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Cost-effective analysis of hybrid electric vehicles charging station

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K E Y W O R D S

Distributed Generation

Electric Vehicles

Internal Combustion Engine

Plug-in Hybrid Electric Vehicles

Photovoltaic

Renewable Energy Resources

A B S T R A C T

Electric vehicles (EVs) are a very essential part of the automobile industry and play a vital role in the development of the economy of a country. Due to their eco-friendly nature and lower operating cost, EVs have acquired great attention globally. Almost all leading automobile manufacturers are developing cost-efficient EVs. However, with the increase in the number of EVs day by day, the need for efficient charging stations to deliver economical charging needs to be developed. To charge these EVs from the conventional grids is an additional burden on these grids as more electricity will be required to charge these EVs, which may result in incremental energy production as well as the energy cost for the general consumers. These days, increasing the number of EVs can bring sustainability problems in Pakistan as the considered country already facing the worst electrical energy crisis in the last ten years. For this purpose, we must require some alternate methods for charging the EVs charging to avoid overloading on existing grids. The use of renewable energy resources (RERs) is an effective solution to tackle this shortage of power. Therefore, in this paper, a cost-effective solution is proposed by hybridizing the different types of RERs to charge the EVs from the charging station. A different combination of RERs is used as case studies for a specific area of Pakistan named Kallar Kahar. Simulation is performed on MATLAB/Simulink and energy cost is being compared for different case studies. The proposed hybrid power system used approximately 50% wind, 40% solar, and 10% biogas as RERs. The results show that case 4 is best among all which provides yearly power production of 375,220 kWh at a net annual cost of 43,174.06$/year while the net annual cost to provide the same power with the grid is 59,304$/year. There is a 1.37% reduction in the overall annual cost of the proposed charging station as compared to the utility grid.

1. Introduction

Growing issues concerning worldwide global warming, air pollution, and oil shortages caused the development of energy-efficient and clean cars referred to as EVs [1]. EVs are predicted to become a primary component of the energy grid due to their environmental, social, and economical benefits. There are many advantages of EVs over traditional fuel cars such as low pollution, low per-mile cost, easy maintenance, opportunity to use renewable power sources, and rapid charging cause EVs to be the potential future of transportation [2]. New generations of EVs and PHEVs have prolonged mileage, thereby increasing their comfort to be used in everyday life[3]. For example, Chevy Volt can tour as much as forty miles in one charge and has a 375-mile range while

using an ICE [4]. Moreover, EVs are more power efficient then fuel cars which makes EVs less expensive [5]. Smart charging methods are available in modern charging systems [6]. We now live in a time when power has become critical to a country's development. Every country wants to improve its generation capacity by utilizing all available energy resources, yet increased generation from geothermal, nuclear, and diesel power plants has had severe environmental implications. These power plants run mostly on fossil fuels and produce large amounts of harmful chemicals into the atmosphere, such as carbon dioxide, nitrogen, sulfur, and carbon monoxide. Air pollution is a critical problem that is now being tackled all around the world [7]. In comparison to non-renewable energy resources, the international trend is shifting toward the use of RERs. For ages, people have depended on renewable sources including wind, solar, microhydral, and biogas. These materials are accessible at all times and do not pollute the environment. The only drawback to using renewable energy is the hefty capital costs connected with their installation [8]. However, thanks to advancements in technology, the cost of renewable energy equipment has reduced to lower levels in the current day. The electricity usage per hour of the people can simply determine a country's technological progress. In the case of our country, Pakistan, this figure is far lower. We must also create new methods for generating electricity from these renewable resources.

This is well known that the rising expense of conventional fossil fuels has an impact on the global electrical and transportation sectors. Furthermore, these two sectors account for the majority of global GHGs (Green House Gases) emissions. As a result, for Pakistan's long-term growth, now is the moment to prioritize RERs over petroleum resources. For the transportation and electricity generation industries, the scarcity of fossil fuels and their rising costs is a major issue. It is vital to meet the electrical demand in both urban and rural areas to encourage sustainable development. Solar, biogas, and wind are examples of renewable energy sources that can provide electrical demand in remote areas when grid electricity is unavailable [9]. The current energy picture clearly indicates that optimizing the use of RERs in our generation is a viable solution for meeting the country's energy demand[10]. Hafiz Bilal and Syed Jawad [11] concluded from their research that RERs must be developed to alleviate the present energy crisis. Renewable energy sources (RES) such as the sun, biogas, and wind can all be used to create electricity in Pakistan to charge EVs.

Transportation uses a considerable amount of energy, accounting for 48% of petroleum energy and 12% of overall natural gas use. Furthermore, Pakistan only reserves 8% of total petroleum demand, 1.6 million tons of crude and 2.9 million barrels of refined oil to be imported each year [12]. In the year 2017–2018, its energy imports were around US$ 14.4 billion as compared to US$ 10.9 billion in the previous year [13]. This increase is due to the higher energy prices. There is also a shortfall of above 5000MW between supply and demand in Pakistan which becomes wider in the summer season. This deficiency results in a 4%–7% reduction in the country's gross domestic product [14]. Furthermore, the energy and agriculture industries are going to accelerate CO2 emissions [15]. The growing amount of freight cars required to assist the large population is a warning sign of pollution and petroleum consumption. So, to increase the country’s economy and to reduce pollution to eliminate the risk of GHGs (Green House Gases), EVs are the best option [16] but its charging in Pakistan is a critical issue.

In Pakistan, charging stations rely on grid electricity, however, off-grid rural places make this form of EV charging almost difficult. As a result, Pakistan needs stand-alone hybrid renewable energy generating [17]. To address the following EV charging challenges, Pakistan needs to build a sufficient charging network, a charging facilitation framework, and a charging plan. In addition, a cost-effective alternative strategy to electricity production is needed to lessen the demand on the national grid while sustaining good quality power throughout the country.

So, to overcome this electricity and charging station problem a hybrid charging station based on solar, wind, and biogas energy is constructed in this research using MATLAB software, and then cost analysis of this hybrid charging station is done with the present grid to check how much cost will be reduced.

1.1 Literature Review

The combination of PV with wind electricity has been mentioned in [18]. However, such a system needed either a grid link or a storage system to continuously supply load power. The use of storage devices combined with the PV sources can offer an important means to deal with the functions. The careful selection of energy storage technology and its size layout enable better deregulation on the demand side, leading to lower

running costs. The authors in [19], have used the battery storage system in grid connection and PV device to enhance power quality. Providing a stable electricity generation for PV systems was the main concern of energy storage system in [20]. An energy management method is discussed in [20] to control PV devices in combination with a storage system to produce constant power. In [21], the Battery storage system turned into linked to the grid along with the PV system to decrease fluctuations on the way to maximize incomes, while keeping utility restrictions on PV power that may be supplied to the grid. The battery sizing has been mentioned in [22].

The EV charge scheme in Shenzhen, China, has been studied in [23] To verify its technical and economic viability. The results reveal that the total cost of the PV and grid station meets 4,500 kWh a day. In this situation, the entire system costs roughly 0.097 kWh. The sensitivity assessment was carried out to determine parameters for the EV price method, PV system capital and tariff feed-in guidelines. The author concluded that the energy cost will grow from 0,028 Kwh to 0,098 Kwh, with an increase of 0 to 5%.

Reference[24], Designed a PV and electrical grid hybrid loading system for workplace parking. In the process of analyzing numerous solar radiation and price behavior, two different locations, Columbus Ohio and California, were established in Los Angeles. Multidisciplinary EV load planning relates significantly to a centralized approach. The sensible approach aims at decreasing the grid power and maximizing the use of photovoltaic power. A smart strategy is seen to improve economic performance.

Reference [25] has developed a photovoltaic charging station in the Congo for small electric-powered trucks. The charge station is connected to the wind turbine, battery storage system and photovoltaic system. 7 kW wind turbines and 19 battery storage system cells provide the best arrangement. The wind turbine generates 1517 kWh/year.

In this paper, several points of research focus on the advantages of combining PV, wind, and biogas turbines with battery storage systems to offer stable electricity at lower operational costs. We presented a complete PV, biogas, and wind hybrid charging station economic analysis in this paper as a case study for Kallar Kahar Pakistan. Simulation is done through MATLAB software. After simulation cost comparison is done manually by checking the number of units consumed in all cases through MATLAB simulation. With the help of these results, we can clearly identify which method of EV charging is most viable for any particular location.

There are total nine sections of this paper. The second part discusses the problem statement, the third part discusses the contributions for the proposed system, the fourth part discuss the methodology, the fifth part discusses the data of the proposed system, the sixth part discusses the specifications of the equipment, seventh part shows the Simulink model of the system, eighth part discusses the simulations and results and the final section of this research paper includes the conclusion.

2. Problem Statement

In Pakistan with 16700 MW of generation and 21600 MW of demand, the power gap reached 4900 MW in mid-2015, and it has been increasing since then. This is a very concerning scenario. According to reports, just 60% of Pakistan's population has access to power. In this alarming condition, Pakistan approves its EV policy and gives different benefits to consumers for promoting EVs in Pakistan. As more EVs will import to Pakistan, more electrical energy will be needed to charge these vehicles. And Pakistan is already facing the worst load shedding from the past few years. So, these vehicles will burden the grid which will result in more shortage of electrical energy and more load shedding.

Hence, the solution to this problem is given in this paper which is the combination of solar, wind, and biogas energy to make EVs charging stations so that the shortfall of electricity does not affect the use of EVs in Pakistan.

3. Contributions

The following are the main contributions:

- Proposed a cost-effective solution of charging system for EVs that employs solar energy, wind energy, biogas energy, grid connection, and a storage system.

- Shifting charging system of EVs from grid power to RES power to reduce the burden on the grid.
- Calculating the total cost involve in charging EVs from RES as compared to grid.
- Ensuring proper power management between hybrid sources and EVs.

4. Research Methodology

The hybrid system is a mixture of renewable and non-renewable energy forms. To develop and analyze the proposed system, first of all, examine the load profile of the chosen location. As Kallar Kahar is the selected location in our research. Its load profile is given below. After this identify the existing supply system and local tariff. In our case, IESCO is providing electricity to Kallar Kahar. Next is to collect the climate data for the selected location. In the case of our research, detail of climate data is given below. Then based on climate data propose which sources of renewable energies are to be used here by modeling the system in MATLAB software. In last simulate the model with the lowest Net annual cost and identify the best configuration.

5. Data of Proposed System

5.1 Load Profile of Selected Area

Kallar Kahar a city of Pakistan is selected as a case study for this research. Its latitude is 32.7769° N, and its longitude is 72.7068° E [26]. Load demand and charging time from different electrical vehicles owners are taken and implemented in this simulation. Load demand increases in the morning and then decreases at night. This load demand can also vary day by day. The load profile of the selected location is given in Fig. 1.

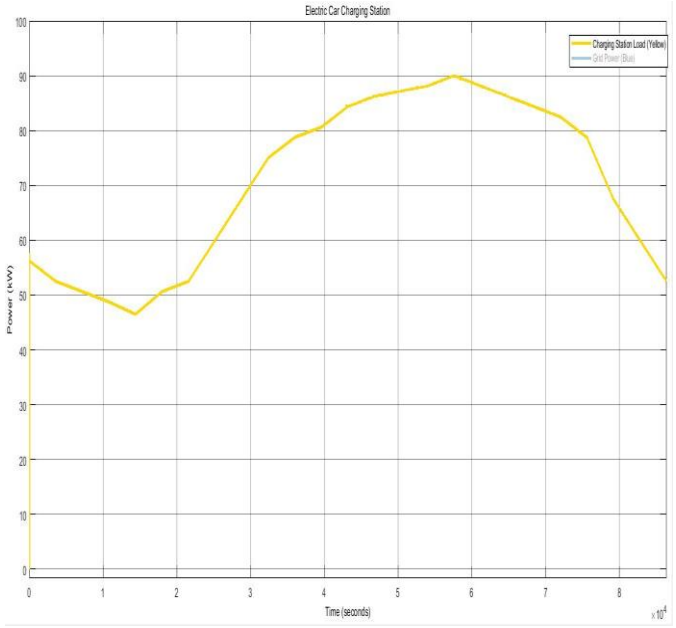

Fig. 1. Load profile of selected location

5.2 Solar Input

Sunlight is accessible in Kallar Kahar for maximum duration. This area's solar irradiance graph is illustrated in Fig. 2. This graph is taken from HOMER software.

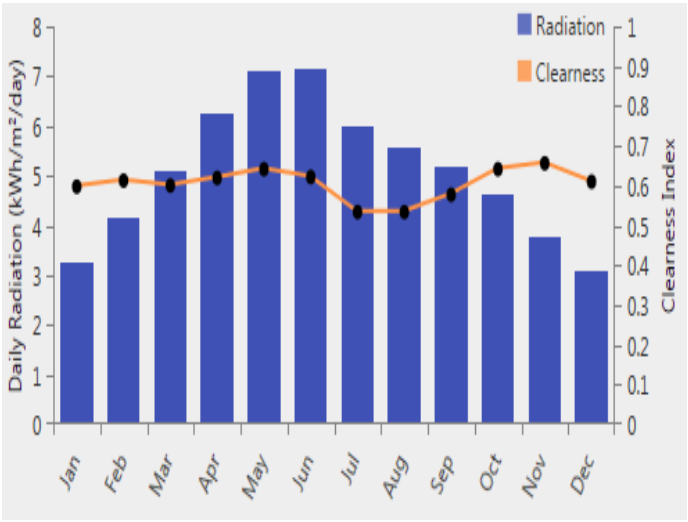

Fig. 2. Kallar Kahar solar radiations [27]

It shows that the average amount of solar radiation in May and June is close to 5.13 KWh/m2/day which can generate enough electricity.

5.3 Wind Inputs

Kallar Kahar is also feasible for wind energy generation. The average yearly wind velocity in this location is 7.3 m/s, with maximum wind speed in May and June, as shown in Fig. 3.

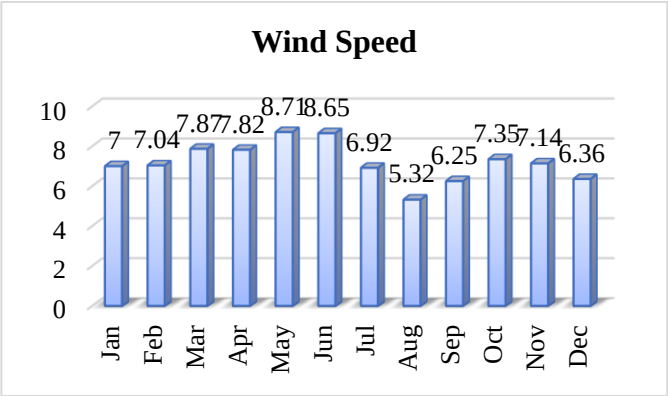

Fig. 3. Monthly average wind speed [27]

5.4 Biogas Inputs

There are many villages around this city. Different type of biomass is available in large quantity. Fig. 4 shows that an average of 120t/d of biomass is available in this city. This quantity is very large and it is suitable to generate enough electricity.

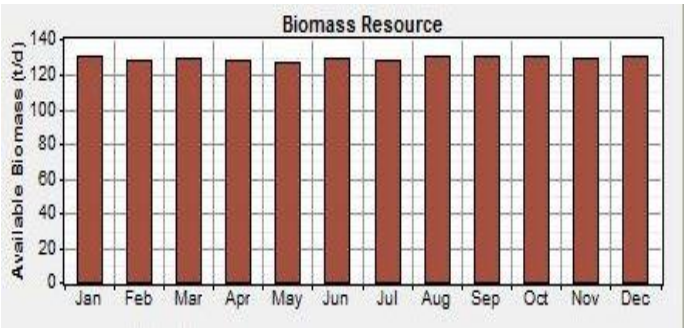

Fig. 4. Biomass availability [27]

6. Specifications of the Equipment

The following are the specifications for the various components:

1) 40kW from PV panels. These panels have a capital cost of 11329.57 $ and a life expectancy of 10 years. So, the initial cost for one year will be 1168.57 $.

2) 50 kW from two Eocycle EO25 Class III wind turbines (each with a 25 kW capacity). These two turbines have a capital cost of 19390.56 $. The life span of these turbines is 20 years so the initial cost for one year will be 1000.29 $, a replacement cost of 7,000 $, and an operation and maintenance cost of 150 $ per year is also associated with it.

3) 10kw from biogas turbine which has an initial cost of 3874.71 $. The life of this plant is 10 years, so the initial cost for one year will be 400$.

4) The power from the PV panels is converted into AC using a 100kW converter. The converter's capital cost is listed as 7376 $. The converter is predicted to have 95 % efficiency and a 25-year lifetime.

5) In this system battery of 6V is also attached. It is calculated that integrating 8 batteries into the system will cost 29218.4 $, and the cost of operation and maintenance will be 20 $ per year.

7. Simulink Model of System

The proposed system is grid-connected and has a total power output of 100 kW. The model of the system is shown in Fig. 5. The DC link connects the PV panels and biogas with the battery. This link is linked to an AC link via a bidirectional AC to DC and DC to AC converter. The load, wind turbine, and grid supply are all connected by the AC link. This system is expected to last for 25 years. A diesel generator is also connected to this system to provide power in an emergency case when grid or renewable is not present at any time.

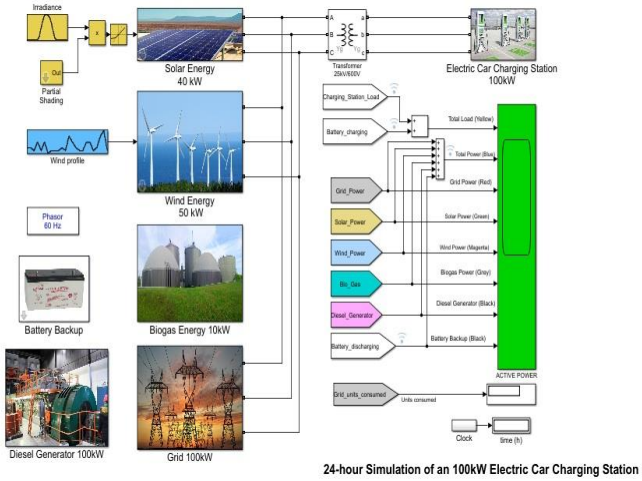

Fig. 5. Simulink model of proposed charging station

8. Simulations and Results

The total outcomes of hybrid charging station are divided into four cases:

Table 1

Cases Division

Case	Description
Case 1	When the only source of electricity is the grid
Case 2	When renewable energy contributes to the majority of grid supply
Case 3	When battery backup is added to the proposed system
Case 4	An emergency case when diesel generator is added

- Simulation results of case 1 according to table 1 are provided in Fig. 6. When the grid is the dominant source of power and renewable energy

is not included with it, then we have to face two major drawbacks:

1. Expensive per unit
2. CO2, CO, N, and other hazardous gases will pollute the environment.

Fig. 6 also shows that 1028 units are consumed by the load in 24 hours. These units are used to calculate the bill. Bill is calculated through the official website of Islamabad Electric Supply Company (IESCO) as IESCO is providing electricity to Kallar Kahar. With the help of cost analysis given in table 2, it is shown that this system is very expensive with the highest net annual cost.

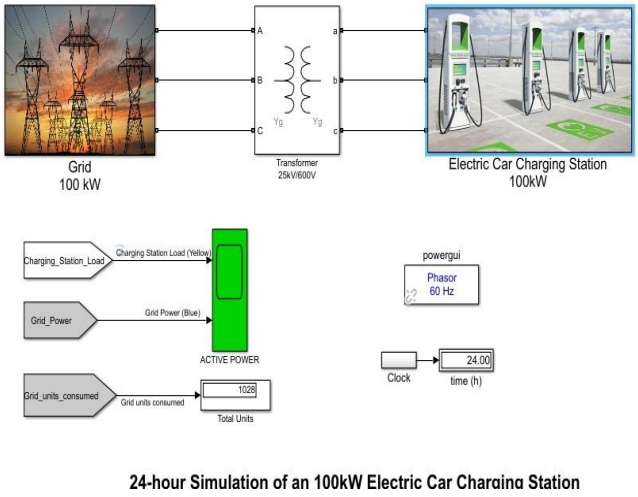

Fig. 6. Grid only case

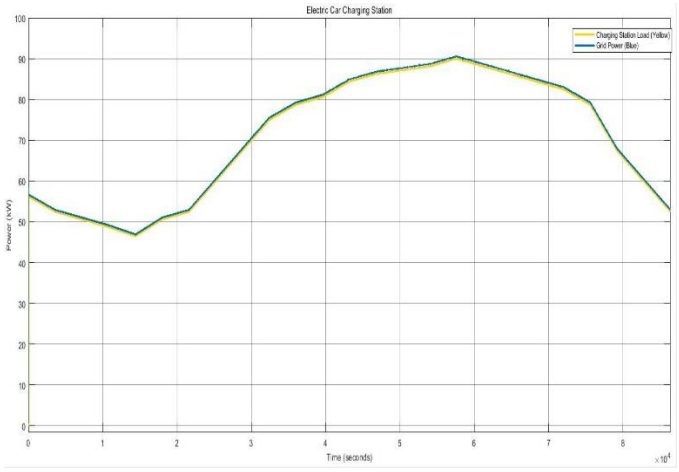

Fig. 7. Results when only grid supply power

Fig. 7 clearly shows that all charging station load is met by grid power only and there is no other external power source.

- According to case 2 from table 1 when RES are added our operating and energy expenses begin to reduce. We combine renewable resource generation with grid supplies, as shown in Fig. 8. When renewable energy is taken into account, the annual operating cost drops to $18635/year. It is the lowest of all configurations.

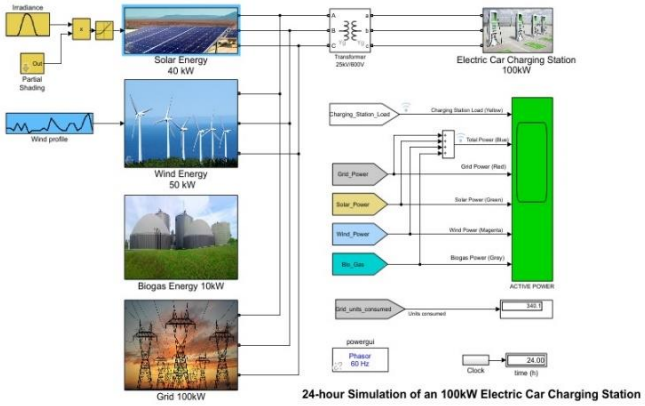

Fig. 8. Renewable energy resources added.

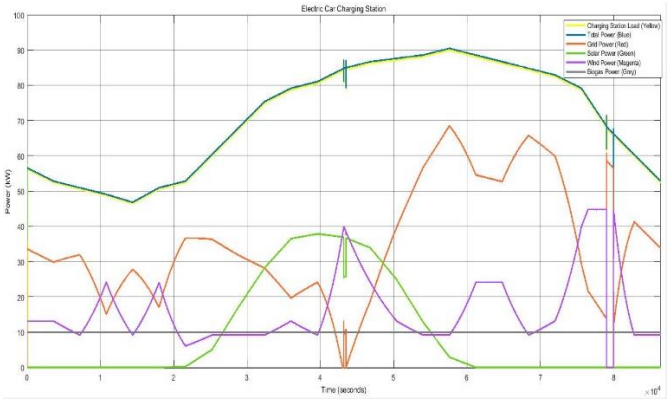

Fig. 9. Results when renewable energy resources start generation

These results in Fig. 8 clearly show that when all renewables e.g. (solar, wind, biogas) are added then grid units are dropped from 1028 to 340.1. This configuration will lower the burden on the grid with the lowest net annual cost. Fig. 9 shows that grid power becomes 0 when renewable energy has maximum share and grid energy consumption increases when solar and wind energies start decreasing. To lower grid power consumption in the evening (when solar and wind energy production is approximately 0) another configuration is made with battery backup. In cost analysis to calculate per year cost, the life of PV panels is taken as 10 years. The life of wind turbines is taken as 20 years. Life of biogas plant is taken as 10 years and life of diesel generator is taken as 15 years. Cost analysis of this configuration is given in table 2.

- Fig. 10 shows the optimization outcomes of integrating the battery, case 3 according to table

1. This system also contains a six-hour battery backup. These results demonstrate that if we incorporate battery backup, our initial cost rises by 29218.4$/year due to the high cost of battery bank but our operating expenses remain relatively low with a net per year cost of 44,318$/year. So, by adding a backup system our initial cost and per year cost increases but we get 6 hours backup and this is still the second favorable outcome in all results.

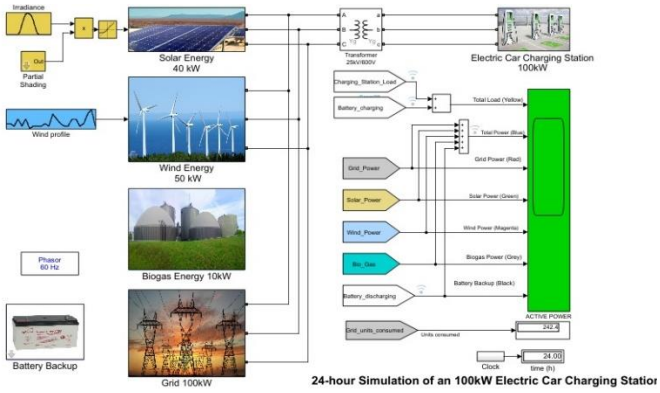

Fig. 10. Battery backup added in proposed system

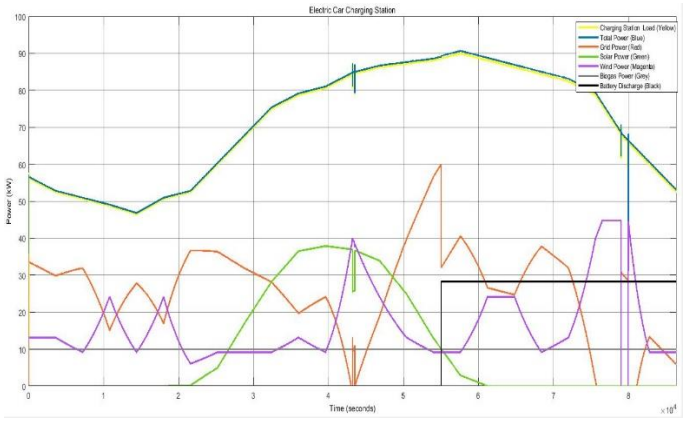

Fig. 11. Battery discharging

In Fig. 11 battery discharging is shown with a black line. The battery is charged in the morning when a large amount of renewable energy is present and it will discharge in the evening when solar and wind becomes 0 and all load is shifted on the grid. The battery will lower the burden on the grid even in off-peak hours. Only 242.4 units will consume through the grid when the battery back is added. Cost analysis of this configuration is given in table 2.

- Case 4 according to table 1 is when grid or renewable energy is not present at any time. In emergency cases when we have either grid supply is not available or renewable energy is not available then we have added a standby diesel generator. A diesel generator will be ON and supply the power according to the load demand when needed. In this way, the system becomes more accurate and practical. So, by adding diesel generator our initial cost and net per year cost increases but this system is more reliable. This configuration can be seen in Fig. 12.

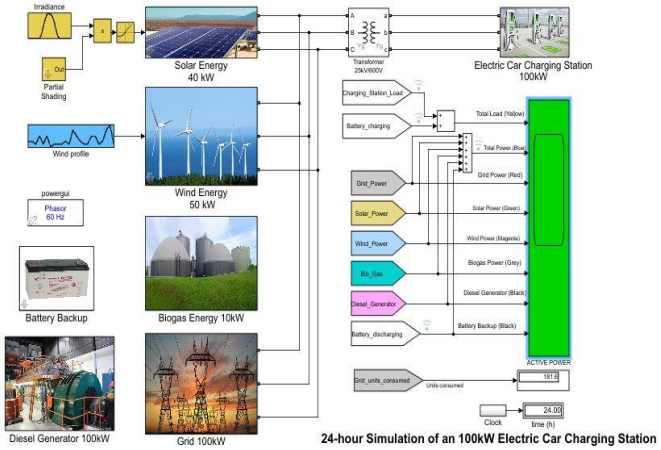

Fig. 12. Results when diesel generator is added to proposed system

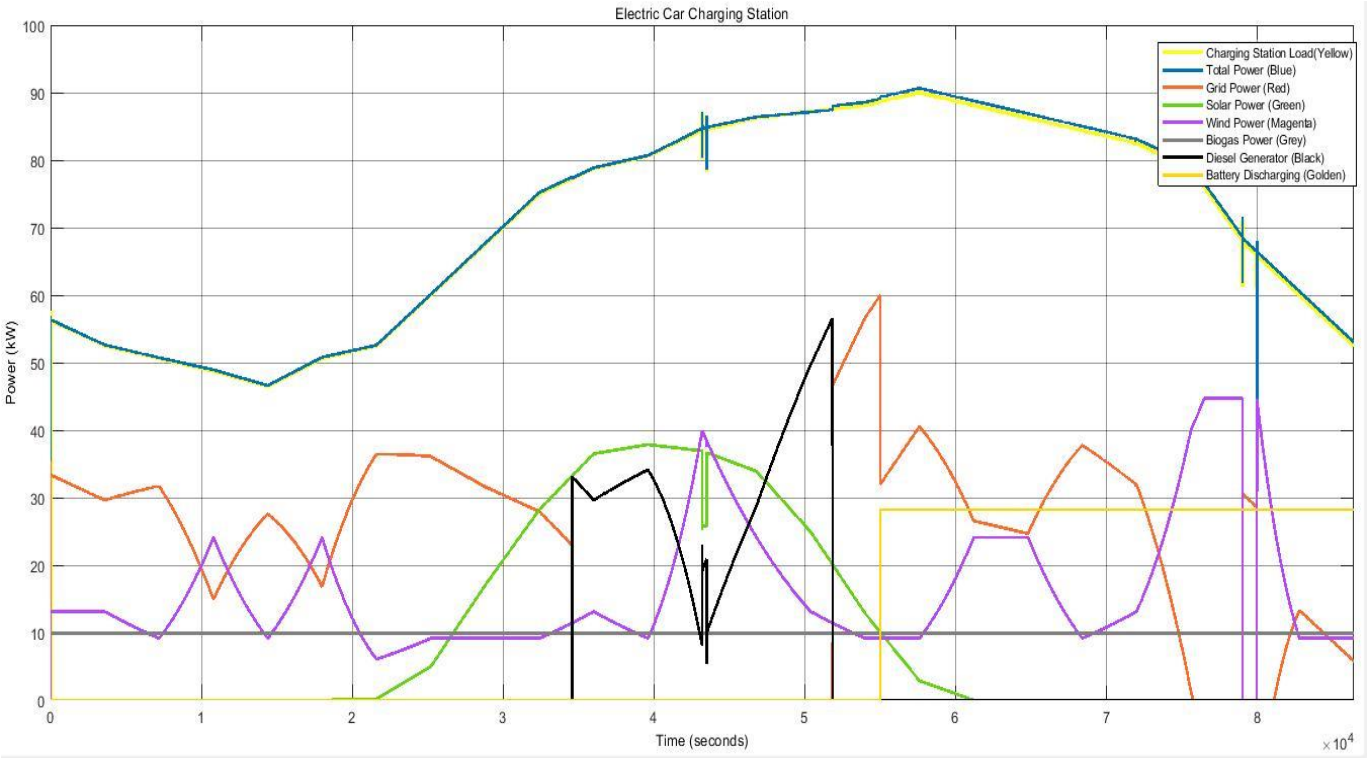

Fig. 13. Power graph of diesel generator.

The black curve is of a diesel generator. Fig. 13 shows that when grid supply becomes zero due to any fault in the grid then the diesel generator will ON and starts to supply according to the load demand. When the grid starts supply again then the diesel generator will OFF. Cost analysis of this configuration is also given in table 2.

Table 2

Cost Analysis of All Cases

Case	Description	Remarks
Grid only	Initial Cost = Rs. 0 = 0$ Units consumed / day = 1028 Units consumed / month = 30840 Electricity cost / month =49,40.65$ Electricity cost / year = 59,304.70$ Net Cost / year = 59,304.70$	Most expensive System
Renewable Energy	Initial Cost Solar/year =1168.57$ Initial Cost Wind/year = 1000.29$ Initial Cost Biogas/year = 400$ Grid units consumed / day = 340.1 Grid units consumed / month = 10203 Grid electricity cost / month = 1338.7$ Grid electricity cost / year = 16,065$ Net Cost / year = 18,635$	Most economical System
Battery Backup	Initial Cost Solar/year = 1168.57$ Initial Cost Wind/year = 1000.29$ Initial Cost Biogas/year = 400$ Initial Battery Cost/year = 29218.4$ Grid units consumed / day = 242.4 Grid units consumed / month = 7272 Grid electricity cost / month = 1120.58$ Grid electricity cost / year = 13446.95$	Second most economical System

	Initial Battery Cost = 29218.4$ Net Cost / year = 44,318.69$	
Diesel Generator	Initial Cost Solar/year = 1168.57$ Initial Cost Wind/year= 1000.29$ Initial Cost Biogas/year = 400$ Initial Battery Cost = 29218.4$ Grid units consumed / day = 181.6 Grid units consumed / month = 5448 Grid electricity cost / month = 861$ Grid electricity cost / year = 10,335$ Initial Diesel Generator Cost/year = 1938$ Diesel Cost Per Year = 500$ Net Cost / year = 43,174.06$	Net per year cost will increase but still less than grid only case and this system is more reliable and best.

Cost analysis of hybrid charging stations is done in table 2. There are total four cases discussed in this paper as given in table 1. For optimizing cost analysis first of all we calculate the initial values of all cases. Initial values are concerned with the cost which is used in purchasing and installation of the system. Through MATLAB simulation we calculate the total units consumed for 24 hours in charging the EVs and also calculate these units for the whole month. Then we calculate the bill of these units through the official website of IESCO to check the total cost. In the last, we calculate per year cost with the help of the above data as shown in table 2. From table 2 we can clearly check that as we add renewable resources, cost is reduced and the proposed charging station has the lowest per year cost.

9. Conclusion

The above findings suggest that the proposed hybrid charging system is very cost-effective for the Kallar Kahar climate, and it can be installed at any location of Pakistan with minor modifications (changing the solar and wind energy data). It is evident that combining renewable energy generation with conventional grid reduces per year cost to 43,174.06$ instead of 59,304.70$, results show a significant reduction in operating costs. If we don't incorporate storage and diesel generator, this system is having the lowest energy cost, but the system's reliability will suffer. As a result, it is preferable to incorporate storage and a diesel generator as well. In this way, the overall efficiency of the system is also increased.

10. Future Work

In the future, we can add combinations of different other renewable resources for electricity generation purpose to further reduce the charging cost for EVs. In this way, we can also lessen the burden on the conventional grid. As Pakistan is facing the worst electricity crisis from the last few years so by using renewable resources with conventional grids we can develop a system that can also decrease load shedding.

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