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RESEARCH PAPER

Electrification of Isolated Rural Areas Through Hybrid Wind/Solar/Diesel Micro Station
A case study in the Kurdistan Region of Iraq

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A B S T R A C T:

This paper presents a framework for the electrification of an isolated rural residential area through a decentralized hybrid renewable plus diesel energy system. Solar/wind/diesel power units have been combined to supply continuous electrical power to a small isolated rural community in the Kurdistan Region of Iraq. The selection of the unit rates for an optimum cost-effective solution is evaluated. The framework activities include wind/solar speed/ Radiation data collection via monitoring instruments on the test location and a time-based load forecasting calculation method. Based on the available data for the wind/solar attributes a control system is designed to manage the hourly synchronization of the three units. The system is tested by the MATLAB simulator with satisfactory results.

KEY WORDS: Renewable energy, Hybrid power system, Rural electrification, wind/solar combination, Energy optimization.
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1.INTRODUCTION :

Electrification of geographical-difficult locations of isolated small rural residential areas is challenging energy authorities in many countries worldwide. Supplying electrical power in these circumstances through the national power grid is not feasible due to high transmission costs, no access to roads, and geographical barriers. The energy industry proposes decentralized hybrid renewable energy sources to overcome the problem and be environmentally friendly too.

Some examples show that remote and mountainous areas use renewable energy sources to generate electricity such as wind, solar, and other sources depending on their availability (Dewan et al., 2014). Small communities use wind energy to generate electricity for remote and mountainous areas due to their altitude above sea level, where there are more wind energy sources.

Sometimes the wind speed at the surface is not enough to drive a wind turbine, so a slight increase in height may produce much more power (Bhandari et al., 2015).

Communities dependent on wind turbines must manage their daily electricity activities according to the hours of electricity availability, or have alternative sources, especially renewable energy sources, which are very important for rural and remote areas due to low maintenance costs, sanitation, scarcity, and sustainability. Solar energy and wind power complement each other when the output of one is below the nominal value (Shrestha et al., 2019), (Javed et al., 2020). To ensure that the system meets load requirements under all natural conditions and climate change, wind, and solar renewable energy sources are combined with diesel generators and battery banks (Shafiey Dehaj et al., 2021). The integration of electricity generation through renewable energy with battery banks and diesel generator backup systems is becoming a major cost solution instead

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of using renewable energy sources alone (Islam et al., 2014).

In The Kurdistan Region of Iraq (KRI) remote communities and villages are generally located in mountainous areas. Providing electricity to these remote areas through the national power grid is difficult, complex, and expensive. People in these locations cure resort to using diesel generators to generate electricity, but this is not feasible due to fuel transport because of the distance and unavailability and/or no access to roads during the four seasons. Also, the use of diesel fuel causes environmental concerns to people and authorities. In this paper, a framework is proposed and designed to supply electrical energy to isolated rural residential areas through a hybrid renewable off-grid system. The framework is tested in a small village called HamzaKor south of Erbil city in the Kurdistan Region of Iraq.

2.Data Collection

The framework requires appropriate data to be used in selecting units. The best available data in renewable energy design is the collection of study site information through measuring stations and the International Geographic Atlas. In wind and solar energy systems, many attributes help to evaluate electricity generation in space/time. The Ministry of Electricity in the Kurdistan Regional Government (KRG) owns several solar and wind data collection stations distributed across Kurdistan. The station used in this study is located near Hamza Kor village in Qushtapa district of Erbil province. It is longitude 044006.06 E, latitude 35057.31 N, and 448 m above sea level.

2.1 Wind Data

HamzaKor is a good candidate to generate electricity through wind energy. Due to its openness, plain and flat district nature, most of the year around there is significant potential for wind energy. The Hamza Kor site measurement station consists of several sensors for receiving wind and solar energy data. The sensors are mounted on a tower of metal masts, with the highest points of the metal mast reaching 50 m above ground level, as shown in **Figure 3.11111**

Wind characteristics; wind pressure and wind speed are obtained through anemometer sensors located at three different height levels of 10,30 and 50 meters on the tower. The wind vane sensor is installed at the same height as the anemometer to determine the third wind attribute, the wind direction. The minimum range for locating wind turbines is 6 meter overhead and 76 meters distance from anything else (Buchanan et al., 2021).

The data for the three attributes of the wind has been collected and stored electronically per hour for four years continuously between October 2014 to February 2018. The speed and direction data diagrams are shown in **Figures 2 and 3** ~~r~~espectively. The diagrams show that the site is feasible for wind energy partially.

Figure 1: The research data collection station (Wind and Solar) at Hamza Kor.

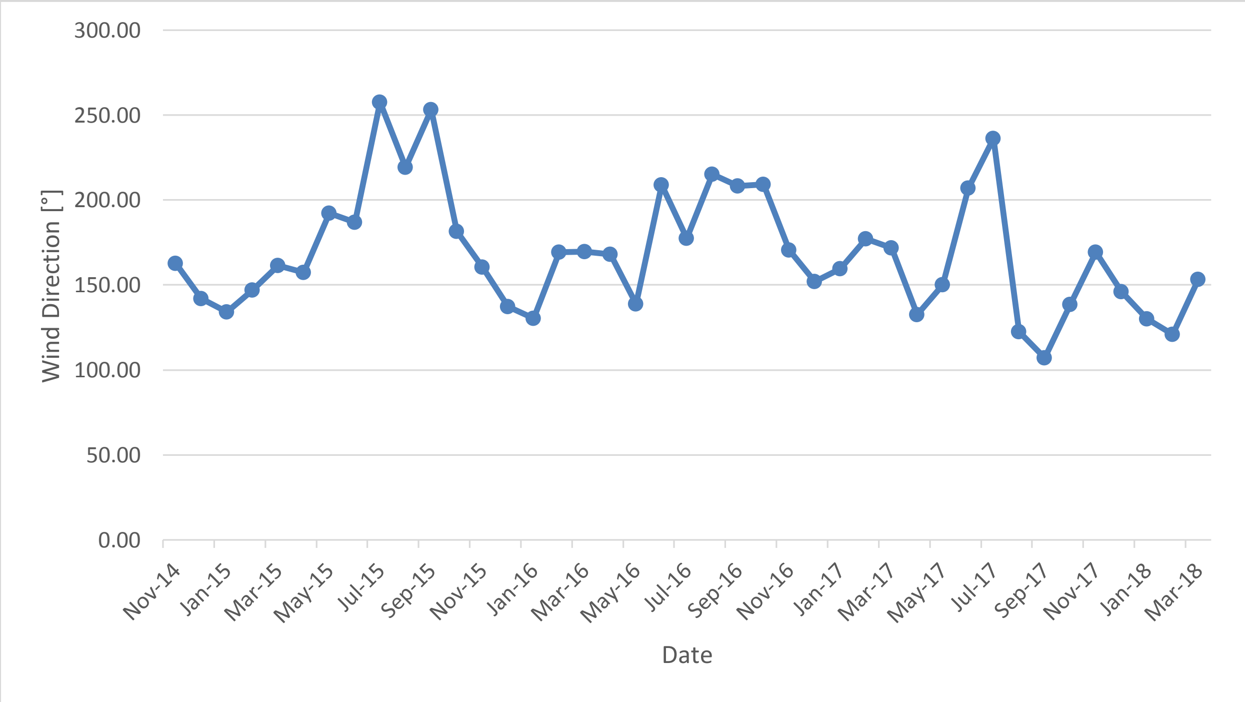

Figure 2: Monthly average wind direction at HamzaKor (2014–2018).

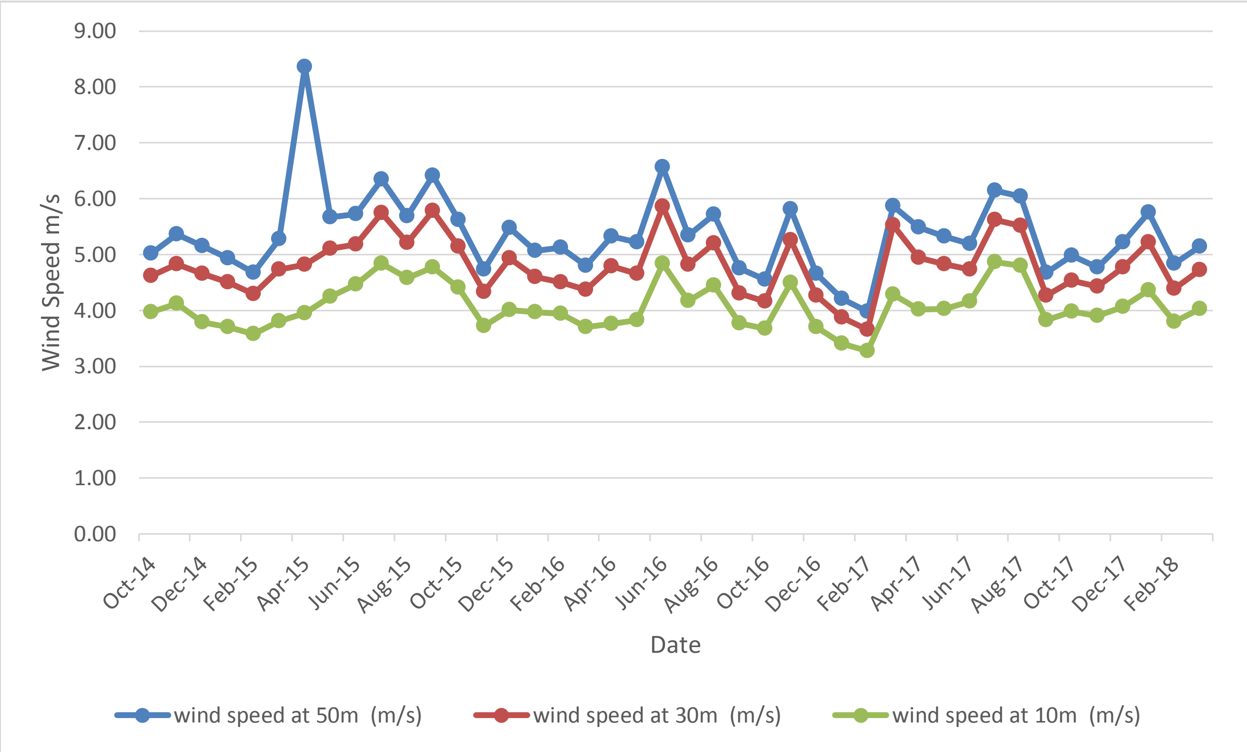

Figure 3: Monthly average wind speed at 10m,30m, and 50m in HamzaKor (2014–2018).

2.2 Solar Data

Four solar attributes are collected in this study, they are humidity, air temperature, air pressure, and solar radiation. These data are obtained through thermometers to measure temperature and humidity, pyranometric sensors to measure radiation, and air pressure obtained through manometric sensors, all mounted at a height of 9 meters above the ground. The power needed to operate the sensors is supplied by a solar panel mounted on the mast metal tower at a height of 8 meters above the ground. with a control cabinet located 2 meters below the solar panel. The cabinet contains a battery bank, a charger to provide continuous power to the instrument sensors, and a Meteo-32 memory logger to continuously record data. Long-term data collection (i.e., several years) helps to develop a better insight into the space/time information which is necessary to select the best type and installation of solar panels. **Figures 4, 5-7** show the collected data on solar energy such as humidity, air temperature, air pressure, and radiation for the four years of the study area respectively.

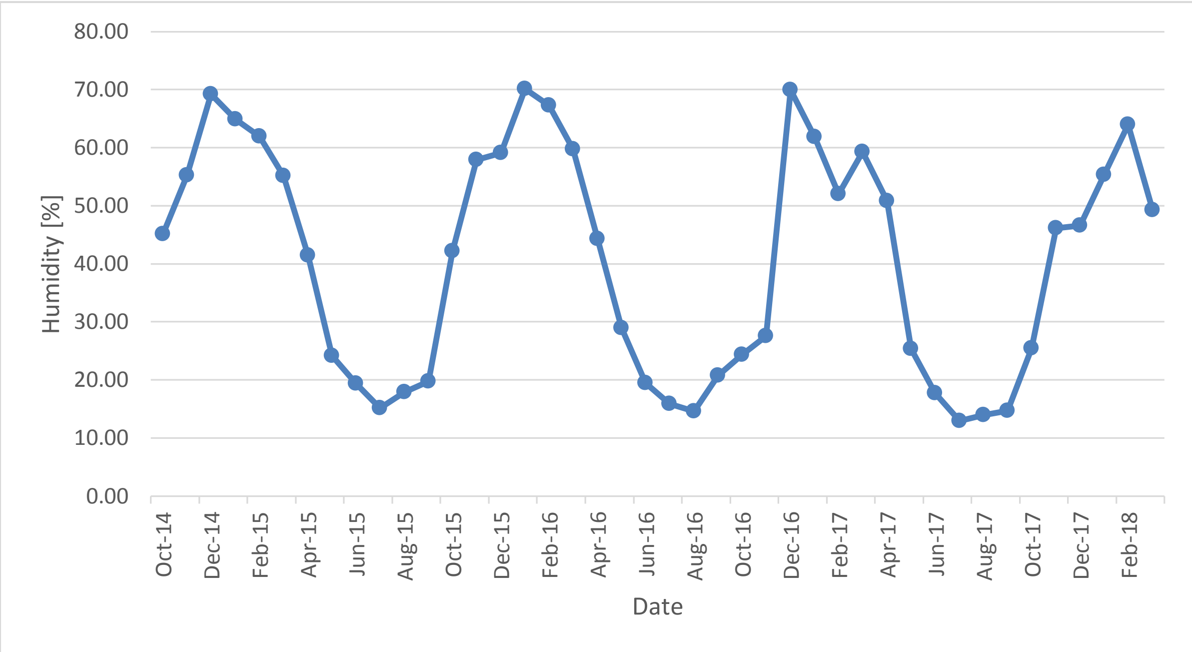

Figure 4: Annual variation of humidity extent for the study area

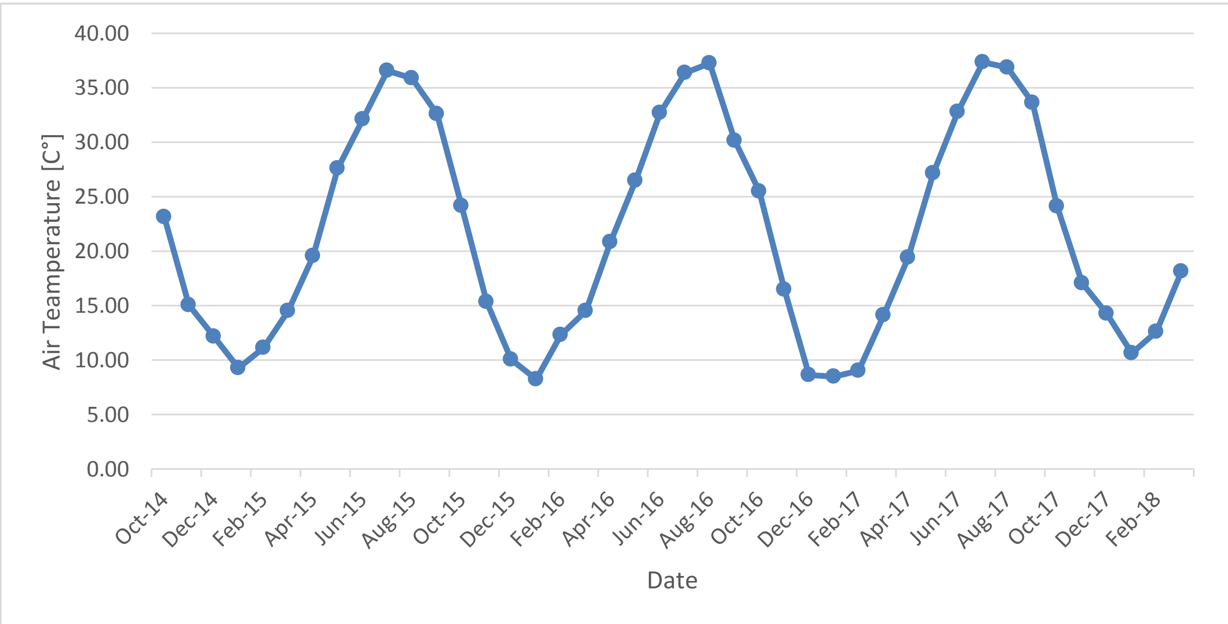

Figure 5: Annual variation of Air temperature for the study area

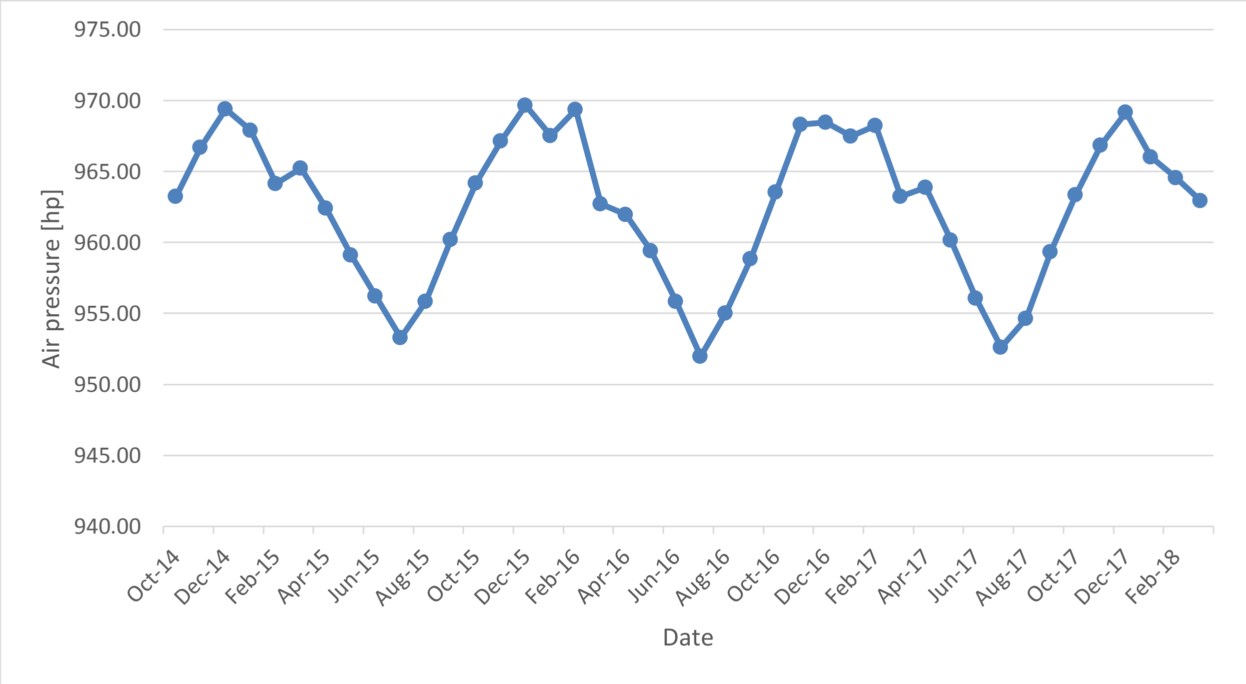

Figure 6: Annual variation of Air pressure for the study area

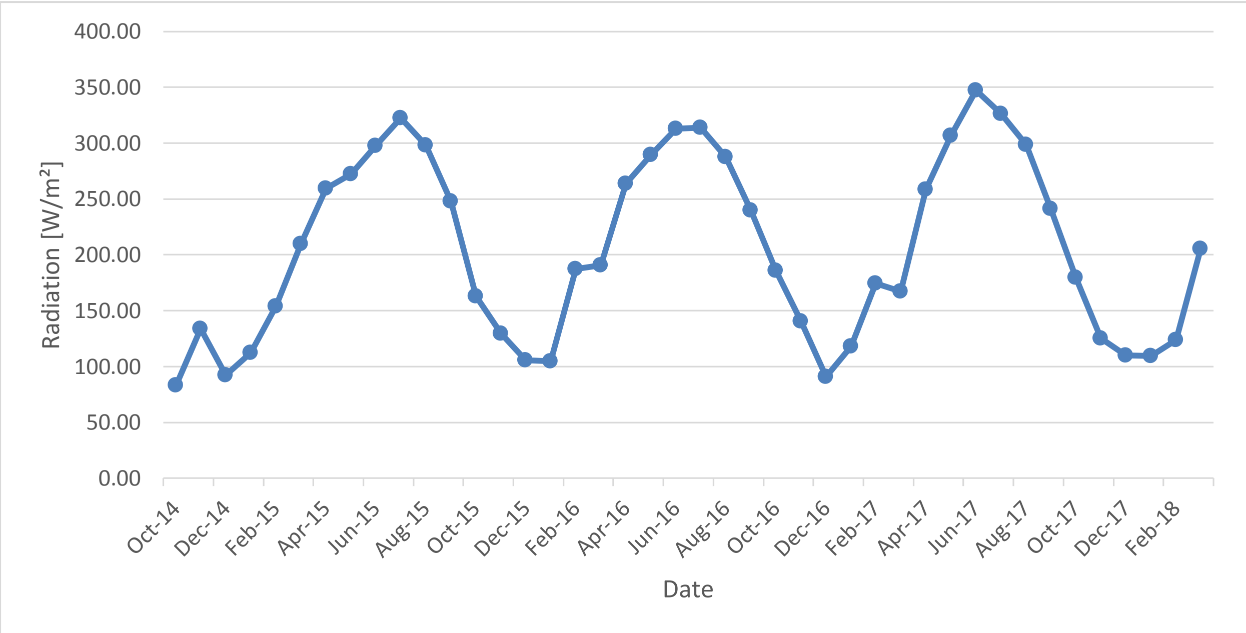

Figure 7: Annual variation of Radiation for the study area

3.Load Forecasting

Load forecasting is an essential tool for power systems in general and decentralized power systems for remote and rural areas with unregulated power systems. There are three categories for load forecasting: short-term, medium-term, and long-term forecasting. Short and mid-terms are used in operating and controlling distribution systems, while long-term forecasting plays a key role in infrastructure planning (Iwafune et al., 2014).

The short-term forecast of household conditions is directly related to lifestyle habits. Some appliances, such as televisions or refrigerators, are used weekly, such as vacuum cleaners, and some have no way of using them. Machines that are reused daily are more suitable for predictability. The more accurate the household load forecast, the more useful it is to manage power distribution even at small levels in rural areas. It also allows consumers to better program their appliances to save on their electricity bills (Razghandi et al., 2021).

In this study, the type and number of electrical appliances commonly used in a household were first determined, then the power required to operate the appliances was determined and collected to find the total electricity consumption of the community. To determine the full demand load, you must have the demand factor of each electrical device separately, to decide the actual size and capacity of battery banks, diesel generators, solar panels, and wind turbines (Siddiqi et al., 2022).

The demand load appliance with their specifications is shown in **Table 1.** The same method has been used in HamzaKor (Patel and Singal, 2016), (hussein, 2018).

4.Mathematical Considerations

4.1Wind component

The basic equation representing the mechanical power output from a wind turbine (in watts) is expressed as:

$Pw = \frac{1}{2}\, Cp\, (\lambda, \beta)\, \rho A V^2$……………………..1

Where Cp is the power coefficient, ρ is the density of air (in kg/m3), A is the cross-sectional area of the rotor blades (m²), V is the average wind speed (m/s), and λ is the tip velocity ratio. The optimum speed for rotation of a wind turbine increases with increasing wind speed and falls with increasing blade length and the number of blades (Pfaffel et al., 2017).

4.2 Solar Component

A solar cell consisting of a solar array block is a semiconductor P-N junction, capable of generating electricity due to the photovoltaic effect. The output power of a PV array is based on sunlight (solar irradiant) and ambient temperature according to the following equation (Sampaio et al., 2017), (Bagher et al., 2015):

Ppv = ηpvg A pvg Gt……………2

where η*pvg* is the efficiency of PV production, A *pigs* this e area (m²) of PV generation, and G*t* is the solar irradiance on the module plane (W/m²). Equation 2 represents the maximum productivity of the PV model. Several PV models connected in series and parallel make up a PV system. The total output power of each array of NP parallel cells and NS series cells connected with the power of each module is calculated as follows:

$Parray = Np\, Pm$ ………3

4.3 Load component

The load forecasting method explained in **Table 1** was used to calculate the site load. The total energy (kWh) for the entire village, which consists of 14 households, a primary health center, and a school, is 626.2 kWh by calculating the required operating time of the equipment (hours) with the connected load (kW) of the village. By collecting the power required to operate the electrical equipment in the study area, it is found that the demand load (kW) multiplied by the demand factor, is (69.24 kW) for the entire village.

After determining the total electricity of the village, it will be easy to decide on the installation of wind turbines, the number and size of solar panels, and their capacity (Ramli et al., 2017). According to the total load of the village, 99 solar panels with a capacity of 700 watts are needed. It is explained as, (99 panels*700 watts=69.3 kW).

The dimensions of each of these 700-watt panels are 2.40 m long, 1.303 m wide, and 35mm thick. Therefore, an area of about 300 m2 is required to install this number of panels in the area. Regarding the installation of wind turbines and determining the size of wind turbines to meet the same amount of demand depends on the application. To meet the demand quantity of the study area of 69.23 kW through wind turbines, based on the data and the average wind speed in Hamza Kor village of 5.36 meters per second (**Figure 8** shows the average wind speed) which is 11.98 miles per hour, a medium-sized wind turbine with a capacity of 72 kW meets the load requirement of the village.

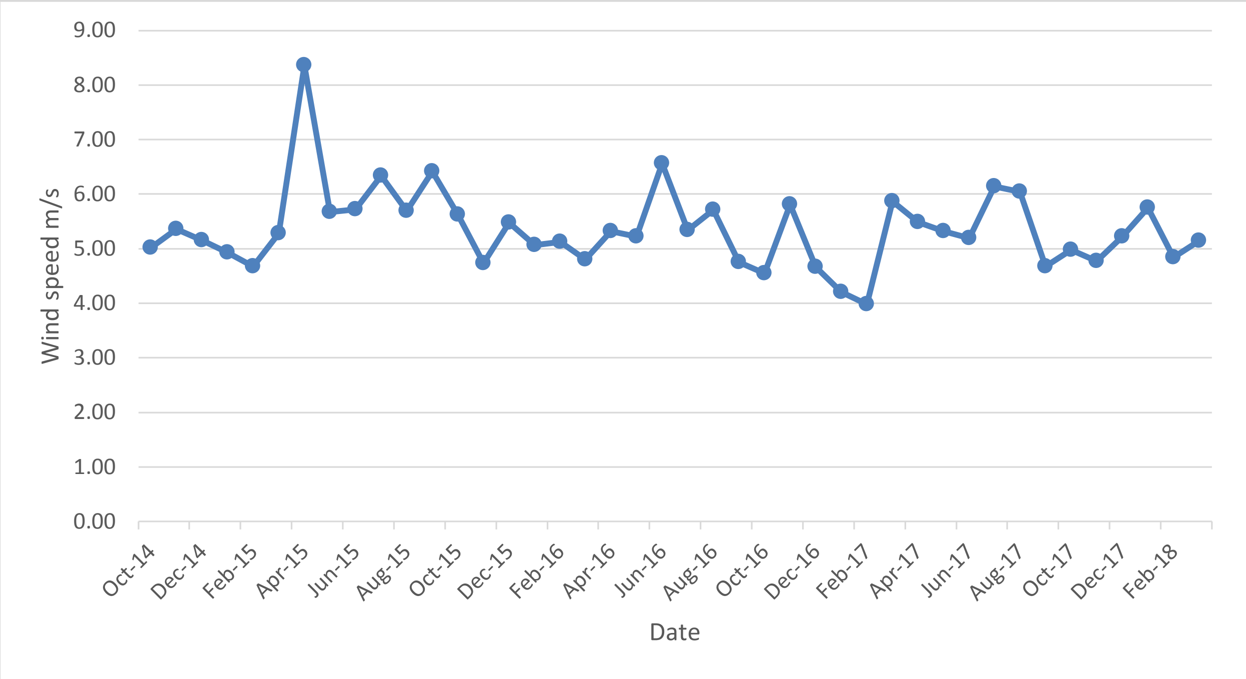

Figure 8: Annual changes in average wind speed for the study area

Table 1: Pre-load forecast for HamzaKor village

No.	Description	Quantity	Unit Load (kW)	Connected Load (kW)	Operating time (Hrs.)	Energy in (kWh)	Demand Factor	Demand Load (kW)
1	Lighting	110	0.06	6.6	12	79.2	0.4	2.64
2	refrigerator	16	0.35	5.6	24	134.4	1	5.6
3	TV.	16	0.2	3.2	8	25.6	0.6	1.92
4	Water Pump	16	0.75	12	3	36	0.4	4.8
5	Exhaust Fan	20	0.1	2	6	12	0.6	1.2
6	cooler	20	0.45	9	5	45	0.6	5.4
7	Elect. heater	16	1.6	25.6	5	128	0.6	15.36
8	Boiler	16	2.5	40	3	120	0.6	24
9	Sockets	104	0.4	41.6	1	41.6	0.2	8.32
10	Sum	---	---	150	---	626.2	---	69.24

5.Simulation and Results

MATLAB/Simulink has been used to simulate a system based on our proposed framework. The Simulink of MATLAB R17 model for the system is shown in **Figure 9.** The model includes four blocks for wind, solar, and diesel generators and batteries, a block for the control system, and an inverter block.

The collected data and equations 1, 2, and 3 have been used in the design of the related blocks. Component ratings were evaluated with the output values: wind output power= 2.8 kW, solar output power= 2.6 kW, diesel generator output power= 2.5 kVA, and batteries= 500 Ah.

The PLC block is programmed using ladder programming language to check the demand every 10 minutes. Depending on energy resource availability and priority settings. The controller coordinated among resources to meet demand during climate change and the disappearance or depletion of generation resources. The system is simulated for the following scenarios:

Case 1. Sunny Day, with No wind

According to the data collected at the study site, the global radiation in April, May, June, July, August, and September is higher than in other months of the year. It reaches about 340 W/m2 as shown in **Figure 10** as a chart. The control system is programmed for the optimum solution of using renewable sources with the least maintenance time and cost, The demand was about 2.7 kW. When the power of the solar panels exceeded the total load demand, it started charging the batteries for a prescribed duration. On the other hand, in the case the load exceeded 2.7 kW the solar panels could not reach their full capacity, the shortage was compensated by first the wind turbine (if available) and then the batteries.

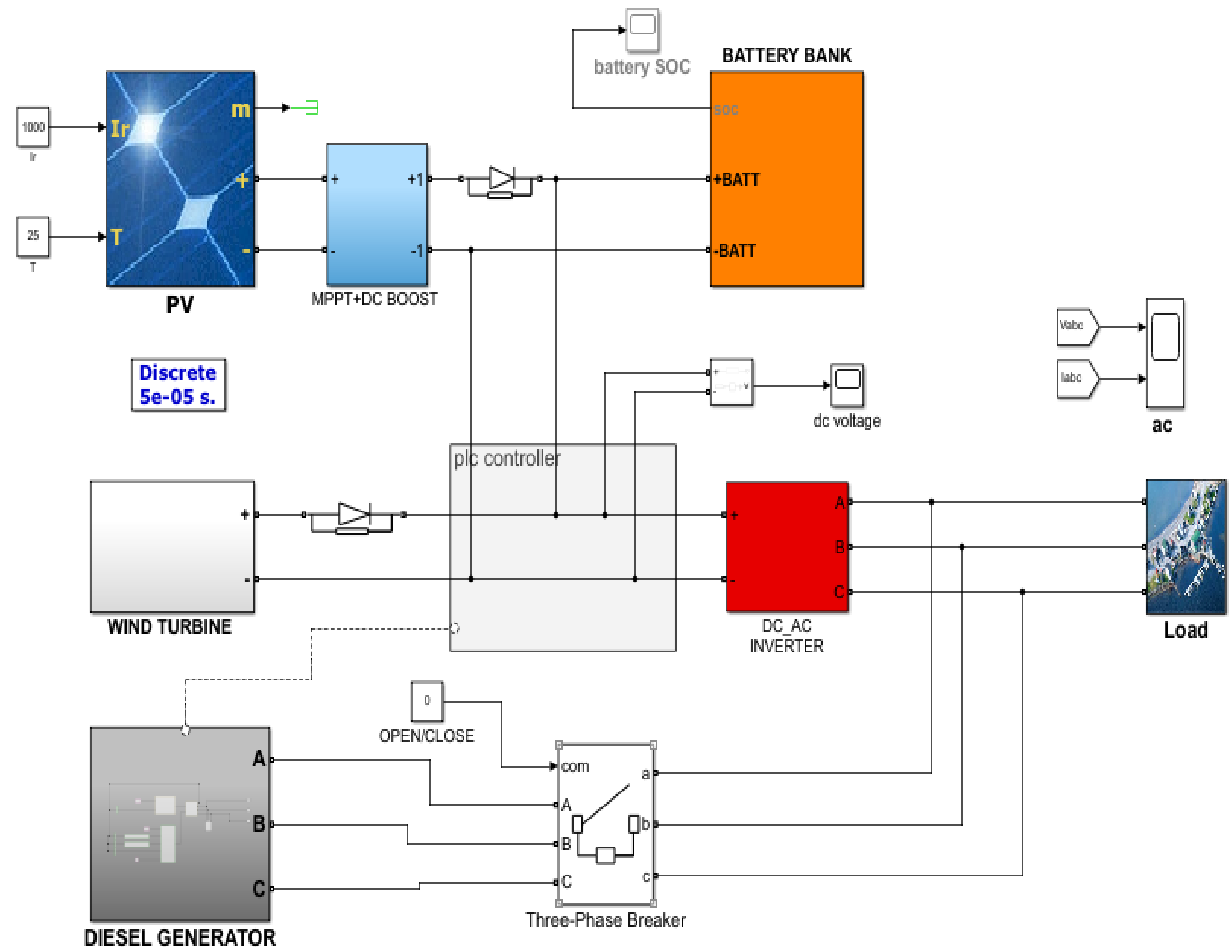

Figure 9: Overview of hybrid renewable energy modeling by Simulink/Matlab.

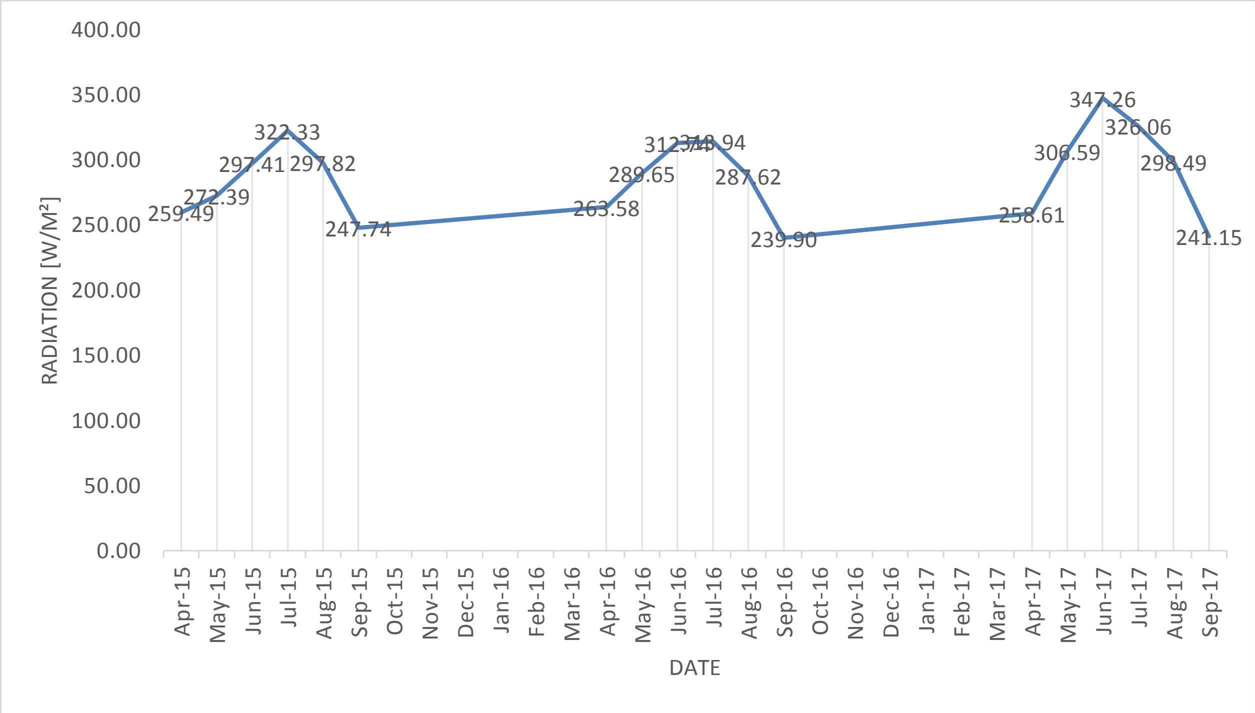

Figure 10. Global radiation data from months between April and September in HamzaKor.

Case 2. Cloudy and Windy Day

The solar panels could not deliver their full capacity on a cloudy day. Therefore, the wind turbine, according to the optimality settings, the wind turbine started directly through the control recharging the batteries when power exceeded the demand. In case of insufficient wind or any problems with the wind turbine, the batteries provided the necessary power.

Case 3. Windy Day and Night

Considering the data collected in HamzaKor village at three different height levels of 10, 30, and 50 meters, it is observed that the wind data in June, July, and August have a better speed compared to other months of the year, and at night time it reaches 5.85 m/s as demonstrated in **Figure 11.** Therefore, the wind and the batteries were mostly sufficient to provide the full power demand. In the case of a lack of generation through these two sources, the generator started automatically via the control program, and the coordination of the three sources worked well in the optimum mode to reduce the cost and maintenance factors.

Case 4. Windless at Night

This is the worst-case scenario from a renewable energy perspective because in the absence of wind energy and at night when solar energy is unavailable, you have to rely on the battery bank and the generator. Therefore, according to optimal settings for cost reduction and maintenance, the PLC system first uses the battery and then starts receiving support from the generator when the battery charging power alone cannot meet the loading requirements. **Figure 12** shows the case when the batteries run out of stored energy at night and wind power is unavailable, the diesel generator acts as a backup.

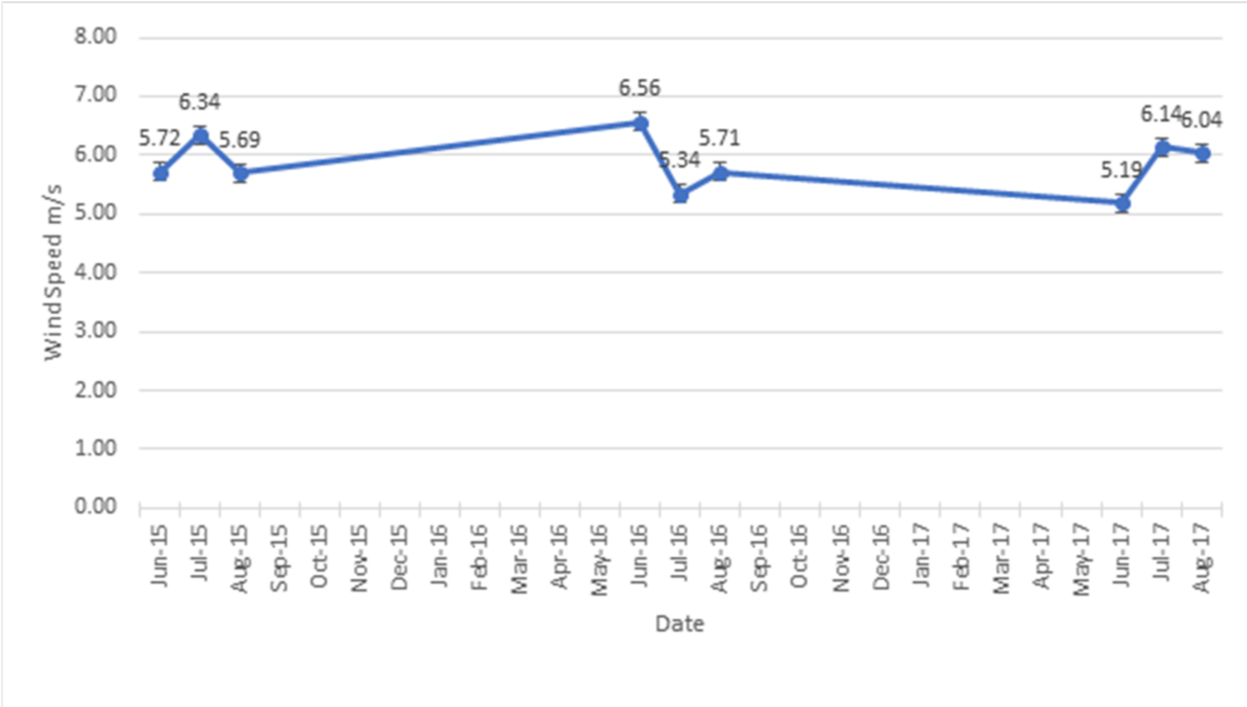

Figure 11. Wind speed data from months June to August at 50m height in HamzaKor.

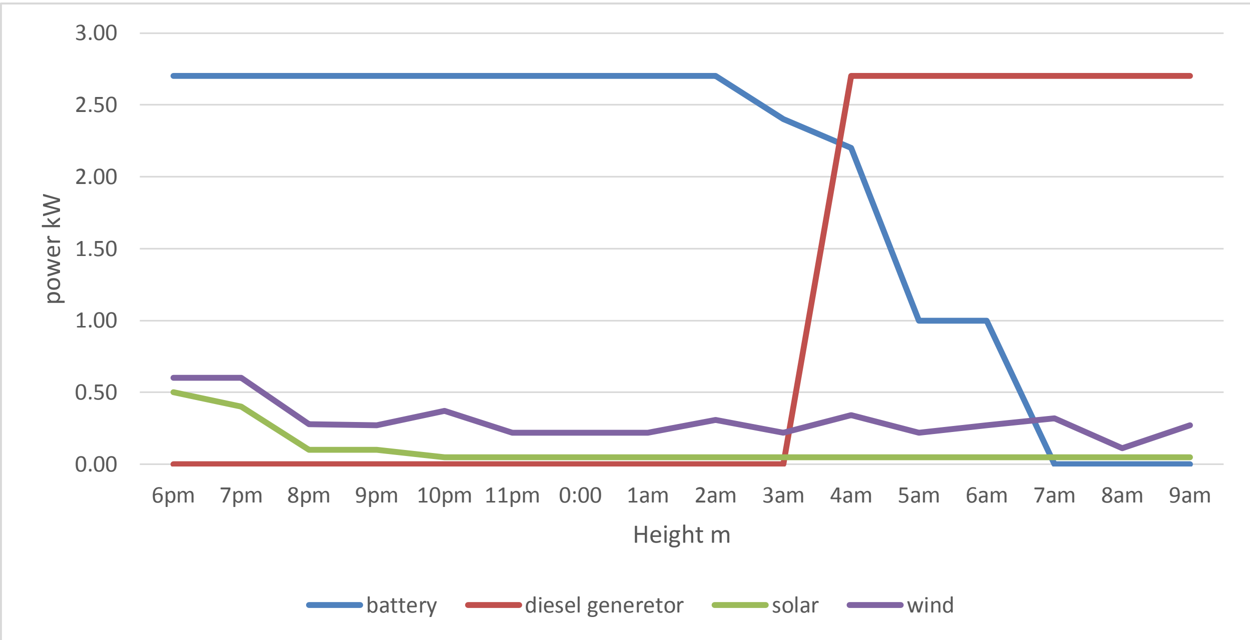

Figure 12. Supply of 2.7 kW by batteries and diesel generator (at night).

6.Conclusion

This paper presented a framework to design and investigate the performance of an offline decentralized hybrid renewable power system in the electrification of an isolated rural residential area. Four power components, wind, solar, battery bank, and a generator have been combined to supply power to a pre-forecasted load. The wind/solar data has been collected with a monitoring station from a small rural area called HamzaKor village near Erbil in the Kurdistan Region of Iraq. An optimum control system using PLC has been programmed and used to minimize the running cost and maintenance time during the combination process between the components. The components, the battery bank, the inverter, and the collected data have been used to build a model in MATLAB/Simulink. The model has been simulated in four different scenarios.

It is concluded that solar energy was the most cost-effective and does not need a long period of interruption for maintenance, this is why whenever the solar system was ready to supply the demand the optimum algorithm started to get the advantage of it.

The designed optimum algorithm greatly reduced the running cost and maintenance time by combining the available power components. The simulation results showed that the output power was stable and vibration-free in adverse weather conditions. With a proper control strategy selection, the batteries and the diesel generator had a minimum annual operation to prevent environmental pollution and reduce fuel consumption. Finally, the proposed framework is generalizable to all small isolated sites with solar/wind real data availability and an efficient control algorithm.

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