quality index. The transit shift from fuel-based vehicles (FFVs) to electric vehicles is, therefore, unavoidable and the best way to protect the country's transport sector from decarbonization.

Keywords: *Electric Vehicle Charging Station, Hybrid EV Charging System, GWO-based EV Optimization, Renewable Energy System, Nooriabad Sindh Pakistan*

1. Introduction

Pakistan's energy and transport sectors are primarily powered by fossil fuels, and according to a global survey, it is the worst country in terms of climate change [1]. On the other hand, as per the World Air Quality Report 2020, it is the world's second-worst emitter of greenhouse gases [2]. Year on year, consumption of fossil fuel oil is increasing dramatically in the country, where inflation in the economy and increased fuel prices in international markets have forced inhabitants to fall below the poverty line. Although Pakistan imported oil with a larger desire in the 1990s, it was substantially reduced due to the use of gas extracted from their own resources up until 2016 [3]. Because of this drop in oil prices, Pakistan once again relied on imports. Figure 1 depicts the current state of the situation, which shows massive oil use up to 2020 [3]

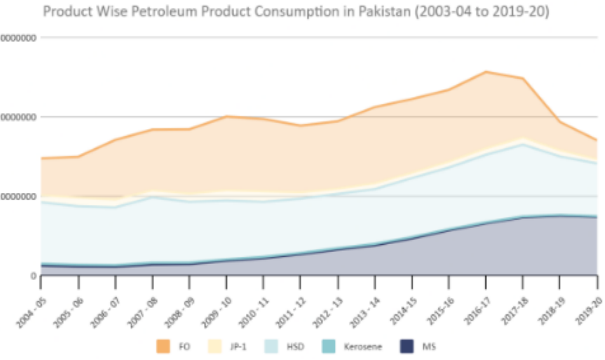

Figure.1. Oil Consumption Statistics in Pakistan

The transport sector of Pakistan has been overwhelmed for a long time. Low reliability and high fuel costs hinder the country's economic growth [4]. And conventional vehicles will have a drastic impact on polluting the environment by 128% by 2030. These emissions could increase from 35.4 metric tons of CO2e in 2012 to 80.7 MtCO2e in 2030. Instead of high emissions and fuel prices from transportation, the growth of vehicles is still increasing day by day due to population growth, which pollutes the environment [5]. In the fiscal year 2020–21, the population of Pakistan increased from 209.47 to 213.84 in comparison with the previous year. Furthermore, the number of cars per 1100 people is growing at a rate of 21, which shows Pakistan's move towards urbanization [6]. According to the report for the 2018 year, almost 18.2 million vehicles were registered, which is further expected to increase by 30.1 million by 2025, which will consume 302,000 barrels of oil per day as shown in Table 1 [7].

Table.1. Vehicles' Growth in the Transport Sector

S.No	Year-wise Growth	Road passenger vehicles	Road Freight Vehicles	Aviation
1	2015	23.5	14.5	1.7
2	2020	29.1	18.9	3.2
3	2025	36.1	24.2	3.5
4	2030	45.2	30.6	4.3

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Instead of high emissions and fuel prices from transportation, the growth of vehicles is still increasing day by day due to population growth, which pollutes the environment [8]. In the fiscal year 2020–21, the population of Pakistan increased from 209.47 to 213.84 in comparison with the previous year. Furthermore, the number of cars per 1100 people is growing at a rate of 21 and is still increasing as Pakistan moves towards urbanization. Shortfall crises are always there with a country's power generation capacity. This excessive generation of electricity demands a higher fiscal cost. Power producers must pay large capacity charges; this price is expected to reach $1,500 billion by 2025 [9]. Pakistan's current contributors to electricity are thermal energy, which is the main contributor to CO_2 and toxic gases [9]. For this reason, the federal government started an initiative to set a target of 20% renewable energy-based generation by 2025 and, up to 2030, 30% by the national grid. This target to reduce CO_2 emissions is undertaken. RE sources are utilized by Pakistan to achieve climate change agreements. Other than the industrial sector, the transport sector is one of the major contributors to air pollution; statistically, the emission of GHG in the country is 168.44 tetra grams, from which the transport sector is purely responsible for 22.83% in the equivalent of 38.1 telegrams [10]. This growth in vehicles is highlighted in Fig.2.

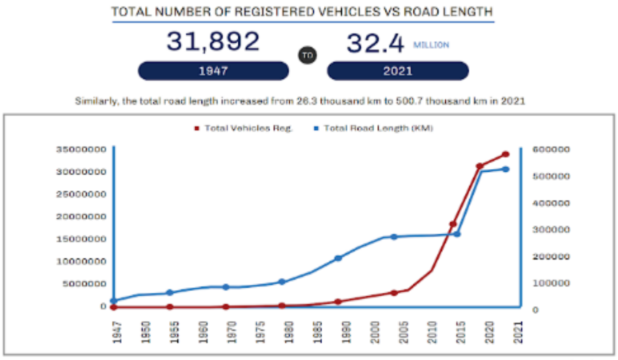


Figure.2. Growth in the Transport sector of Pakistan

A potential way to address this climate change issue is renewable energy-based power generation and RE EVs, which help lower capacity-based payouts and produce profitable revenue as EV charging station is indicated in fig.3

Figure.3. EV Charging Station

2. Research Aim and Objectives

The aim of this research is to determine optimized sizing and relevant analysis of renewable energy-based grid-tied EV charging systems.

- To investigate renewable energy potential.
- To design a solar energy-based grid-tied EV charging station by using GWO for optimal sizing.
- To analyze the results.

3. Location Details and Energy Resources

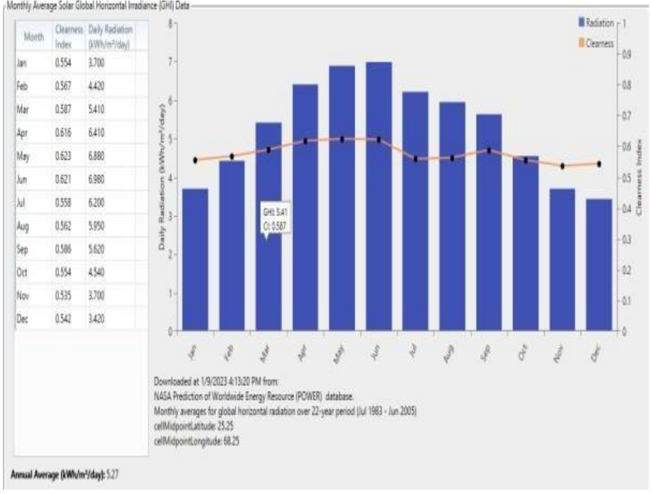
The city of Nooriabad is in Pakistan's Thatta Sindh district, with latitude and longitude of 25.273685° and 068.487069° respectively.

Figure.4. Map of Noori-Abad Location

Fig.4 shows the huge potential for solar and wind energy in this region. That is impacted by the huge flow of transport sections towards Karachi, the country's trade hub.

3.1 Solar Energy Potential in Noori-Abad

According to NASA's Global Solar Report for January 2023, the direct normal irradiance annual average is 1688 KWh/m^2, and the specific power production is 1750.8 kWh/kWp. The average of the monthly DNI data for Nooriabad is shown below. This information is based on data from the global solar atlas, which shows that in June, radiation reaches a maximum of 6.98 $kWh/m^2/day$ and a minimum of 3.420 $kWh/m^2/day$, with an average of 5.27 and 6.98 $kWh/m^2/day$.


Monthly Average Solar Global Horizontal Irradiance (GHI) Data

Month	Clearness Index	Daily Radiation (kWh/m²/day)
Jan	0.554	3.700
Feb	0.567	4.420
Mar	0.587	5.410
Apr	0.616	6.410
May	0.623	6.880
Jun	0.621	6.980
Jul	0.558	6.200
Aug	0.562	5.950
Sep	0.586	5.620
Oct	0.554	4.540
Nov	0.535	3.700
Dec	0.542	3.420

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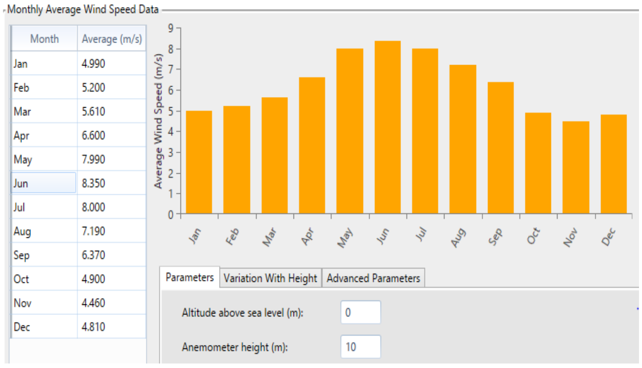
NASA Prediction of Worldwide Energy Resource (POWER) database.
Monthly averages for global horizontal radiation over 22-year period (Jul 1983 - Jun 2005)
cellMidpointLatitude: 25.25
cellMidpointLongitude: 68.25

Annual Average (kWh/m²/day): 5.27

Figure.5. Solar Potential in Nooriabad

3.2 Wind Energy Potential in Noori-Abad

Nooriabad's location has a significant potential for green sources of wind energy. This data is taken from the global wind atlas, which has a maximum wind speed in June, a minimum in November, and an average wind speed of 8.35 m/s, 4.4 m/s, and 7.68 m/s, respectively, at a height of 100 m, as shown in fig.6. This persuades me that Nooriabad's location has rich potential for PV solar and wind energy, thus making it suitable for the installation of an EV charging station to charge all types of vehicles travelling to and from the hub of trade in Pakistan to reduce daily emissions along with fossil fuel costs.



Month	Average (m/s)
Jan	4.990
Feb	5.200
Mar	5.610
Apr	6.600
May	7.990
Jun	8.350
Jul	8.000
Aug	7.190
Sep	6.370
Oct	4.900
Nov	4.460
Dec	4.810

Altitude above sea level (m): 0

Anemometer height (m): 10

Figure.6. Monthly wind potential in the Noori-abad location

4. System Designing and Description

The system is designed for seven Electric Vehicle rickshaws. The motor used for testing purpose is rated at 3 kW, due to lighter in weight. The small and efficient battery used in an electric rickshaw is 48 volts, 135 Ah, and 6 kWh. Research methodology opted for designing the system consists of three ways to achieve the research aim. The best way to start before designing the system is to draw a block diagram of the system. A block diagram of a RE-ESU-based charging station is clearly visible in Fig.7

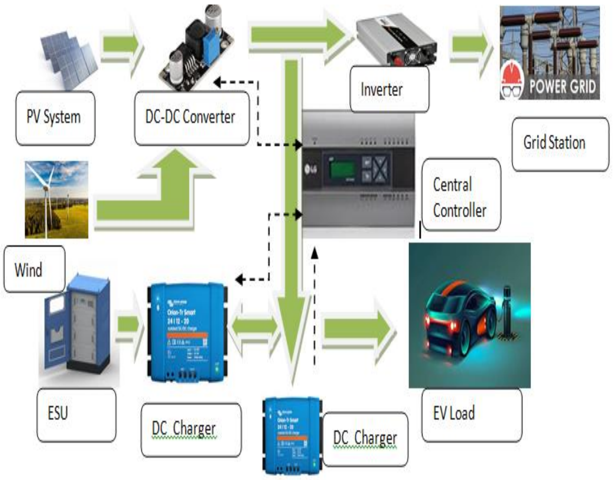


Figure.7.RES-based EV Charging

➡ = Power Lines - - - - -➔ Z= Communication Lines

4.1 Modeling of Electrical Components in Matlab

This whole system of an EV charging station is modeled in MATLAB by designing different subsystem, and Grey Wolf Optimization (GWO) AI-based technique is used to achieve the optimal results. The following are the subsystems explained one by one.

4.1.1 Modeling of PV Power

Simulink PV arrays are modeled for solar panels using built-in blocks. This model consists of three sections: the Photovoltaic (PV) model, the Gray Wolf Optimization (GWO) algorithm for the Maximum power point tracking (MPPT) charge controller, and the boost converter. With the change in solar irradiations and temperature, both the voltage and current of the PV module are changing; thus, the duty ratio changes. It adjusts itself to extract the maximum power from the solar module and send that power to a DC-DC converter, which either works as a buck converter or boost converter and tries to track the maximum power extraction. The module used in the PV array is a 1-Soltech 1STH-215-P with two parallel strings and six series-connected modules in each string and a maximum power of 213.15 watts.

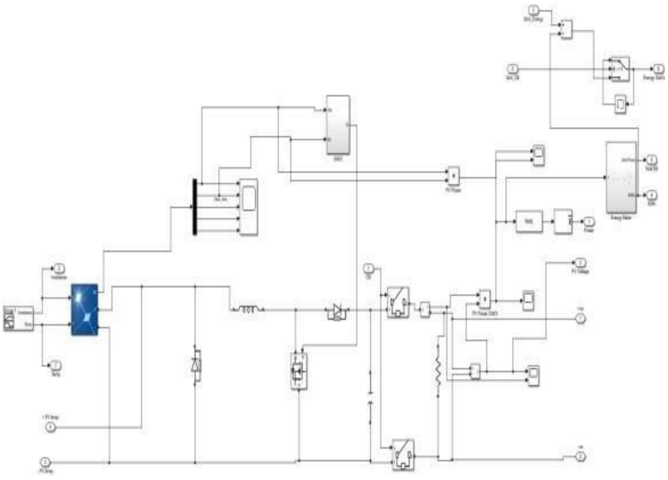


Figure.8. PV Array in Simulation Model

4.1.2 Modeling of MPPT Charge Controller

Maximum power point tracking (MPPT) is a technique with uncertain output sources, like the PV model, The MPPT controller is used to track maximum power. One of the major problems in PVs is that the output efficiency is dependent on irradiance, temperature, and load; all these inputs are variables; therefore, efficiency varies. In this paper, MPPT controllers are used with the gray wolf optimization (GWO), which works for iteration, initialization sequence PV, solar PV current, and voltage, respectively.

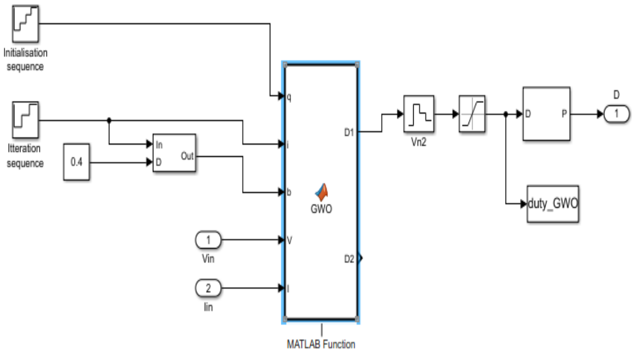


Figure.9. GWO MPPT-Based Function

4.1.3 Modeling of Energy Storage Unit (ESU)

ESU is modeled using the generic battery type of lithium-ion battery as shown in Fig.10, The battery system used with charge controller aims to protect the battery from overcharging, over-discharging, and fluctuations. Controller connects with ESU through a boost converter with the main DC line; when the charging level touches peak, a battery bank is used to allow the charge from solar panels.

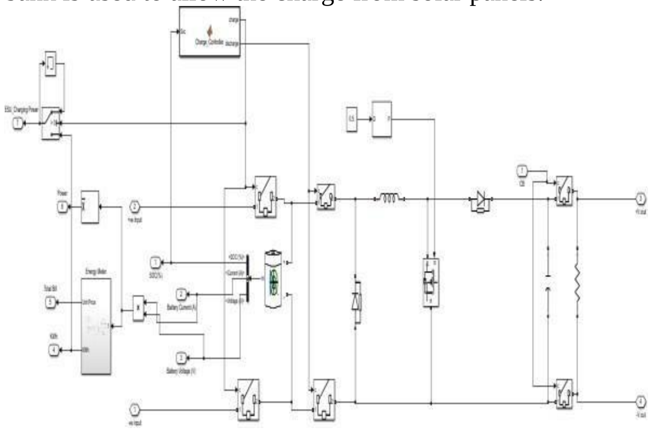


Figure.10. Energy Storage Unit (ESU) for backup charging

4.1.4 Modeling of EV Power

The power requirements of the EVs are modeled using a lithium-ion battery. This block connects with the DC line using a buck converter. Fig.11 shows how ESU power is calculated using the battery, current, and voltage before being supplied to an energy meter to determine kWh and the cost of energy per unit consumed as a load.

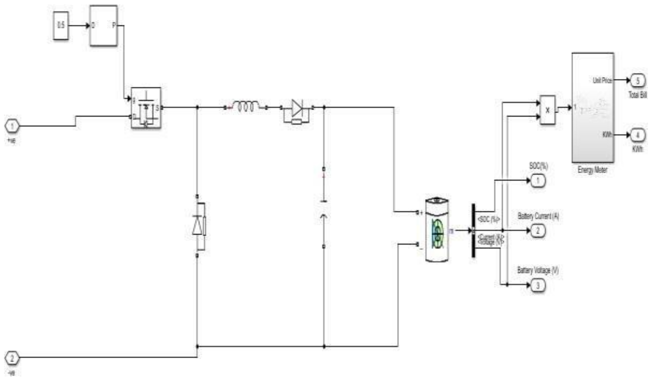


Figure.11. Modeling of Battery EV Block

4.1.5 Modeling of Grid Station

In this research, the grid is modeled by using the RLC branch and AC source in the Simulink model. The transmission line model is neglected as the grid is proposed to be near generating station as shown fig.12.

Figure.12. Single Phase Model of Grid Station

4.1.6 Modeling of Rectification Block

This block is connected between the grid and the EV charging station, as shown in Fig.13. The output of this rectifier is further smoothed using a capacitor, which consists of an energy meter to calculate per unit price and kWh energy consumption by ESU and EV load as well.

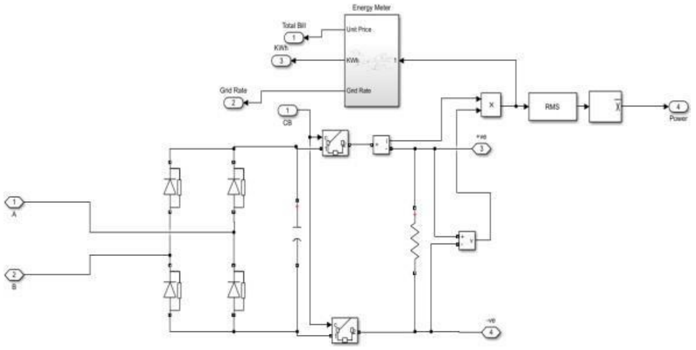


Figure.13. Modeling of Rectifier Block

5. Results and Discussions

In previous subsystems, electrical component modeling and the GWO algorithm were discussed. For a better understanding of the charging system, Optimized results of simulation are most important to learn, for that results from each source of the system are discussed one by one.

5.1 Results of PV System

At the initial stage, solar irradiance has a constant value up to 0.5s; then, after the dawn rays increase and touch the maximum generation capacity of 750 W/m^2, again intensity of light decreases up to 1.1s. This repeated intensity graph is achieved and sampled as day-night. A similar situation is for temperature occurrence. Fig.14 shows the output of PV voltage, current, irradiance, and temperature. Initially, PV voltage and current are at their minimum, then change after the sun's rays are drastically increasing and reach their maximum. At 1.1 s, it becomes constant again.

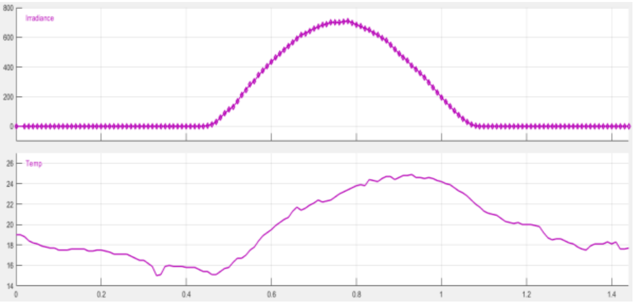


Figure.14. Temperature and Irradiance Graph

5.2 Results of MPPT Converter

GWO algorithm implemented for MPPT controller based on the output of PV system, which is supplied to MPPT controller via DEMUX, GWO block generates duty cycle for extraction of maximum power from PVs as shown in fig.15. In the first occurrence, due to constant irradiance, there is no PV to GWO power, which shows constant voltage in the boost converter, and then it varies increasingly when the day begins. In this span, some spikes are found due to the intermittent nature of solar. At a peak value of approximately 750 W/m^2 PV power, GWO has a maximum of 5700 W due to extraction of maximum power by MPPT charge controller, after 1.1s, it decreases to a minimal value.

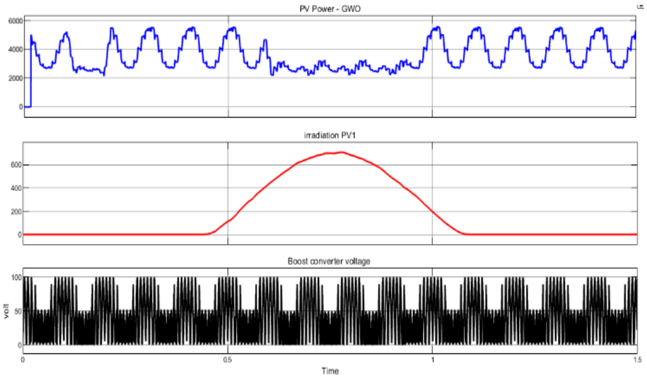


Figure 15. PV GWO Power, Boost Converter Output & Irradiance

5.3 Charging of EV with Different Operating Modes

EVs can be charged via PV arrays, wind sources, ESUs, and finally grid connections. The main objective is to charge EV systems from renewable energy sources and maintain reliability and availability of charge; for this reason, modes of charging are optimally selected by the GWO algorithm.

The first graph in Fig.16 shows an EV SoC graph in which an EV load is continuously charging with different modes of power from "PV, Grid, and Energy Storage System" to avoid interruption of EV charging. The left side of Figure 16 has four electric outputs from the system. The last three graphs in Fig.16 show EV charging from various modes, i.e., GRD2EV, ESU2EV, and PV2EV, at minimum and maximum irradiance levels, respectively, which guarantees an interruption-less charging station model for an EV system. Furthermore, the interpretation of the below modes is: "Due to the lower value of irradiance and temperature from 0 to 0.48 s, power flow from the solar system to EV is less than EV demand; initially, EV is charged by grid supply; at 0.2 s, when grid power is load-shaded, EV is charged by ESU as that time sun is not available; after 0.48 s, there is sun energy; hence, EV demand is satisfied by sun energy; sun energy of 5.5 kW is achieved with a maximum 750W/m2. At the same time, grid supply is minimized, and systems (EV and ESU) are charged from renewable energy sources. On the right side of the system, the first graph measured a fixed energy rate of PKR 18 without a source rate in the figure. 16. The last two show the nature of irradiance and temperature; the sun is rising towards its peak value from 0.5s to 1s. The values of temperature and irradiance for solar are also are increasing to their peak of 750W/m^2, so most EV charging demand from 9 a.m. to 5 p.m. is fulfilled by PV systems.

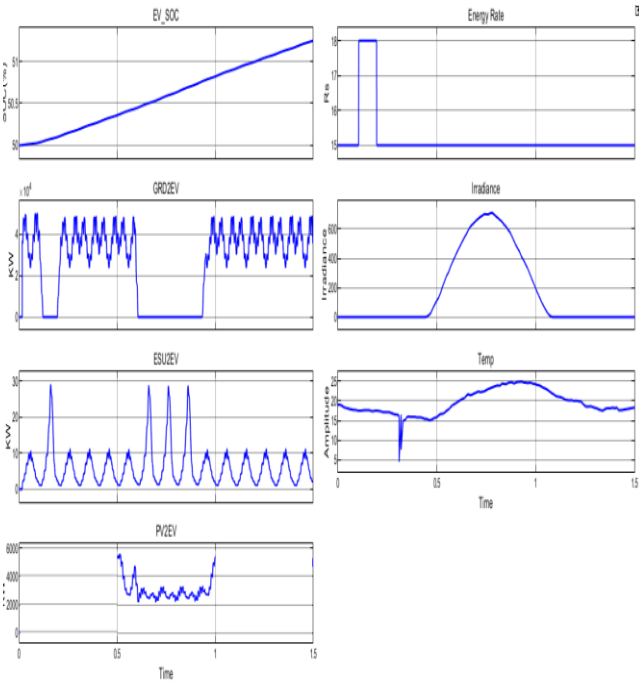
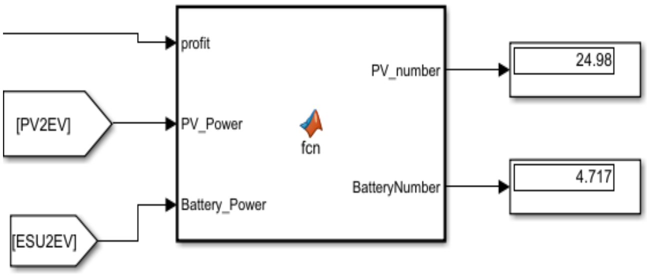


Figure.16. EV Charging with Different Modes

5.4 Optimized Results by SCADA System

According to the discussion above, the electric source for the main grid source varies from time to time, and the SCADA system monitors the SOC of ESU, so when peak tariff starts from any source, SCADA switches the source to minimum value-based energy and the whole operation rotates as PV2ESU, W2ESU, and Grid2ESU, and when it meets the SOCU limit, surplus solar power is delivered to the grid, usually between 11 a.m. and 5 p.m., where the SCADA system checks the quantity of PV and batteries at each iteration level in order to achieve even a minimal profit but not a loss, as shown in Figure 17: “23 PV panels and 5 batteries are required to charge 7 EV rickshaws”.

Figure.17. Optimized number of PVs and Batteries



5. Conclusion

Evidence from the results and discussion is analyzed, which suggests that EV systems are charged reliably from the proposed system irrespective of energy source, whether wind, PV, ESU, or grid. The optimal sizing of the EV system charging is accomplished using GWO for the developed system, and the SCADA system helps to charge it from RE-based sources by comparing the availability of sources and the cheaper paper of those sources without affecting the reliability of EV charging and supplying the surplus energy to national grid stations with a target of even less profit but not loss. The developed system helps to reduce losses and calculates the number of PVs to be 5 and the number of batteries to be 25, with a rated storage of 175 Ah. This system uses 5500 watts of PV and 4 kW of national grid data to charge 7 SAZGAR rickshaws.

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