Design of A Hybrid System for Powering Wireless Communication Units / Original article

Samer Rabih[1, a], Ahed Alboody[2, b]

1 Professor at Faculty of Mechanical and Electrical Homs University Homs-Syria

2 Associate professor CESI Ecole d'ingeneurs – Nice-France

a samerrabih@gmail.com

b aalboody@cesi.fr

Abstract

Wireless and optical communication units are becoming more widespread nowadays, especially in rural areas. Therefore, feeding electricity has become essential for the continuity of services. As a result of economic and social development, there has been an urgent need to supply electrical power for the basic requirements of wired and wireless telecommunications equipment. This is linked to public safety, long life, and connection to uninterruptible power systems to ensure continuous power supply, whether from renewable energy sources or traditional diesel systems. This research studies and designs a renewable energy (solar) power system to power telecommunications equipment. The proposed power system consists of the following main components: photovoltaic panels, a wind turbine, an energy storage system (battery), in addition to the traditional power system represented by a diesel generator. The study addresses several principles, including reliance on meteorological information and the condition of the battery used in this system. This type of system offers the following benefits: reduced fuel consumption, lower CO_2 emissions, and lower logistical costs.

1. Introduction

Many governmental and private organizations and institutions are working to utilize renewable energy and increase its efficiency in the near future, depending on available resources. Renewable energy can be used to power wired and wireless communications units using hybrid systems. Utilizing renewable energy reduces greenhouse gas emissions and lowers electricity consumption in buildings, transportation, and electrical logistics applications [1],[2]. Du to the positive benefits of renewable energy, such as mitigating global warming and other environmental issues, it also reduces the consumption of fossil fuels in electricity generation. This has prompted serious consideration of utilizing renewable energy, especially hybrid systems, to power wired and wireless communications centers in remote locations far from the public grid where electricity is unavailable [3], [4].

Renewable energy, with its high efficiency, can be a viable solution for many large investments. Therefore, governments must make regulatory, administrative, and legislative efforts and create frameworks to stimulate investments in this field due to its positive advantages. The investment proposed in this research is securing electricity for a communications center. Renewable energy sources include fuel cells, photovoltaics, wind generators, tidal, geothermal, and hydraulic. The investment proposed in this research combines renewable energy (photovoltaics and wind) with conventional energy (diesel). One of the positive features of a hybrid system (energy and storage system) is the continuous provision of electricity from both sources or one of them, thus achieving reliable electricity supply. In this research, the hybrid system will be reviewed in terms of design, calculation, size, and control. The system includes the following components: photovoltaics, a wind turbine,

a diesel generator, and a storage system (batteries). These elements play an important role in the system's operation to be at its best performance.[5], [6].

2. Requirements

The basic requirements for supplying a communications center must ensure public safety, long life, and continuous electrical power supply [7], [8].

The proposed power supply solution must achieve high efficiency in usage, energy consumption, and reliable operation of the electrical equipment connected to the center. Sometimes, the power consumed can be an important indicator of the total power consumption where the equipment is installed. The hybrid power system is designed to supply the equipment with the appropriate voltage, whether direct current, alternating current, or both. To avoid high and prohibitive costs, an optimal approach must be followed [9]. One of the design requirements is to combine costs with the potential utilization of the system, achieving both economic and technical feasibility.

When choosing renewable or hybrid energy systems, they must achieve economic feasibility within acceptable limits compared to conventional systems or obtaining energy from the public grid, in addition to the goal of preserving the environment and reducing pollution and its harmful effects.

The total cost of the hybrid energy system is expressed by the following relationship:

$$f = \left(\sum_{k=1}^{4} \left(I_k - S_{Pk} + OM_{Pk} \right) \right) \frac{1}{E_Y . N} \tag{1}$$

k : Elements of a hybrid energy system (solar, wind, diesel generator, and battery)

N : Project lifespan (system)

I_k : Initial value of the project (initial investment)

S_R : The present value of implementing each system element

E_Y : Annual energy required by the system

OM_{Pk}: Present value of operating and maintenance costs

3. Outdoor cabinet design

Some stations may be located outdoors to avoid weather factors, external influences, and mechanical protection. This requires good design for outdoor stations. Sometimes (summer, for example), the center's internal climate plays a significant role in influencing the operation of the equipment. This requires the provision of insulating materials such as rigid insulating panels or insulating glass wool (rock wool, polystyrene, polyurethane, foam, and fibricated fiber), as shown in Figure (1). The concept of thermal insulation and its applications in centers are linked to the country's legal regulations and the encouragement of investments in this field. This solution of direct insulation ensures that the internal temperature does not rise, thus reducing energy consumption.
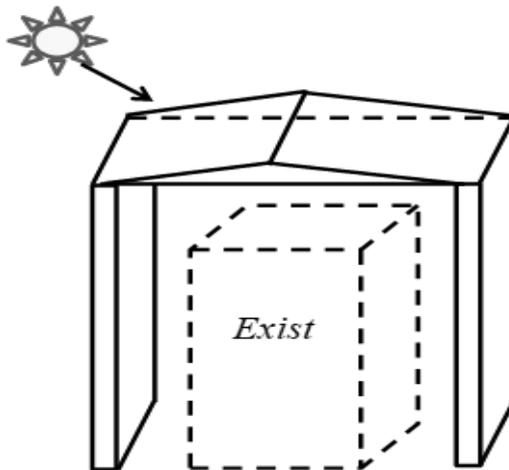

Fig 1: outdoor cabinet

For new cabins or centers, it is preferable to build them from insulating materials according to the standard specifications used and applied in this field. In areas with high solar radiation (long periods of sunshine), it is preferable for the walls to be made of two layers of insulating materials, as shown in Figure (2). Therefore, the use of insulating materials is considered an important indicator of reduced electrical energy consumption, and on the other hand, it is considered a positive factor at the environmental level [10].
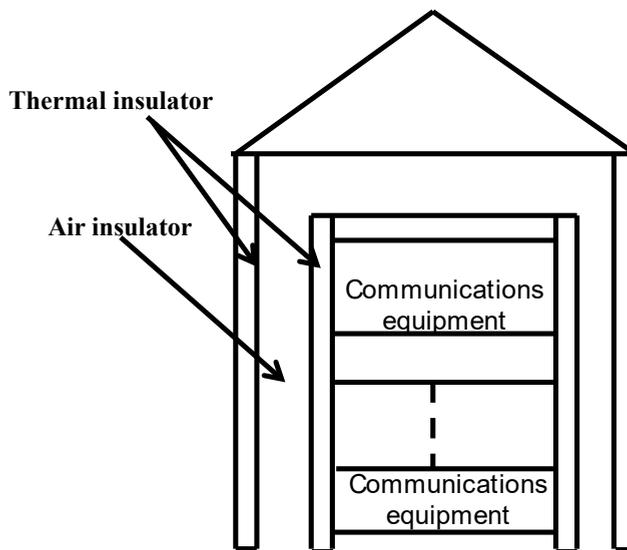

Fig 2: insulation materials

3-1- Photovoltaics panels

Solar radiation can be harnessed to generate electricity directly using a photovoltaic panel. However, the associated problem remains the high cost per watt produced by the panel. One of the key requirements in designing a hybrid energy system is optimizing the size of the photovoltaic panel. Factors that affect photovoltaic panel and must be considered when designing an

energy system include the small site (rooftop or adjacent garden), weather conditions, the type of cell technology, and financial costs [11].

The area occupied by the photovoltaic panels is expressed as a symbol $A_S(m^2)$, where the price per square meter is expressed as a symbol $\alpha_S(\$/m^2)$. Therefore, the cost of photovoltaic panels, after taking into account the purchase price per square meter S_S, we get:

$$f_{PV} = S_S.A_S.fac1 \qquad (2)$$

The total annual cost after taking into account operating and maintenance costs $\alpha_{OMS}(\$/m^2/year)$ is as follows:

$$OM_{PV} = \alpha_{OMS}.A_S.fac2 \qquad (3)$$

Where $fac1 = \dfrac{(1+j)^N}{(1+r)^N}$

r : Interest factor.

j : Inflation factor.

N : Project lifespan

3-2 Wind turbine

Electricity generation depends on wind speed, with slight changes in speed resulting in minor variations in electricity generation. On the other hand, wind disturbances result in fluctuating power generation [12]. Therefore, a key requirement is to ensure as constant and stable electricity generation as possible. When designing, a wind atlas and accurate data are required.

The operational cost of a wind turbine can be expressed by the following mathematical relationship, which is linked to several factors,

including: the area that the turbine can occupy (A_w), the price of one square meter ($\$/m^2$) S_w, as well as the interest factors (r), inflation (j), and the time period of the project (system) N.

$$f_w = S_w . A_w . fac1 \tag{4}$$

By entering the annual maintenance cost and the annual operating cost, we can calculate the total cost over the life of the wind turbine system in terms of investment and maintenance costs.

$$OM_w = \alpha_{OMw} . A_w . fac2 \tag{5}$$

α_{OMw} : Annual cost of operation and maintenance

$$fac2 = \sum_{y=1}^{N} \frac{(1+es)^y}{(1+r)^y} = \frac{(1+es)}{(r-es)} . \left(1 - \left(\frac{1+es}{1+r} \right)^N \right) \tag{6}$$

Which (*es*) is escalation rate (for *es*=r we obtain $fac2 = N$).

3-3 Energy storage

There are different types of energy storage (batteries, hydrogen fuel cells, etc.). Storage is a critical component of the energy system to ensure energy is available at all times. When selecting batteries, considerations must be given to the number of charge and discharge cycles, lifetime, technology, depth of discharge, resistance, and cost. The following table shows the technical characteristics of several types of batteries.

Table 1: Technical characteristics of several types of batteries.

Type	Electrolyte	Faraday effeciency %	Energy effeciency %	energy density Wh/kg	Lifespan at 20°C	Operation T $\left[^0 C \right]$
Pb	H_2SO_4	>99%	75-90%	20-35%	500-2000	-20 → 60
Nickl-Cadmium	KOH	>99%	70-87%	40-60%	500-2000	-40 → 60
Nickel-metal alloys	KOH	>99%	70-87%	60-80%	500-2500	10 → 50
Lithium	$LiPF_6$	>99%	70-95%	100-200	500-4000	-20 → 60

The total cost of storing electrical energy (battery cost) is expressed by the following formula [14]:

$$f_{batt} = \alpha_b . R_b . \sum_{x=1}^{x_b} \left(\frac{1+es}{1+r} \right)^{(x-1).L_b} \tag{7}$$

α_b : Capital per kilowatt-hour

R_b : Battery cost

x_b : Number of batteries to be purchased over the lifetime of the system

L_b : Battery lifetime, which is typically less than the lifetime of the system as a whole

r : Interest or inflation rate

es : Escalation rate

Neglecting the operational cost of the battery, and taking into account the annual operating and maintenance costs $(\$/kWh/year)$ α_{OMb} , we find that the total cost of the battery during the system lifetime is:

$$OM_b = \alpha_{OMb} . R_b . fac2 \tag{8}$$

3-4 Diesel back-up generators

Diesel generators are used in a hybrid power system to continuously provide electrical power to telecommunications equipment. One requirement is to optimize the generator's size and reduce fuel consumption, thereby reducing carbon and greenhouse gas emissions CO_2.

It is necessary to purchase a diesel generator at the beginning of the project to calculate the costs of the diesel generator, which will later serve as a backup component in the proposed power system. We take into account the generator's capacity $R_d(kW)$ for a lifetime L_d, which is typically shorter than the turbine's or photovoltaic panel's lifetime. The initial investment value is calculated according to the following equation [14]:

$$f_d = \alpha_d . R_d . \sum_{x=1}^{x_d} \left(\frac{1+es}{1+r} \right)^{(x-1).L_d}$$

(9)

Which $\alpha_d(\$/kW)$ is the initial cost.

The total annual cost is as follows:

$$OM_d = \left(\alpha_{MCd} + \alpha_{OCd} \right) . R_d . T_d . fac2$$

(10)

From the relationship (10), we find that the fuel price is calculated using the factor $\alpha_{OCd}(\$/kWh)$, while the operating and maintenance costs are calculated using the parameter $\alpha_{MCd}(\$/kWh)$. The total number of working hours is expressed using the factor T_d.

4. System design

Many methods and algorithms are being developed for designing and modeling hybrid power systems. To obtain the optimal model, as well as to calculate and design the system's components, the climatic data of the area

where the center (operating communications equipment) or telephone booth is to be built must be known. The reliability of the system to provide electrical power must also be determined. In the detailed study of the hybrid power system, the financial costs, maintenance and replacement costs, investment and operating costs must be determined [13]. To calculate and size the power system, it is necessary to know: the geographical location, meteorological data, temperatures, the insulation period per year, the type of insulating material used, the insulation period per day, the voltage required to supply the electrical equipment, the operating time of the backup diesel generator, and the charging and discharging periods of the battery. These requirements play an important role in determining the total cost of the hybrid power system to be invested in [5].

For example, in a region with unstable and variable climatic conditions throughout the year, high-capacity batteries are used. These batteries are charged via photovoltaic panels, which are the most expensive component of the system, and also via a wind turbine. In this case, diesel generators operate at a minimum, thus reducing the fossil fuel consumption required to operate the generators. Therefore, accurate and precise data are essential when designing a hybrid energy system.

The hypotheses that will be taken into consideration in this study are:

- Temperature varies from -150C to +400C ¬
- Number of hours of sunshine per year 2400h
- Average daily sunshine 7h
- Number of hours of sunshine per day in summer 9h
- Nominal voltage 48Vdc
- Input voltages for communications equipment range from $\left(40.5VDC \rightarrow 57VDC\right)$

- Equipment capacity (load DC) 1000W
- Load current 20A
- Need for diesel generator operation 15days/year
- Need for two batteries to operate continuously 2days

These assumptions can affect system costs, and they vary from one system to another and from one geographic region to another. In areas with greater sunshine, generator operating hours are reduced, resulting in reduced fuel consumption and environmental conservation.

5. Calculation and component sizing

The principles adopted in this work are: operation at direct current (DC) and nominal voltage 48Vdc. The inverter will not be considered in this study, given that the center's equipment operates on direct current and is powered solely by the proposed hybrid system. The remaining components operate at high efficiency. There are numerous studies and researches that take inverters (DC/AC) into account and calculate the necessary parameters (output voltage, distribution, meandering and disturbances, peak values, and harmonics). Figure (3) shows the power system used in this study and illustrated in this work.
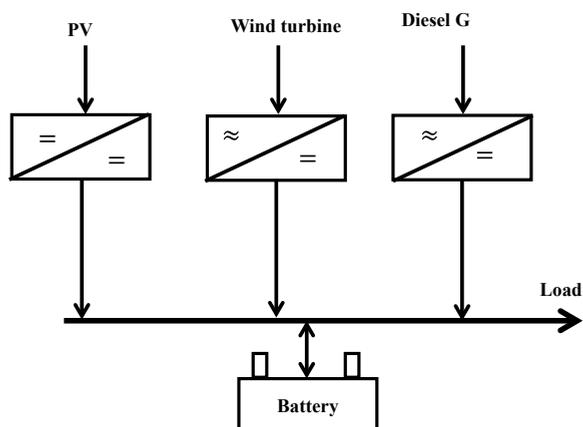

Fig 3: the power system used

5-1 Capacity of battery

The minimum battery capacity can be calculated according to the following formula:

$$Q_{\min} = I_{DC}.T.K_1(Ah) \qquad \text{(11)}$$

I_{DC}: DC power for communications equipment (20A)

T : Battery self-recovery time

K_1 : Battery capacity factor, which depends on the type of analyzer and increases with decreasing temperature. Its value is equal to 1.15.

$$Q_{\min} = 20A \times 48h \times 1.15 = 1104(Ah)$$

In this system, four Lithium batteries (4×300Ah) connected in parallel and with the same voltage will be used 48Vdc.

$$Q = 4 \times 300(Ah) > Q(Ah)_{min} = 1104(Ah)$$

This type of battery offers a balance between price, the number of charge and discharge cycles, the depth of discharge, and the specific resistance. Another important characteristic is the high charging current, which, in turn, shortens charging times. On the other hand, a high charging current reduces battery life and increases operating costs. Typically, the battery current is fixed at a constant value, while the intelligent control system adjusts the current value based on battery condition and weather conditions.

Amperage capacity of the battery pack used:

$$C_{Ah} = 4 \times 300(Ah) = 1200(Ah)$$

Thus, the battery current according to the manufacturers:

$$I_{batt} = 0.1C_{Ah} = 120A$$

Maximum battery charging current

$$I_{batt\,\max} = 0.15C_{Ah} = 180A$$

5-2 Area of photovoltaic panels

Many methods and algorithms have been developed for optimal photovoltaic panels. In this study, photovoltaic panel size is a critical factor due to price and cost. The basic principle of using PV panels is to obtain electrical energy to power equipment and charge the battery. This research relies on photovoltaic panels during the summer, and the panel size is determined based on the equipment available at the center. The day will be divided into two periods: the first period 9h (during this period, the cell provides maximum power), and the second period 15h (black period, during which no electrical energy is obtained from the photovoltaic panels). The requirements of the photovoltaic panels during the first period 9h are to provide power to the telecommunications equipment and to charge the battery sufficiently during the black period 15h (the second period), which is predetermined based on meteorological data. Diesel generators can also provide power, but the goal is to reduce fuel consumption. A larger area for photovoltaic panels means more electricity, not just in the summer, but also during periods of less sunshine. The end results are linked to lower operating costs and lower greenhouse gas emissions CO_2.

Two methods are proposed to determine the size of panels necessary to provide energy to fit the available space.

5-2-1 Method I

In this method, the electrical energy generated by the photovoltaic panels during the summer will be determined to supply power to the equipment and charge the battery [9]. The energy stored in the battery is determined based on the power required to supply the equipment, according to the following relationship:

$$E_{PV} = I_{DC}U_{DC}T_{ins} + I_{DC}U_{DC}T_{back-up} \qquad \textbf{(12)}$$

E_{PV}: Power generated by photovoltaic panels

I_{DC}: DC current for wired and wireless telecommunications equipment 20A

U_{DC}: Nominal voltage 48Vdc

T_{ins} : Sunshine period 9h

T_{back-p} : Battery operating time 48h

$$E_{PV} = 20A \times 48V \times 9h + 20A \times 48V \times 48h = 54.720kWh$$

The power required to be obtained from photovoltaic panels during the period of sunshine is expressed by the following mathematical relationship:

$$P_{PV1} = E_{PV} / T_{ins} = \frac{54.720}{9} = 6.080kW$$

To determine the optimal area for photovoltaic panels, after knowing the technical and technological characteristics of the panels (for example, a monocrystal photovoltaic panels has a higher energy density than a polycrystal cell, and the price is also higher), according to the following formula:

$$S_{PV1} = P_{PV1} / P_m^2 = \frac{6080W}{135W / m^2} = 45m^2$$

S_{PV1} : Photovoltaic panel area (m2)

P_{PV1} : Power generated by photovoltaic panels

P_m : Maximum power per unit area (m2)

5-2-2 Method II

In this method, the electrical power generated by the photovoltaic panels will be determined to supply power to the equipment and charge the battery based on the maximum current of the battery [15].

$$P_{PV2} = I_{DC}U_{DC} + I_{batt\,max}U_{DC} \tag{13}$$

$$P_{PV2} = 20A \times 48V + 180A \times 48V = 9.6kW$$

Therefore, the area of photovoltaic panels is determined according to this method as follows:

$$S_{PV2} = P_{PV2} / P_m^2 = \frac{9600}{135} = 71m^2$$

S_{PV2} : Photovoltaic panel area (m²)

P_{PV2} : Power generated by photovoltaic panels according to Method II

U_{DC} : Nominal voltage 48Vdc

I_{DC} : DC current for communications equipment

$I_{batt\,max}$: Maximum charging current of the battery.

Results for Photovoltaic panels Area According to the two previous methods, it was found that $S_{PV2} > S_{PV1}$: Both of the above methods were used to calculate the photovoltaic panel area. The decision to choose one of them depends on several factors, including price, weather conditions, and operational costs, among others.

In this work, we propose a larger photovoltaic panels area to reduce fuel consumption required to operate the diesel generator, lower greenhouse gas emissions CO_2, and reduce logistical costs through the use of an intelligent simulation system for the hybrid energy system. In general, a smaller photovoltaic panels area can be adopted, but this leads to increased fossil

fuel consumption and greenhouse gas emissions. Furthermore, operational and logistical costs increase due to increased fuel tanks, services, training, and increased staffing, etc.

5-3 Power of wind turbine

The power output of a wind turbine can be determined in several ways, including the power required to supply the load only. In a hybrid power system built on solid ground, the cost of a wind turbine is lower than that of photovoltaic panels. Wind turbines are primarily dependent on wind speed. Wind turbines are used to supply telecommunications equipment and charge the battery with maximum current $I_{batt\max}$. When building a wind turbine, a wind atlas is required to obtain the optimal design, as the output voltage is affected by the wind speed in the area. The turbine is selected based on the equipment and its technical specifications.

In this paper, the turbine provides power to the communication equipment and charges the battery with maximum current $I_{batt\max} = 180A$.

Turbine capacity is determined based on the capacity of the photovoltaic panels $P_{PV2} = 9.6kW$, since the turbine's output power depends on wind speed and ambient weather conditions. Therefore, a 12kW wind turbine is selected.

5-4 Diesel back-up generators

Diesel generators are used when electrical power is not available from solar panels (due to lack of solar radiation) or a wind turbine (wind speeds are very low), and the battery is discharged. In this case, diesel generators power telecommunications equipment and charge the battery at the

maximum charging current $I_{batt\,max}$. Generator power is determined based on the capacity of the photovoltaic panels. From the following relationship, we find:

$$S_{min} = \frac{P_{PV2}}{\cos\ \varphi} = \frac{9.6}{0.8} = 12kVA$$

A generator with a power of approximately $15kVA\left(\cos\phi = 0.8\right)$.

Therefore, the presence of a backup diesel generator is a positive factor for system reliability and complete power security. Typically, a large-capacity diesel generator with a sufficient power factor is recommended for powering equipment and other applications, if any. Small generators lack the high quality and capacity, and the voltage is unstable, resulting in unstable voltage and frequency. There is no possibility of using an intelligent monitoring and control system for the backup diesel generator.

Calculating the fuel tank capacity V required for the generator, assuming the generator will operate during certain times of the year (mostly in winter) $T_{aut} = 15days$. Average fuel consumption required $220g\,/\,kW$, knowing that $1Liter \approx 1Kg$.

$$V = 0.220 \times 9.6kW \times 15dayes \times 24h = 760Liters$$

Therefore, we suggest adding backup diesel generators to fuel tanks (for certain periods of the year, such as during the winter) in case electricity from the public grid is unavailable. Failure to add seasonal tanks (during the winter) increases operational and logistical costs, as well as reduces system reliability.

6. Principle of hybrid power system operation

Figure (4) shows several types of electrical energy acquisition strategies. The primary goal of a hybrid energy system is to secure electrical energy from renewable energy sources (solar and wind energy) to power the load (communications equipment) and charge the battery, if possible (Figure (4a). If the electrical energy generated by either photovoltaic panels or a wind turbine is insufficient, the load is supplied without charging the battery (Figure (4b). When the electrical energy supply to the load from renewable energy sources (solar and wind) is interrupted, the supply is secured from the batteries and a diesel generator after the battery is discharged (Figure (4c). When the diesel generator is operating, this indicates that the battery has been discharged (4d). Care must be taken to protect the battery from deep discharge, where the minimum voltage must be fixed at a constant value $(1.8V / cell)$, and from overcharging, where the voltage must also be fixed at a constant value corresponding to the maximum current $I_{batt \max}$..
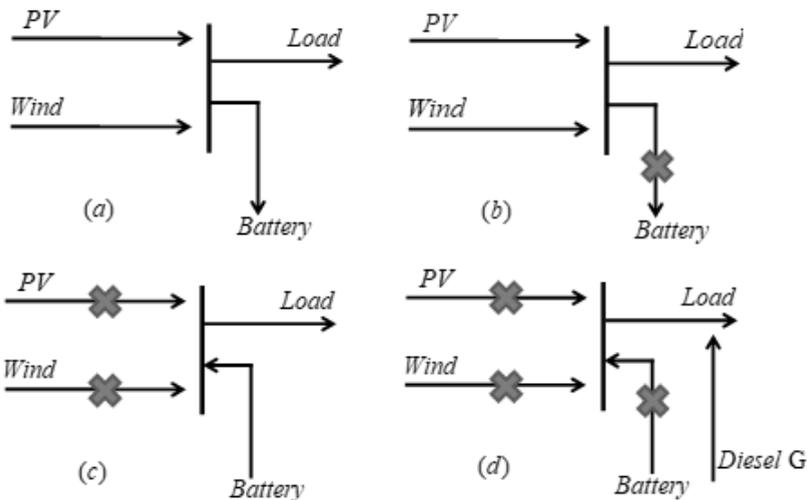

Fig 4: several types of electrical energy acquisition strategies

7. Control of hybrid power system

The basic principles of hybrid power system control are based on the principles outlined in the previous paragraph. If energy is not available from renewable energy sources, it is obtained and supplied either from the battery or a diesel generator, primarily from the battery and then from the generator. The battery can be charged with a lower current, which requires a longer charging period. Conversely, if the charging current is high, the charging period is shorter, resulting in a shorter battery life [15], [16]. There are many battery parameters that must be taken into account, such as the minimum battery voltage and the maximum charging current. In this research, the variable parameters can be programmed as follows:

- Battery monitoring: Two capacitors must be calculated based on the available information: the actual capacity (representing the battery's instantaneous capacity) and the charging capacity (representing a percentage of the battery's nominal capacity). The battery can be safely used up to a charging capacity greater than the nominal capacity. If the charging capacity is close to the nominal capacity, this indicates a high charge level (increased charging time) and a low minimum allowable voltage.

- Weather information, such as air temperature, relative humidity, wind speed, and atmospheric pressure at the center's geographical location. This is to obtain accurate information over a short period.

The control system relies on the battery's state of charge, as well as controlling the diesel generator when needed. Figure (5) shows the control of the hybrid power system without the presence of a central battery charger.
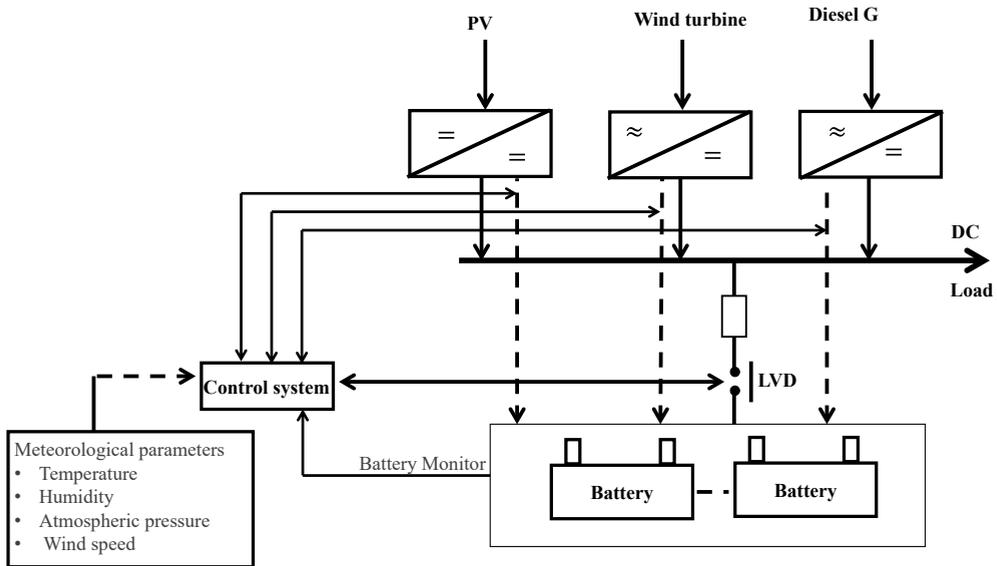
Fig5: control of the hybrid power system

8. Conclusion

These days, there is a consensus among scientists, engineers, economists, and politicians worldwide on the need to provide energy to all sectors of life, including the information and communications technology (ICT) sector, without harmful environmental impact.

In this work, a hybrid energy system is proposed that combines renewable energy sources (solar and wind) with conventional sources (diesel generators) with the possibility of storing energy through batteries. This represents a solution for the efficient use of energy resources to provide stability and reliability.

The use of renewable energy systems can be connected to the public grid (in-grid), and this system can constitute the primary source of power supply in the absence of an off-grid. Another goal of the hybrid energy system

is to reduce fuel consumption, lower greenhouse gas emissions, and lower operational and logistical costs. Many algorithms can be applied to the operation of a hybrid energy system, depending on economic and technical feasibility.

This hybrid system can also be further developed by adding another type of energy storage, such as hydrogen fuel cells. This research also presents some of the investment and operating costs of the hybrid energy system components to compare economic and technical feasibility. Changes in climatic conditions and investment programs affect the cost of the system and the selection of its components, depending on the need to secure electrical power for the loads.

Overall, the purpose of this work is to provide some practical applications for hybrid energy systems, stimulate and develop new ideas in this field, and promote the widespread use of this technology, both now and in the near future.

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