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Capacity Optimization Design of Hybrid Energy Power Generation System

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ABSTRACT

Environmental concerns and higher energy demand require more energy. Solar and wind are renewable energies. One of the most important and available renewable energy sources is the use of wind and solar sources. This study examines energy generation and battery storage systems for lowering peak load and smoothing a residential substation's load curve. This study aims to present a useful and effective mechanism for improving the design of a hybrid system using solar panels and wind turbines to provide the common peak load and as much actual load demand as possible at the desired location. The proposed method provides the optimal solution after obtaining light radiation, wind speed, and load demand. Training and learning-based algorithms optimize. This study focuses on reducing lifetime costs. Prices and equipment are accurate, and power plant costs include initial and ongoing costs. PSO optimizes Karachi's anemometer and radiation data. The results showed that the network's summer, fall, and winter peak outputs are 12368 kW, 14865 kW, and 77 147 kW; the systems are 68.31 kW, 29.38 kW, and 2337 kW. Using the seasonal average rather than the annual average improves the system's dependability and provides a more accurate response to the desired peak load. Wind and solar hybrid systems connected to the grid can reduce the grid's peak load and total cost over time.

1. INTRODUCTION

Wind and solar energy are of interest since they are readily available and do not produce greenhouse gas emissions. Additionally, wind and solar energy can be a wonderful complement to each other when it comes to the production of electric power. The current worries regarding fossil fuels have led to the development of new tendencies in the application of various technologies that generate sustainable sources of energy [1-3]. Off-grid methods of collecting energy from the sun and the wind are the subject of a significant amount of research that is being carried out right now. They studied whether or not it would be possible to power residential housing in one of Karachi's rural districts by utilizing a hybrid system that consisted of solar panels, diesel, and batteries. In the course of this inquiry, four distinct diesel generators that utilized cost-effective fuel were utilized [4, 5]. The study methodology that was used was called the "Pack Model." Simple optimization to find the system's optimal location, which ensures excellent dependability at the lowest possible cost in terms of fuel. They found that this scenario is less expensive for diesel systems only when the fuel is subsidized; however, when the fuel subsidy is eliminated, the diesel generator's contribution to the system's necessary energy supply is reduced. They found that only when the fuel is subsidized is this scenario less expensive for diesel systems [6, 7].

The objective of providing this approach is to enable users to determine the optimal number and kind of units to use in the computation by consulting a list of devices that are currently available on the market. This method guarantees that, within 20 years, not only will the total required load be covered and therefore provided, but also that there will be a reduction in the overall cost of the system as a result of the restriction placed on the amount of energy that will be required [8]. This method ensures that the system's costs are reduced to the absolute minimum without putting the supply in jeopardy. The findings of the research indicate that the costs associated with utilizing a solar wind hybrid system are significantly lower than the expenses associated with using individual wind and solar systems [9, 10]. According to the findings of a recent study, it is possible to construct an independent hybrid energy system using solar panels, wind turbines, and batteries. The primary sources of power for the system are forms of renewable energy, such as wind and solar electricity; the battery is solely used for the purposes of providing redundancy and storing extra energy [11]. Following the specification of the system's components based on total year cost, the total annual cost is regarded as the target function that should be achieved. In the course of this work, a mathematical model was utilized in order to conduct an analysis regarding the prices of the various system components. After then, the performance of a number of different PSO algorithms was analyzed in order to find out what the best configuration for the solar, wind, and battery system would be [12, 13]. Finally, reliable meteorological data from the area was used to determine the appropriate size of the system's component parts. Investigations have been conducted throughout the southern, northern-western, and northern-eastern regions of Pakistan respectively [14, 15].

In the framework of the system for the production of energy, one of the most important concerns is the fact that some of the proposed systems include energy storage methods such as storage pumps and batteries in order to supply a consistent flow of energy [16]. On the other hand, a number of studies have proposed the utilization of internal combustion engines, such as diesel engines, in conjunction with a combination of such engines and batteries as a means of overcoming challenges associated with random production. Another possibility is linking the system to the national network; in this setup, the network acts as a technology that bolsters the functionality of the system [17, 18]. It is absolutely necessary to make use of data on solar radiation, wind speed, and load demand in order to improve the efficiency of these systems. When it comes to the optimization of hybrid systems, one of the major qualities is the information that is being input. This information is one of the essential components of the problem. A significant portion of the already available articles do not make use of the most recent data. The fact that daily and seasonal statistics aren't always correct gives us reason to believe that the analysis isn't credible [19]. A thorough examination of a number of sources reveals, among other things, that there has been little research done on the optimization of hybrid systems that are connected to the grid, and that there is little information regarding prices. When taken together, we have reason to suspect that the analysis is not as reliable as it could be. It is not conceivable for there to be consistent access to electricity [20].

As a novel strategy, this research aims to provide a realistic and effective method for designing a more efficient hybrid system based on solar panels and wind turbines. This design should be able to accommodate both the real load demand and the peak load commonly encountered at the location of interest. After determining the quantity of light radiation, the amount of wind speed, and the required weight, the proposed method gives a satisfactory solution to this problem. An algorithm based on teaching and learning is employed for optimization. An additional crucial objective of this research is to calculate the total cost of the system, which includes not only the initial investment but also all anticipated costs over the system's lifetime. This evaluation will take into account not only the initial expenditure, but also all projected costs. Using the annual average of information rather than the seasonal average can boost system reliability and give a more precise response in terms of supplying the required peak load, according to the conclusions of this example research. The reason for this is that seasonal averages are calculated more frequently than annual averages. It is also evident that employing a grid-connected wind and solar hybrid system is an appropriate way to regulate the peak load of the grid, and that using it in large quantities can ultimately contribute to a reduction in the overall cost of the grid. This is something that can be observed.

2. RESEARCH METHOD

In this section of the research, we will discuss about Necessary parameters for interval management, dimensions and operation of hybrid systems and Specifications of system dimensions.

2.1 Necessary parameters for interval management

2.1.1 Load distribution and load continuity curve

The graphical representation of changes in the amount of electric power consumed by each customer over the course of time is referred to as the "load curve." The variations in network electricity consumption can be investigated to establish the boundaries of peak and off-peak hours, the maximum and minimum output power of power plants, and load factor as represented by the network load curve. All of these parameters can be found on the network load curve. By timing the occurrences of maximum and minimum power consumption, one may extract and use metrics such as the load's electrical energy balance, demand condition during peak and off-peak hours, and maximum and minimum power consumption. One can do this by using the load curve [21].

2.1.2 Demand factor

Customers are absolutely necessary for the day-to-day operations of organizations that are in charge of power generation and distribution. principally due to the fact that the component determines the capacity of the power plant that needs to be built in order to fulfill the requirements of the clients.

2.1.3 Load factor

It determines the ratio of the average load for a specific period to the highest load for that same time period by computing the difference between the two. The percentage represents this proportion that is presented. Because load factor is defined as being greater than one when E is reduced (because E is always less than one), the most efficient type of consumption happens when load factor is at its highest possible value. This is because E is always less than one.

2.2 Operation of hybrid systems

The goal of this part is to build a proper production-to-consumption ratio in the intended hybrid system in order to enhance the household load consumption pattern and reduce peak load. This ratio will be determined in order to meet the needs of the proposed hybrid system. This ratio will be determined in order to meet the requirements for the hybrid system that has been proposed. In this sense, determining the system's dimensions is critical in order to provide appropriate levels of power generation while also ensuring that it achieves the best potential level of economic efficiency. The following equation, which should be used to achieve this goal, can be used to calculate how large of a gap there should be between the power output of new energy sources (P_{Gen}) and the power output of the load (P_{load}).

$$\Delta P = P_{Gen} - P_{load}$$

The researched system's block diagram is depicted in Figure 1, which may be found here. In this particular setup, energy storage comes from both wind and solar sources. Figure 1 illustrates how the outputs of the devices are connected to a DC bus. This bus is connected to a variety of batteries in order to function as a storage system. The energy that is generated by the WG and PV system is stored in lead-acid batteries, which are then introduced into the system during peak load times in order to improve the load curve. The DC/AC converter allows the energy to be transferred from the storage medium to the consumer.

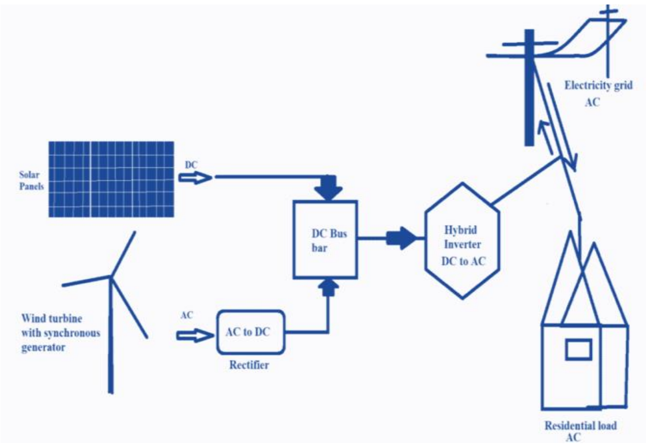

Figure 1. Hybrid system diagram in research

2.3 Specifications of system components

2.3.1 Wind turbine

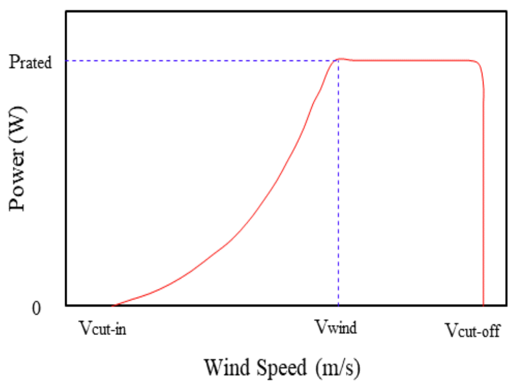

Figure 2. Turbine output power according to wind speed

A wind turbine is a piece of machinery that converts the kinetic energy of wind into mechanical energy. This mechanical energy is then fed into a generator, where it is converted into electrical energy. Figure 2 illustrates how the output power of the turbine can be computed based on the wind speed. It is abundantly evident that, beginning at a particular amount of wind speed, the turbine's output power is fixed, and that when speeds higher than the maximum speed are reached, the turbine ceases to function. The following equation can be used to calculate the amount of power that is produced by the wind turbine.

In Eq. (1), (P_{WG}) represents the wind turbine's output power, (P_R) represents each turbine's rated power, (V_w) represents wind speed, (V_C) represents the low cut-off speed, (V_F) represents the high cut-off speed, and (E) represents the turbine's rated speed.

$$\text{P wind}_{\,t} = \begin{cases} 0 & v_t < v_{ci} \text{ and } v_t > v_{co} \\ P_r(A + Bv_t + Cv_t^2) & v_{ci} \le v_t \le v_r \\ P_r & v_r \le v_t \le v_{co} \end{cases} \tag{1}$$

2.3.2 Photovoltaic panel

One type of photovoltaic electrical device is a photovoltaic cell, which makes use of the photoelectric effect in order to transform the kinetic energy of light into usable electrical current. The framework of solar cells is utilized in the construction of solar modules, with sunlight acting as the primary supply of energy. A solar panel is constructed from a collection of photovoltaic cells that are all laid out in the same horizontal plane. A glass coating is often applied to the face of photovoltaic modules that is exposed to direct sunlight. An array of solar cells is what accomplishes the transformation of the sun's rays into direct power that may be put to beneficial use. Direct current electricity is produced by solar photovoltaic, sometimes known as PV, systems. If the most common form of energy consumption is in the form of alternating current, then any type of renewable energy system will need an inverter to change the electricity from direct current (DC) to alternating current (AC). DC stands for direct current, and AC stands for alternating current [22]. On the other hand, if the DC voltage of the PV sources is obtained at a level that is lower than the grid voltage level or the voltage that is required by the load, then we can use a voltage-increasing converter class. This is the case when the grid voltage level is higher than the voltage that is required by the load. These systems can be as tiny as units ranging from 2 kW to 7 kW that are installed on the rooftops of individual homes or as large as those found in photovoltaic power plants. This technology is designed to function in a manner that makes it possible for electricity generated by the sun to be directly transformed into electricity of the AC type by means of electronic equipment and then injected into the national grid. This takes place at a time when we are able to access and make use of the resources that are offered by the national power grid. When there is sufficient sunlight, the solar panel can serve as a supplementary source of electricity by contributing to the larger power grid [23].

2.3.3 The syntactic pattern of load sharing between the power grid and the photovoltaic-wind system

This section's objective is to maximize load factor while adhering to the aforementioned constraints. These constraints include determining the optimal number of batteries, PV arrays, and the highest penetration factor that the PV system can achieve in the network under dynamic and protective conditions. Additionally, this section's objective is to determine the optimal number of wind turbines. For the purpose of locating these variables in this part, the PSO method will be utilized; however, the problem will only have the pertinent technical conditions applied to it; the economic facets will not be modeled [24]. The most important objective of this section is to successfully lower peak load. The following is an example of the Equivalent to number two for this function:

$$\min f = (\sqrt{(1 - F_{LD})} \tag{2}$$

The constraints of the objective function are expressed as follows:

$$\begin{aligned} 0 &\leq N_{PV} \leq N_{PV}^{max} \\ 0 &\leq N_{\text{Wind}} \leq N_{\text{Wind}}^{max} \\ 0 &\leq N_{\text{Batt}} \leq N_{\text{Batt}}^{max} \end{aligned} \tag{3}$$

The load sharing pattern and how the load is distributed between the grid, the photovoltaic-wind system, and the battery are depicted in Figure 3. The sharing mechanism must use as much of the energy generated by the photovoltaic-wind system as possible (depending on sunlight and wind speed), with the network and backup battery delivering the remainder of the load. This process examines a maximum power level (P_{max}) for each day of the year. This is the greatest amount of power we will be able to acquire from the main power grid. As a result, if the energy consumed is less than the sum of this power and PV power, the difference can be used to charge the battery [25]. The summery of technical properties of the system are presented in Table 1.

Table 1. The summery of technical properties

System Characteristic		
j	10%	Inflation
n	20 years	System life span
Δt	1h	Sampling time
Battery		
S_{Batt}	2.1 Kwh	nominal capacity
Voltage	12 V	nominal voltage
η_{bf}	100%	Charging time efficiency
η_{bc}	95%	Discharge time efficiency
P_{Batt}	$ 150	Initial capital cost
LS_{Batt}	5 years	Life span
DOD	0.85	Maximum discharge amount
σ	0.0002	Hourly discharge rate
N^{max}_{Batt}	150	Maximum number of batteries
Converter		
Rated Power	1,200 w	capacity
η_{inv}	85%	efficiency
P_{inv}	$700	Initial capital cost
Voltage	24	nominal voltage
LS_{inv}	10 years	Life span

2.4 PSO optimization

PSO simulates the search for food by a flock. The algorithm's simplicity, reduced number of parameters, and ease of implementation are all advantages. Following equation updates its speed and position [26].

$$\begin{cases} v_{ij}^{t+1} = wv_{ij}^{t} + c_1 r_1 (p_{best,ij}^{t} - x_{ij}^{t}) + c_2 r_2 (g_{\text{best},ij}^{t} - x_{ij}^{t}) \\ x_{ij}^{t+1} = x_{ij}^{t} + v_{ij}^{t+1} \end{cases} \tag{4}$$

where, t is the number of iterations, w is the inertia weight of each particle, v_{ij}^{t} is the speed of the particle in i and j at time t, c_1, c_2 are the learning factors, r_1, r_2 are random numbers, p^{best} is the optimal fitness, x_{ij}^{t} is the position of the particles in i and j at time t, g^{best} is the global of each particle,w is the inertia weight [26].

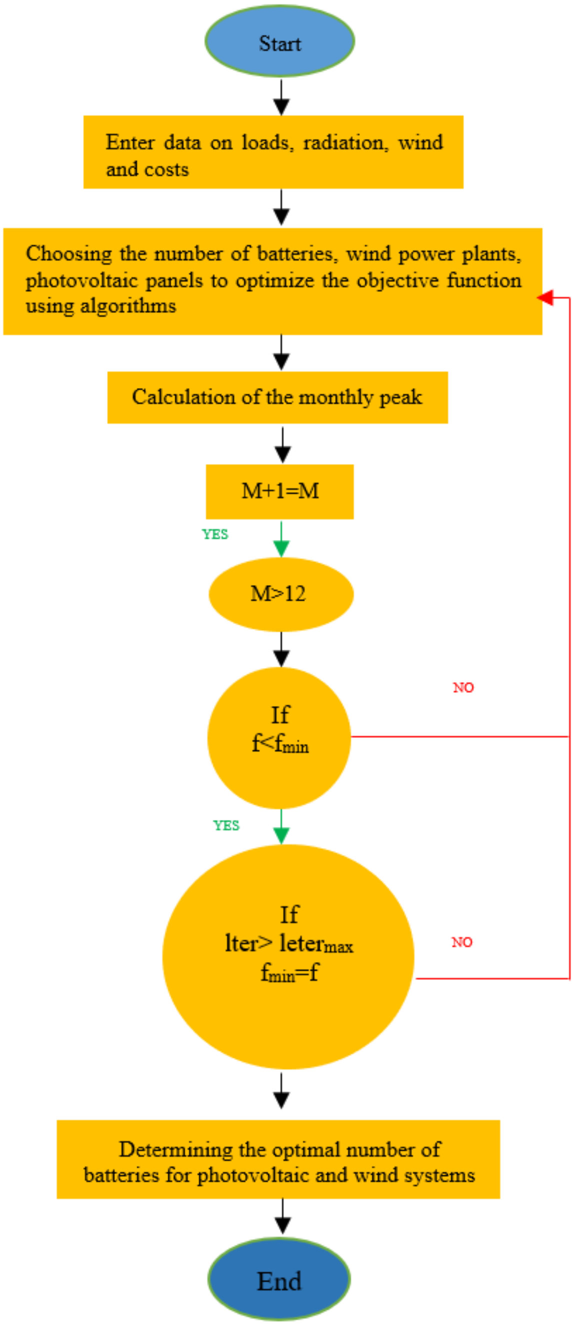

Figure 3. Diagram of objective function optimization

3. RESULTS

In order to carry out research on the typical load curve of a 500 kW transformer, the annual and seasonal averages of Figures 4 and 5 were utilized in this article. These figures were used in this article because they were used in the previous article. This article made use of these figures because they had been utilized in the article that came before this one. Because they had been used in the article that came before this one, the author of this article decided to make use of these figures. The investigation was carried out so that we would be able to provide a satisfactory response, based on the information that is appropriate, to the following query: It was discovered that the value of the annual joint consumption curve that was in effect between 13:00 and 14:00 and 18:00 to 24:00 had a value that was greater than the value that had been established as the target value. This was discovered after it was discovered that this value was greater than the value that had been set as the goal value. Because of this, it was decided that the hybrid system should be utilized in order to achieve the level of consumption that was desired. This was due to the fact that the hybrid system is more environmentally friendly. The previous point had a direct impact on the development of this point. On the day in question, when the load was at its highest point, the residential substation recorded a peak load of 16.152 kilowatts at its highest point in the day when the load was at its highest point. As a direct result of the fact that this is the situation, the hybrid system is required to provide a maximum of 31.45 kilowatts, whereas the network is required to provide a maximum of 36.124 kilowatts. Both of these requirements must be met. In order to remain in compliance with the regulations, it is necessary to achieve either one or both of these maximums. The seasonal consumption curve is shown in Figure 4 over the course of four days, with each day representing a different season in the year. The figure has been laid out in a horizontal orientation so that it can be presented in the clearest possible manner. The consumption patterns of the subscribers will, of course, have an impact on the maximum peak load. This is something that can't be avoided. As a direct result of this, the production capacity of both the network and the hybrid system will shift seasonally depending on the conditions of the environment. During the summer, fall, and winter seasons, respectively, the peak output of the network is 12,368 kW, 14,865 kW, and 77,147 kW. On the other hand, the peak output of the system during those same seasons is 68.31 kW, 29.38 kW, and 2,337 kW, respectively (Figure 5).

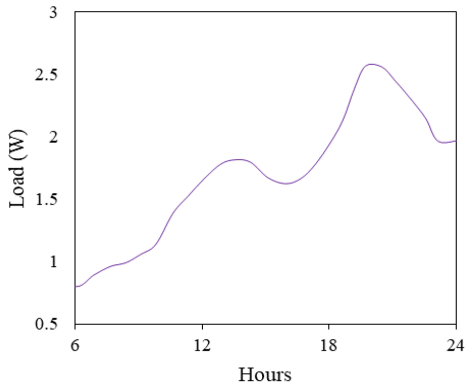

Figure 4. Maximum network generation and annual average load profile

The results obtained by using the annual average of the load profile, solar radiation intensity, and wind speed to arrive at the conclusions drawn from the simulation are depicted in Figure 6 (a). These results were used to arrive at the findings of the simulation. The figure clearly illustrates these findings and conclusions. In this particular circumstance, there is a demand for twenty-three photovoltaic cells (solar panels), eight wind turbines, twenty-two converters, and eighty batteries. It is possible to say that the efficiency of the converters that are currently being used is comparable to the efficiency of the converters that are currently being used. The total production capacity of the hybrid system is also expressed in kW, as is the total required demand of the system as a whole. The total required demand comes in at 130.17, while the hybrid system has a production capacity of 169.14.

The results that were obtained can be seen in Figure 6 (b), which depicts the results obtained by using the seasonal average of the load profile, the intensity of solar radiation, and the wind speed. In this particular circumstance, there is a need for 66 converters, 73 solar panels, and 96 batteries. Additionally, there is a demand for 7 wind turbines. However, the load that is expected to be supported by the hybrid system is only 486.49 kW, which indicates that it is only capable of producing 592.34 kW of power when operating at its maximum capacity. In this scenario, peak demand is satisfied by 486.49 kW of this amount, and 1.90 kW are added to the national grid as a result of the efficiency of the converters that are being utilized, which is comparable to 85%. The efficiency of the converters that are being utilized is comparable to the efficiency of the converters that are being utilized. In addition, the peak demand can be met with the total capacity of this system, which is 486.49 kW. A numerical comparison of the results that were obtained from the optimization of the hybrid system's individual components by the PSO algorithm is carried out.

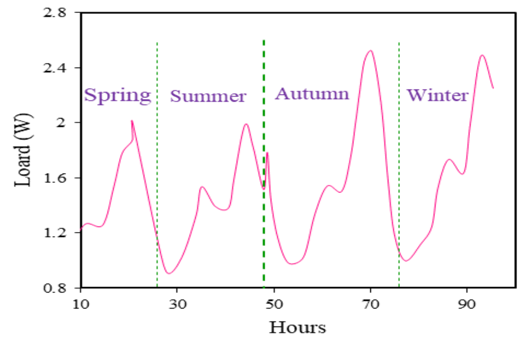

Figure 5. Seasonal average and network production machine

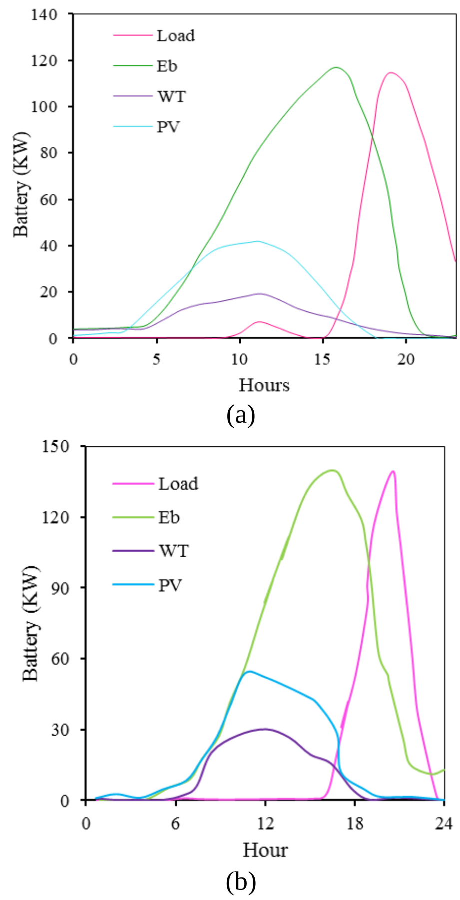

Figure 6. Supply of the hybrid system's: (a) annual, (b) seasonal average peak load

Table 2 presents a comparison of the numerical results obtained from the PSO algorithm applied to the optimization of the components of hybrid systems. According to the data presented in this table, it is possible to deduce that the annual cost of the system when using annual information (the first scenario) is significantly lower than the cost when using seasonal information.

Table 2. Numerical comparison of simulation results for two scenarios

Data	N_{Batt}	N_{PV}	N_{Wind}	Total Cost
Annual	80	23	8	1329.02$
Seasonal	96	73	7	1634.46$

4. CONCLUSIONS

This study used the yearly average as well as the seasonal average of load and weather data collected over the course of the system's 20-year history to determine the ideal configuration for the system in order to reduce costs while simultaneously satisfying peak load demand. In this particular investigation, an algorithm that is based on teaching and learning was utilized in order to identify the best possible combination of components. In light of the consumption method discussed in the previous entry as well as the climate in Karachi, it is possible to draw the conclusion that making use of the seasonal average of the data is the choice that presents the greatest advantage when attempting to determine the optimal number of components for the hybrid system. As a consequence of this, the utilization of seven wind turbines, seventy-three solar panels, ninety-six batteries, and sixty-six converters at a yearly cost of one hundred fifty-two hundred and forty-eight dollars can be regarded as optimal for the purpose of providing peak load for the specified post.

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