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RESEARCH ARTICLE

Energy Management of Microgrid With Renewable Energy Sources: A Case Study in Hurghada Egypt

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ABSTRACT This paper examines the perspective of developing a model for a microgrid to optimize the utilization of local clean energy sources for a grid-connected. The suggested model for a microgrid includes clean energy sources employing wind turbines and Photovoltaic (PV) systems and diesel generators, the grid. This model is examined with Hybrid Optimization of Multiple Energy Resources (HOMER) software. The capacity of the suggested micro-grid model is simulated according to the load profiles and the accessibility of the resources. The basic objectives of energy management are to reduce costs and reduce harmful emissions. The microgrid model with the greatest capacity produced the lowest energy costs, depending on the simulation results, the most significant reduction in CO_2 emissions, and the greatest percentage of renewable energy.

INDEX TERMS HOMER, hybrid energy system, energy management, CO_2 emissions, sustainability, renewable energy, photovoltaic (PV) energy, wind energy.

I. INTRODUCTION

The term ''microgrid'' refers to a collection of power production equipment and loads that are controlled in a separate network that may work in combination with the electric grid or independently of it. The operational viewpoint guarantees the microgrid's sustainability even while part of the sources exits the generating cycle. Through the application of Energy Storage Systems (ESSs) and electricity supplying the power network, excess generation is controlled. Microgrids may have built-in electrical capacity that can range from just a few kilowatts to megawatts. Declining fossil fuel supplies, and deteriorating network structures have encouraged researchers into microgrids and grid enhancements. The basic elements of microgrids are: **(i)** microgrid controllers, which are in charge of local and distributed control operations, **(ii)** distribution energy resources (DERs) such as conventional rotating machines and RESs like Combined Heat and Power (CHP) plants, fuel cells, solar, and wind **(iii)** technologies for separation and protection at the Point of Common Coupling (PCC) [1], [2], [3], [4], [5], [6], [7], [8]. Figure 1 shows the simplified microgrid architecture which contain DC and AC bus and each bus fed by different feeders AC bus contain the grid and wind turbine, diesel generator, AC load DC bud contain DC/DC converter and DC load and battery.

An extensive automated and 24/7 system called an Energy Management System (EMS) operates throughout a system for distributing electricity to schedule and manage DERs and controlled loads in the best possible way. Monitoring, grid details, handling of data and control are all provided by the EMS for all controlled DGS and ESS of a

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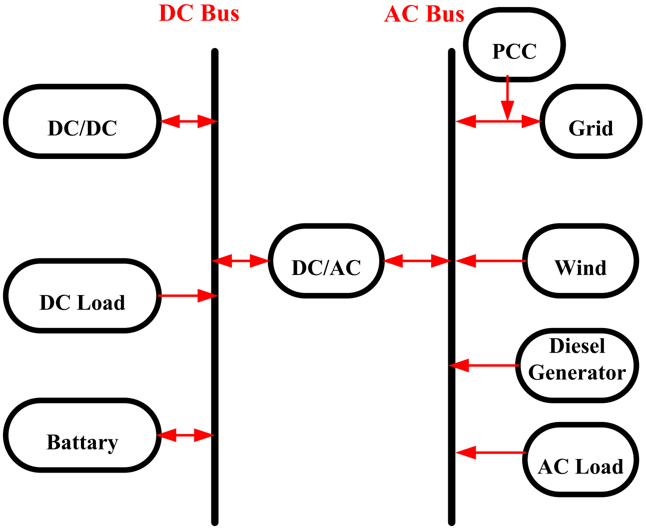


FIGURE 1. Simplified microgrid architecture.

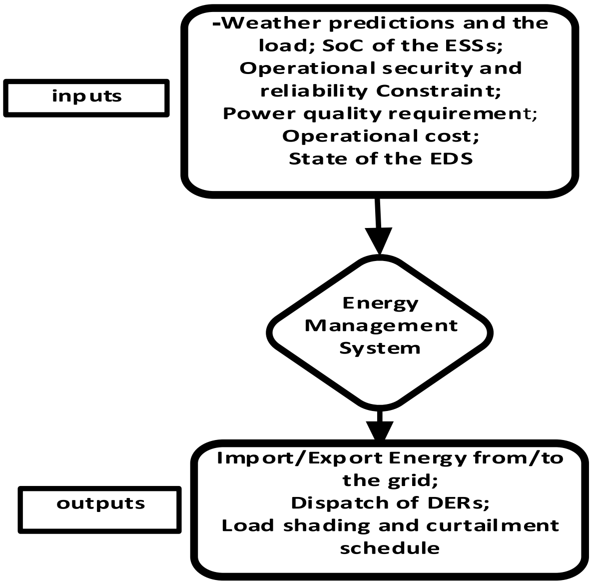


FIGURE 2. Input-output parameters of EMS.

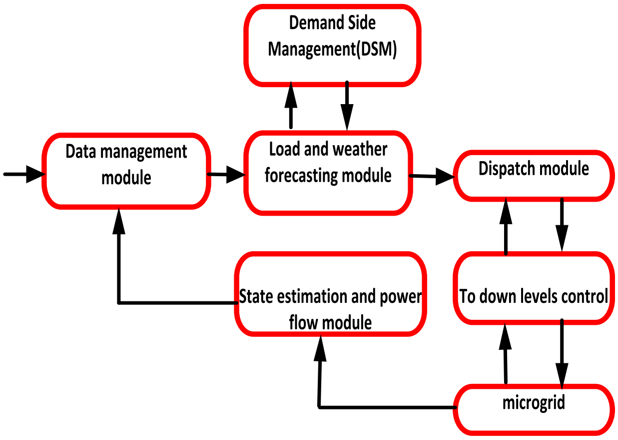


FIGURE 3. Generalized structure of an EMS.

microgrid [9], [10]. The primary duties of an EMS in this situation are [11], [12]: **(i)** increasing system resilience by maximizing each customer's energy availability, **(ii)** reducing energy waste, operational expenses, and greenhouse gas emissions, **(iii)** maximizing the usage of clean energy sources, and **(iv)** reducing the amount of electricity purchased outside of the microgrid.

A standard EMS involves entering information like predictions of non-dispatchable generating units (i.e., renewable resources), estimates of power and heat demands, and predictions of energy markets, operational, security, and reliability [13], [14]. The goals of these activities include reducing the microgrid's total running costs, system pollutants, and losses, as well as power quality, all of which are decreasing [2].

Consequently, as shown in Fig. 2 [15] the EMS provides output data at three different levels: load level (load shedding or curtailment), DERs level (dispatch or connection/disconnection scheduling), and utility level (import/export of power from/to the main grid). Figure 3 depicts the generalized structure of EMS modules, each with its own functionality and information exchange, which might make up an EMS [16].

Several researchers have studied energy management using various methods; however, they have concentrated on identifying the oldest and most efficient microgrid operation. A few researchers used many strategies to handle the control of energy problems and obtain the best microgrid functioning.

Alternative storage and demand-based integration solutions for renewable energy systems have been examined in other recent articles [17].

This concentrates on two important topics: maximizing the use of storage; and improving consumer activity. In their review, the authors in [18] and [19] looked at EM techniques for combined natural energy sources. The proposed strategy in this paper is a mixed-generation clean energy system (more than one renewable source) using a battery as a storage (or diesel generators) due to considerable dependence on climatic and meteorological factors [20]. Hybrid energy systems are widely used to expand the grid to deliver electricity for a wide range of applications [21], [22]. These mixed systems typically provide the best stability and cheapest prices when compared with systems that just utilize a single power source [23], [24].

Following is how the remainder of the paper is structured: Section (I) is an introduction, Section (II) describes the study location and forecasting load and resources of the proposed micro-grid models. The mathematical model of the components is discussed in Section (III) of this paper. Section (IV) presents the results and discussion of the study. Section (V) introduces the limitations and future work. Finally, the conclusions are discussed in Section (VI).

II. STUDY LOCATION AND FORECASTING MODEL

The region of study is located in Hurghada, Red Sea, Egypt. It extends geographically over the southeastern part of Egypt and lies between 27^0 5.5' N latitudes and 33^0 49.7' E longitudes.

The EMS requires important information about load usage and weather predictions [6]. The climate information is utilized for predicting the production of energy from renewable sources, and the demand consumption information allows the EMS to specify the operation of the DGS and ESS. The reliability of the predicted data is crucial to the microgrid's functionality [25].

Due to the insufficient spinning reserves of online systems, grid operation, and stability may be jeopardized if the load-consuming or producing statistics have been overestimated. On another hand, if the amount of demand or generation is overstated, several units are sent out, which will raise the cost of operation. Generally speaking, the peculiarities of the approach employed by the appropriate module limit the accuracy of the load utilization, and climate predictions are calculated. Some of the best forecasting systems produce prediction errors in the range of 5 to 15% [26]. Some prerequisite information for the 24-hour management of energy must be planned ahead of time. The details are as follows:

- Hourly predicted load for the following day;
- Hourly wind and PV generation estimations;
- The price operates, characteristics, and power limitations of DERs.

Where all the data used, such as loads, solar radiation, wind speed, temperature, and other data, are from a real state of affairs.

A. ELECTRICAL LOAD PROFILE

The nature of the electrical load is affected by the devices and operations used. For one hour every day, the power analyzer equipment is used to directly measure the electrical load. An inventory of existing loads and the load capacity have been determined by reading the power meters every hour to establish a daily load profile as shown in Table 1.

B. RESOURCES

Information about the radiation from the sun and the wind speeds can be found on the HOMER Energy Website, which uses the National Aeronautics and Space Administration (NASA) Surface meteorology and Solar Energy (SSE) World data set [27], [28]. Information about the radiation from the sun and the wind speeds is obtained by inputting the study location latitude, longitude, and time zone into the HOMER. The climatic conditions affect the amount and the ability of renewable energy sources such as wind and solar at a specific location. Climate factors are the temperature of the environment, sunlight irradiation, and the velocity of wind. Figure 4 illustrates load profiles for the day, season, and year using Hybrid Optimization of Multiple Energy Resources (HOMER) software.

TABLE 1. Daily load.

Time	kWh
1	742
2	765
3	765
4	767
5	642
6	685
7	690
8	810
9	835
10	830
11	765
12	765
13	700
14	750
15	765
16	760
17	772
18	810
19	810
20	815
21	800
22	725
23	740
24	725
Total kW/day	**18233**

An investigation of the features of solar radiation and wind conditions at a potential site should be done at the stage of genesis to enhance the utilization of the wind and solar resources of energy for the performance simulation of these systems, weather information with hourly solar irradiance, temperature, and wind velocity is necessary.

The HOMER provides the global weather data as shown in Figures 5-7.

III. MODELING OF HYBRID ENERGY SYSTEM COMPONENTS

The mathematics model of the elements of hybrid systems of energy is explained here before moving to computer simulation. The suggested system includes a utility subsystem, a PV subsystem, a diesel generator unit, and a wind energy subsystem.

A. PV POWER GENERATION MODEL

HOMER calculates the PV electricity generated by Eq. (1) [29] as follows:

$$P_{PV} = f_{PV} * y_{PV} * \frac{I_t}{I_s} \tag{1}$$

where: $\boldsymbol{f_{PV}}$ is PV's derating factor, $\boldsymbol{y_{PV}}$ is the PV capacity rating (KW), is solar radiation (KW/m^2), and is 1 kW/m^2 (the typical quantity of radiation). PV arrays are connected in a

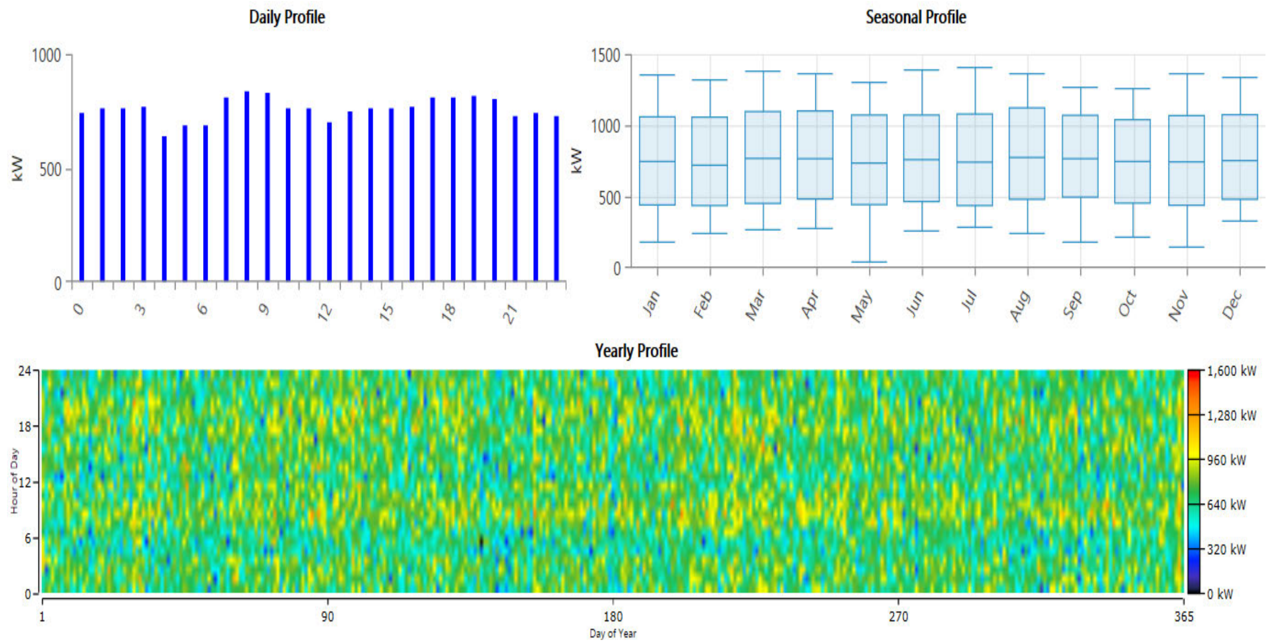


FIGURE 4. Load profiles for the day, season, and year.

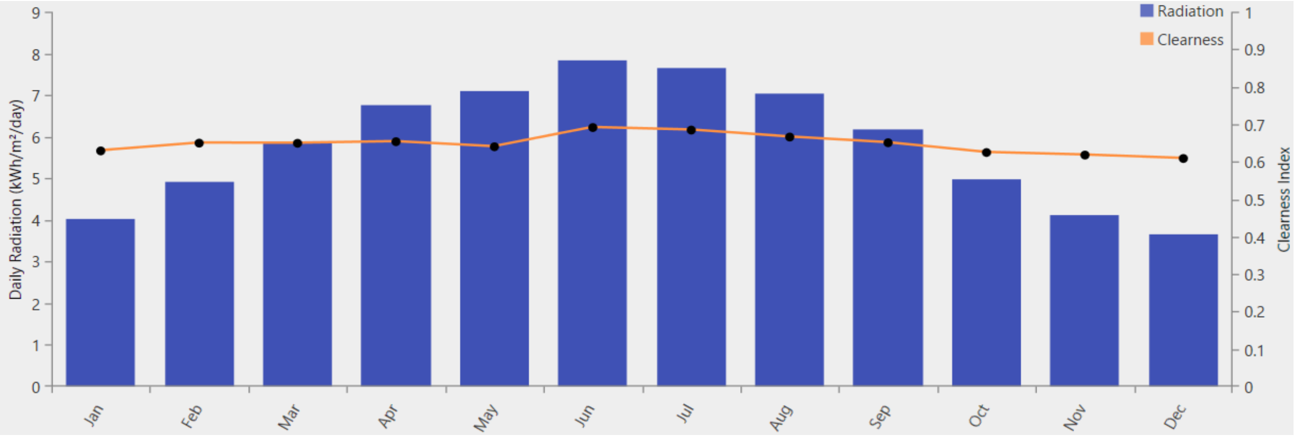


FIGURE 5. Solar irradiance and cleanness index.

series and parallel configuration. HOMER should include the capital cost per KW, which includes the cost of getting solar panels, installing panels, controllers, cables, and setup. The lifespan of the solar module is specified by the specification, which is 25 years [30].

B. WIND GENERATOR MODEL

Hourly energy generated, E_{WEG} by wind generators with rated power output $\boldsymbol{P_{WEG}}$ is defined by Eqs. (2) and (3) [21].

$$P_{WEG}(t) = \frac{1}{2}\rho_{Wind} A \times V^3 \times C_P(\lambda, \beta) \times \eta_t \times \eta_g \tag{2}$$

$$E_{WEG}(t) = P_{WEG}{}^{*}t \tag{3}$$

where: $\boldsymbol{\rho_{WInd}}$ is the density of the air, A is the module's surface area in m^2, v is the wind velocity (m/s), $\mathbf{C_p}$ is the performance coefficient, $\boldsymbol{\eta_t}$ is wind turbine efficiency, $\boldsymbol{\eta_g}$ is generator efficiency, $\boldsymbol{P_{WEG}}$ is wind turbine-generated electricity, $\boldsymbol{E_{WEG}}$ is the amount of energy generated by a wind turbine every hour [30]. C_p isn't fixed, but changes by velocity, turbine rotational velocity, and rotor blade details such as angle of attack and pitch angle. In general, C_p is stated to be an indicator of the ratio of the tip speed λ and the blade pitch angle β.

C. DIESEL GENERATOR MODEL

The energy generated $\boldsymbol{E_{DEG}}$ by a diesel generator with rated power output $\boldsymbol{P_{DEG}}$ is defined by using Eq. (4).

$$E_{DEG}(t) = P_{DEG}(t) * \eta_{DEG} \tag{4}$$

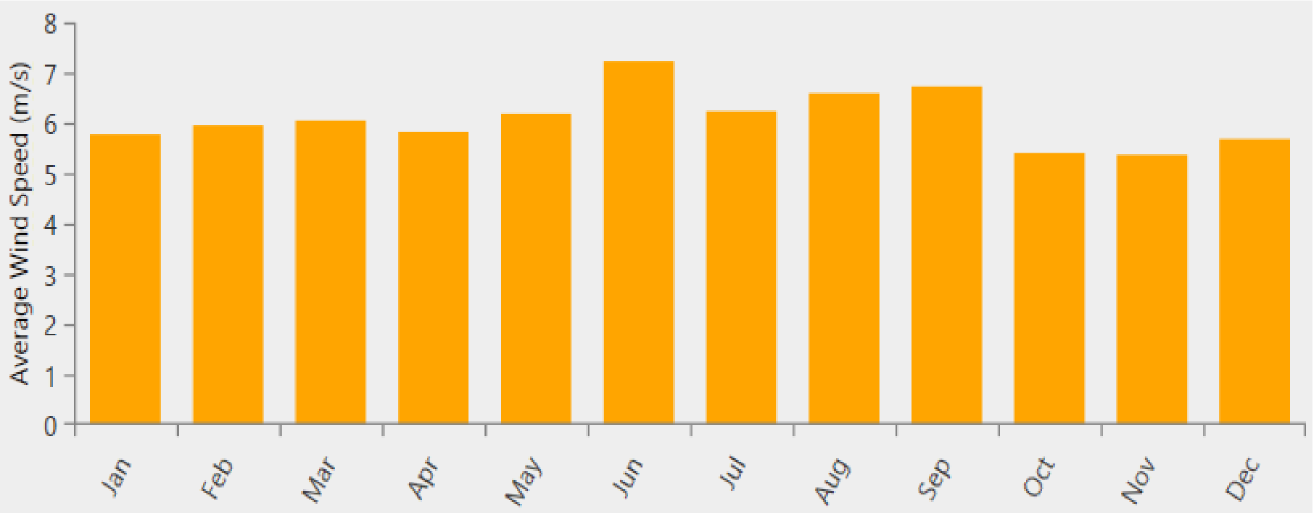


FIGURE 6. **Monthly average wind speed.**

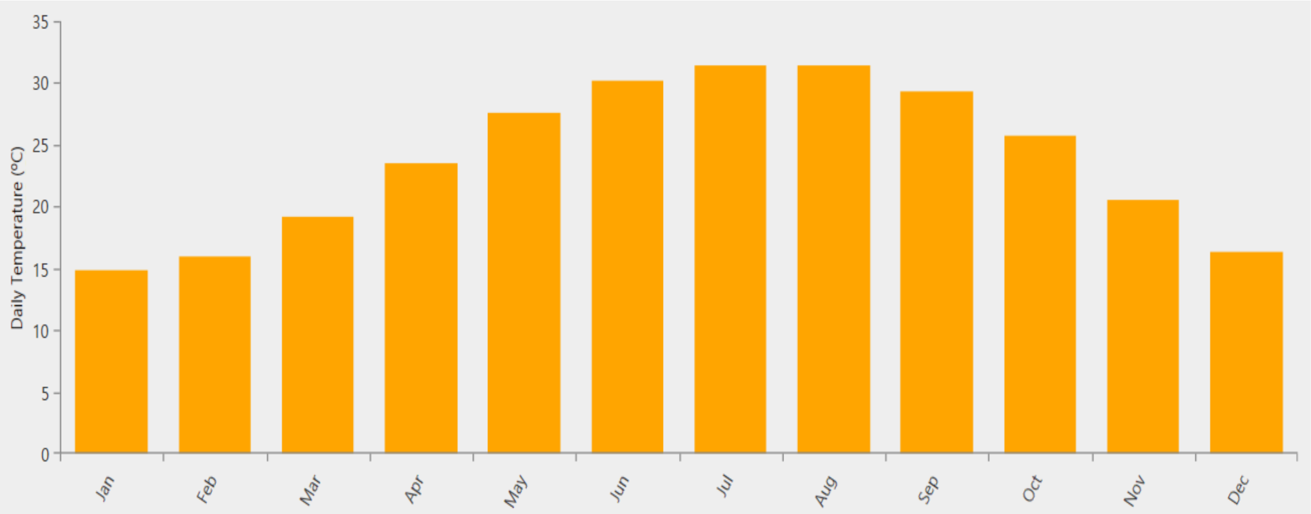


FIGURE 7. **Monthly average ambient temperature.**

The diesel generator is constantly operated between 80 and 100% of its kW rating for optimal performance and efficiency [31].

D. UTILITY GRID MODEL

Thermal power plants that serve as a source of electricity for the grid emit gases including CO_2, N_2O, SO_2, NOx, CH_4, and others during normal operation. CO_2 emissions are among those that have the most impact on global warming. As a result, the current research exclusively considers CO_2 emissions. Based on the emission coefficient and the amount of electrical energy generated by each power plant, the grid system's emission coefficients are computed [32], [33].

The emission coefficient can be calculated by Eq. (5) as follows:

$$Emission\ cofficient\ of\ grid = \frac{\sum_{i=1}^{n} EC_i \times KWh_i}{\sum_{i=1}^{n} KWh_i} \tag{5}$$

where: $\boldsymbol{EC_i}$ is the power plants' emission coefficient to-i (kg/kWh) and $\boldsymbol{KWh_i}$ is power plant production to-i $\boldsymbol{KWh_i}$.

IV. RESULTS AND DISCUSSION

A. STUDY OF A BASE CASE

The current state of our network before adding any DER, which is just loads fed from the grid only, Electrical consumption is 18229 kW/day and the peak is 1417 kW as shown in Fig. 8 obtained from HOMER.

Some of the important results such as energy consumption and annual energy purchase and sold to the grid, production of renewable energy sources obtained by HOMER's program.

Figure 9 shows the annual energy consumption obtained from HOMER.

Table 2 shows the energy purchased per month, the price of energy per month, the peak demand every month, the peak loads are high, and the cost of energy purchase.

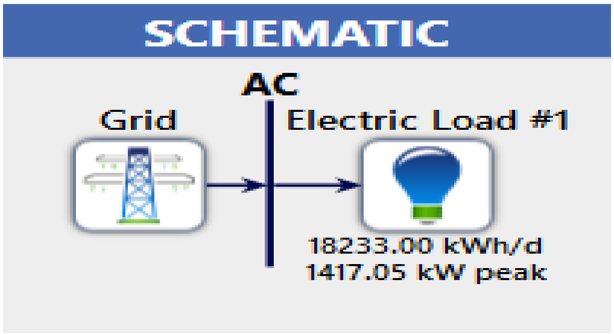


FIGURE 8. Base case (load connected to grid).

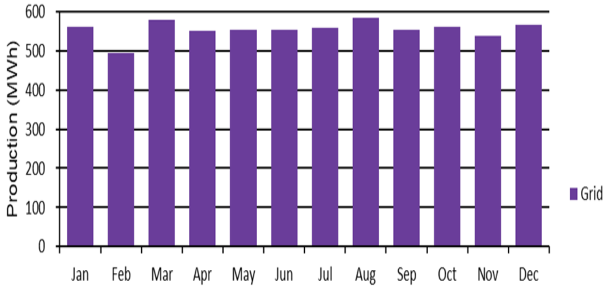


FIGURE 9. Yearly consumption of energy.

TABLE 2. Energy purchase and energy price.

Month	Energy Purchased (kWh)	Energy Sold (kWh)	Net Energy Purchased (kWh)	Peak Load (kW)	Energy Charge	Total
January	560,558	0	560,558	1,363	$22,422	$22,422
February	495,001	0	495,001	1,330	$19,800	$19,800
March	579,867	0	579,867	1,382	$23,195	$23,195
April	549,593	0	549,593	1,366	$21,984	$21,984
May	553,625	0	553,625	1,308	$22,145	$22,145
June	554,482	0	554,482	1,397	$22,179	$22,179
July	559,584	0	559,584	1,417	$22,383	$22,383
August	584,839	0	584,839	1,369	$23,394	$23,394
September	552,955	0	552,955	1,270	$22,118	$22,118
October	560,270	0	560,270	1,264	$22,411	$22,411
November	537,661	0	537,661	1,373	$21,506	$21,506
December	566,610	0	566,610	1,333	$22,664	$22,664
Annual	6,655,045	0	6,655,045	1,417	$266,202	$266,202

The annual energy purchased from the grid is 6,655,045 kWh and the annual energy sold to the grid is 0 kWh.

Table 3 shows the quantity of emissions measured in kilograms from the grid each kilowatt consumed is obtained from HOMER, the amount of emission is very large.

B. THE PROPOSED MICROGRID

The proposed microgrid contains solar, wind, diesel, and grid. This would reduce operating costs and emissions. The network after adding DER is shown in Fig. 10.

This would reduce the operating costs to -$2.90M/yr. the investment has a payback of N/A years and an internal rate of return of N/A as shown in Table 4.

TABLE 3. Emissions from energy consumption.

Quantity	Value	Unit
Carbon Dioxide	4,205,988	kg/yr
Carbon Monoxide	0	kg/yr
Unburned Hydrocarbons	0	kg/yr
Particulate Matter	0	kg/yr
Sulfur Dioxide	18,235	kg/yr
Nitrogen Oxides	8,918	kg/yr

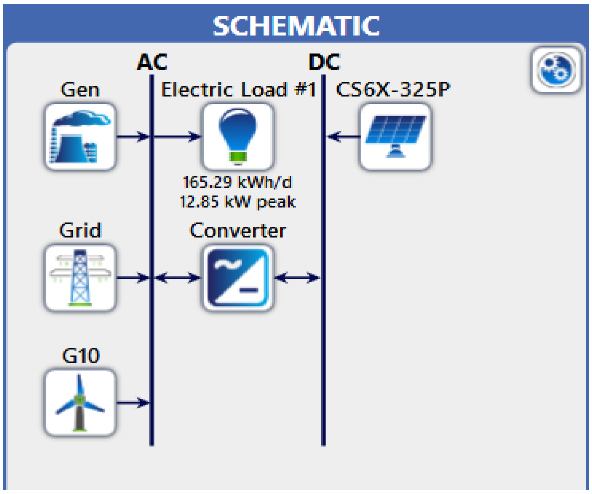


FIGURE 10. Proposed Microgrid.

TABLE 4. Total cost analyses.

Simple Payback	N/A	Net Present Value	-75.0M$
Return on Investment	-0.584 %	Capital Investment	128M$
Internal Rate of Return	N/A	Annualized Savings	3.03M$

Total cost included initial cost and installation cost, operation and maintenance cost and replacement cost.

All of the component combinations supplied in the component input are used by HOMER to simulate system configurations. To achieve the most excellent results possible match between supply and demand, HOMER performs a large number of hourly simulations and provides a list depending upon the Net Present Cost (NPC), practical strategies. The objective of this simulation is to ensure that the electric power generation is able to meet the demand by delivering an adequate amount of electricity. This is achieved via the utilization of a specific technique. To ascertain whether the system was feasible, the grid and diesel generators worked together with renewable energy sources. The system can also be modelled to assess its operational options, which include yearly electrical energy generation, annual electrical load serviced, excess power, and pollution.

Fig. 11 shows the cash flow of energy consumption over the project lifetime (25 years), in addition, the graph shows

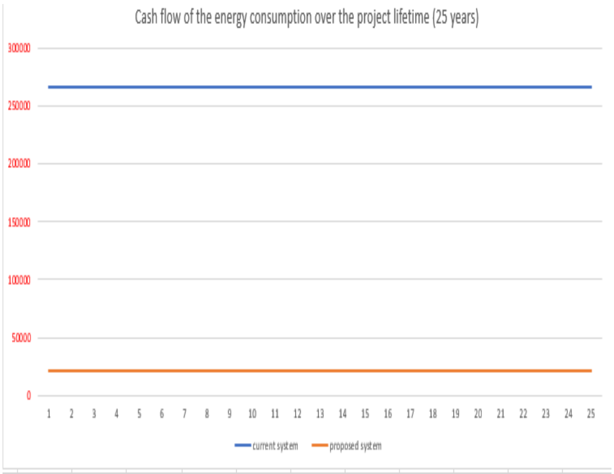


FIGURE 11. Cash flow of the energy consumption over the project lifetime (25 years).

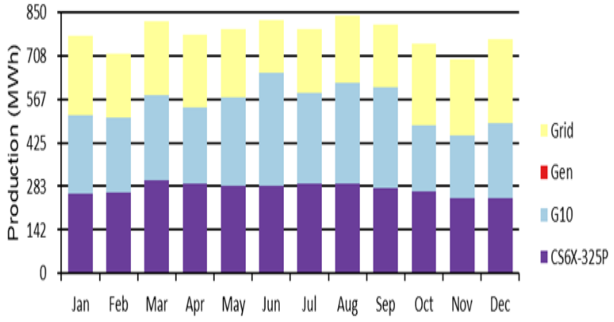


FIGURE 12. Energy production from microgrid sources.

the comparison of the cash flow of the current system and the proposed system.

From Fig. 11, the current system is very expensive compared to the proposed system. The proposed system offers the desired economic solution for only 25 years, where the cost in recent years has increased due to the replacement process of dissolution of the system.

Figure 12 shows the energy production from microgrid sources.

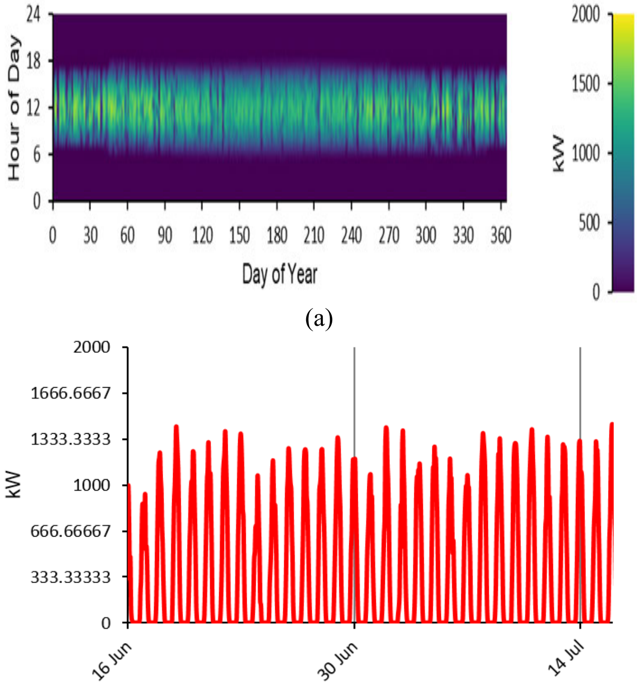
This microgrid requires 25170 kWh/day and has a peak of 2828 kW. In the proposed system, the following generation sources serve the electrical load.

1) PV

The estimated output of the PV arrangement is 1,766 kW. The yearly output is 3,307,821 kWh/yr. Figure 13 shows the energy production from PV and Table 5 shows the cost analyses for the PV system.

2) WIND TURBINE

Energy generated by the wind turbine unit, rated at 1,270 kW, is 3,293,982 kWh/yr. and Table 6 shows the cost analyses for the wind turbine system.



(a)

(b)

FIGURE 13. (a) Energy production of PV. (b) Energy production of PV.

TABLE 5. Cost analyses for PV system.

Rated Capacity	1,766 kW	Total Production	3,307,821 kW
Capital Cost	$4.89M	Maintenance Cost	27,166 $/yr
Specific Yield	1,873 kWh/kW	LCOE	0.0926 $/kWh
PV Penetration	49.7 %		

TABLE 6. Cost analyses for wind turbine system.

Quantity	127	Rated Capacity	1,270 kW
Wind Turbine Total Production	3,293,982 kWh/yr	Hours of Operation	7,514 hrs/yr
Capital Cost	$5.08M	Maintenance Cost	25,400 $/yr
Wind Turbine Lifetime	20.0 years		

Figure 14 shows the energy production of wind turbine.

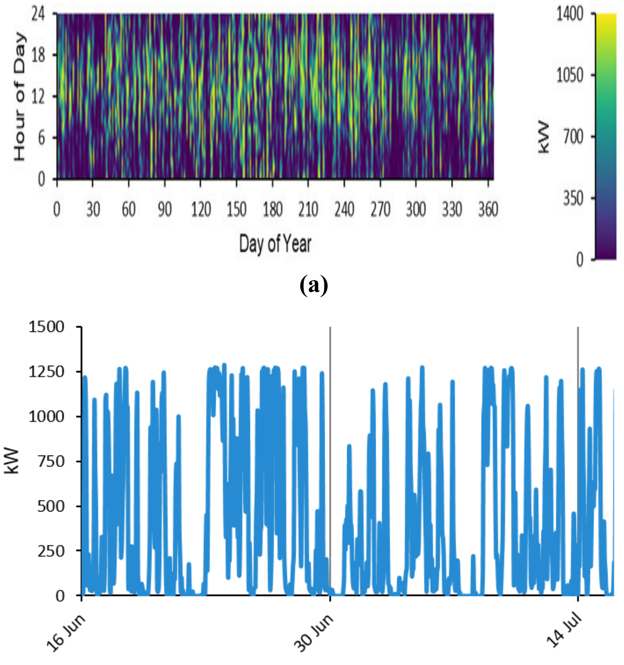
3) GENERATOR (DIESEL)

Caterpillar generator system produces zero kilowatts per year (kWh/yr.) of power, with a rating of 440 kW. The generator hasn't been needed; but it is kept for the purpose of continuity in any emergency as shown in Figure 15.

Table 7 shows the cost analyses for diesel generator.

4) GRID

The yearly grid energy purchased is 2,750,176 Kilowatt-while the yearly grid energy sold is 2,531,543 kilowatt and



(a)

(b)

FIGURE 14. (a) Energy production of wind turbine. (b) Energy production of wind turbine.

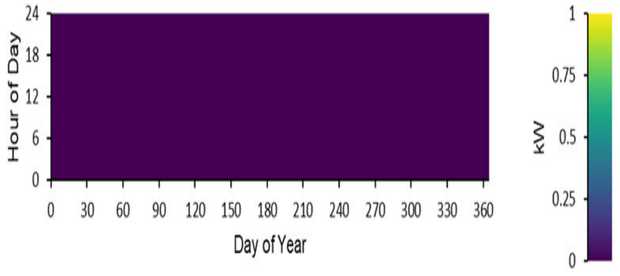


FIGURE 15. Generator operation.

TABLE 7. Cost analyses for generator.

Capacity	440 kW	Generator Fuel	Diesel
Operational Life	1,000 yr	Generator Fuel Price	0.250 $/L
Capital Cost	$75,000M	Fuel Consumption	0 L
Marginal Generation Cost	0.0590 $/kWh	Fixed Generation Cost	50 $/hr

the peak load is decreased as shown in Table 8. The highest possible load is reduced as well and power purchasing is reduced, energy produced from renewable sources almost reaches to energy consumed, which means that energy consumption from the grid is much lower than it used to be.

From Table 8, there is an exchange of energy between the main network and our micro-grid, where, at peak times, energy is imported from the network and the consumption is paid for.

At times when the loads are low and the production from the microgrid is high, the power is sold to the public grid.

TABLE 8. The energy purchase and energy sold.

Month	Energy Purchased (kWh)	Energy Sold (kWh)	Net Energy Purchased (kWh)	Peak Load (kW)	Energy Charge	Demand Charge	Total
Jan.	260,510	200,090	60,420	1,333	$2,417	$0.00	$2,417
Feb.	207,512	205,055	2,457	1,296	$98.28	$0.00	$98.28
Mar.	238,427	224,141	14,285	1,241	$571.41	$0.00	$571.41
April	234,625	212,082	22,543	1,351	$901.71	$0.00	$901.71
May	221,443	227,819	-6,376	1,232	-$255.05	$0.00	-$255.05
June	172,557	256,403	-83,846	1,320	-$3,354	$0.00	-$3,354
July	205,646	219,772	-14,126	1,072	-$565.04	$0.00	-$565.04
Aug.	219,213	238,504	-19,291	1,168	-$771.62	$0.00	-$771.62
Sept.	204,943	243,225	-38,282	1,207	-$1,531	$0.00	-$1,531
Oct.	264,145	172,222	91,923	1,253	$3,677	$0.00	$3,677
Nov.	247,647	148,059	99,588	1,234	$3,984	$0.00	$3,984
Dec.	273,507	184,171	89,336	1,288	$3,573	$0.00	$3,573
Annual	**2,750,176**	**2,531,543**	**218,632**	**1,351**	**$8,745**	**$0.00**	**$8,745**

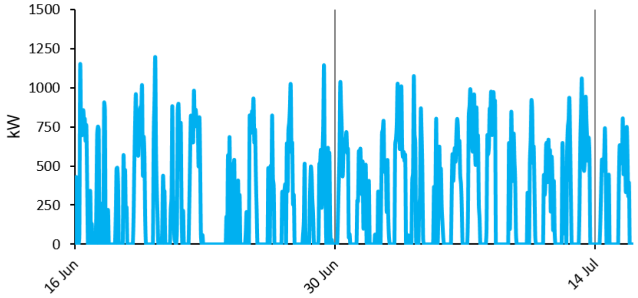


FIGURE 16. Energy purchase from the grid.

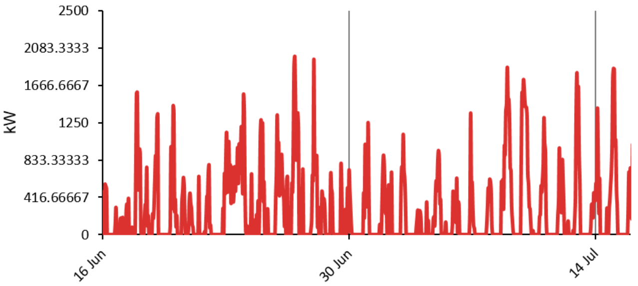


FIGURE 17. Energy sales to the grid.

At the end of the year, the energy sold to the network is higher than the energy purchased, so there's an economic return on the proposed system.

Figures 16 and 17 display the power purchased from the network and the energy supplied to the network.

Table 9 shows the amount of harmful emissions from energy consumption from the grid each kilowatt is consumed, resulting in a quantity of emissions measured in kilograms. The emissions in this case are much lower than in the previous case presented in Table 3.

Figure 18 shows renewable penetration in micro-grid, we also see that the amount of renewable energy in the microgrid is large compared to non-renewable energy.

TABLE 9. Emission reduction.

Quantity	Value	Units
Carbon Dioxide	1,738,111	kg/yr
Carbon Monoxide	0	kg/yr
Unburned Hydrocarbons	0	kg/yr
Particulate Matter	0	kg/yr
Sulfur Dioxide	7,535	kg/yr
Nitrogen Oxides	3,685	kg/yr

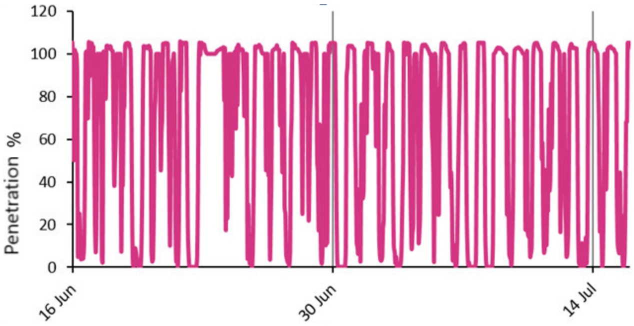


FIGURE 18. Renewable penetration.

V. LIMITATION AND FUTURE WORK

The limitations of this study are that it is concerned only with the economic and environmental aspects, whereas the study is concerned with reducing the cost of consumption and reducing emissions from non-renewable energy sources and those using these clean energy sources.

The proposed solution could also be applied elsewhere because the diversity and availability of renewable energy sources would add depth to the study and help to multiply economic solutions as well.

The shortcomings of this work are that it does not address such important points as:

1- Stability.
2- Protection.
3- Data processing.

In addition, nor it does address hybrid vehicles that sometimes represent the load and sometimes the source as a battery, as it is an important subject and potential area for future research.

To enable auxiliary grid services, cooperate MG control might include the following characteristics.

1- Power quality.
2- Flexibility.
3- Efficiency.
4- Reliability.
5- Security.
6- Resiliency.

VI. CONCLUSION

The goal of microgrid energy management is to create a generating strategy for every system every minute of the following day in order to decrease fuel and operating prices, minimize emissions of gases, enhance voltage shape, and reduce demand peak. Pollution reduction due to the deactivation of supplemental engines through the implementation of technologies and the use of sources of clean energy. Electricity bills are reduced because energy is produced locally through clean energy sources. The proposed energy management approach guarantees an uninterruptible and stable supply for the most important load, allowing the organization to continue running effectively.

This solution can be applicable and expanded at other regions by adding more solar panels and wind turbines and exporting energy to the public grid, but provided that sufficient space is available for solar panels and wind turbines to be installed and the initial cost found.

REFERENCES

[1] A. Maitra, A. Pratt, T. Hubert, D. Wang, K. Prabakar, R. Handa, M. Baggu, and M. McGranaghan, "Microgrid controllers: Expanding their role and evaluating their performance," *IEEE Power Energy Mag.*, vol. 15, no. 4, pp. 41–49, Jul. 2017.

[2] E. Hossain, E. Kabalci, R. Bayindir, and R. Perez, "Microgrid testbeds around the world: State of art," *Energy Convers. Manage.*, vol. 86, pp. 132–153, Oct. 2014.

[3] M. Abdelsattar, I. Hamdan, A. Mesalam, and A. Fawzi, "An overview of smart grid technology integration with hybrid energy systems based on demand response," in *Proc. 23rd Int. Middle East Power Syst. Conf. (MEPCON)*. Egypt: Kafrelshiekh University, Dec. 2022, pp. 1–6.

[4] H. Liang, A. K. Tamang, W. Zhuang, and X. S. Shen, "Stochastic information management in smart grid," *IEEE Commun. Surveys Tuts.*, vol. 16, no. 3, pp. 1746–1770, 3rd Quart., 2014.

[5] H. Hu, N. Xie, D. Fang, and X. Zhang, "The role of renewable energy consumption and commercial services trade in carbon dioxide reduction: Evidence from 25 developing countries," *Appl. Energy*, vol. 211, pp. 1229–1244, Feb. 2018.

[6] A. M. A. El Hamed, M. Ebeed, M. A. El Sattar, A. A. Elbaset, and S. Kamel, "Optimal allocation of PV and DSTATCOM for enhancing the power quality of east delta Egyptian distribution network," *Int. J. Adv. Sci. Technol.*, vol. 28, no. 15, pp. 79–88, 2019.

[7] A. Krishna, J. Schiffer, and J. Raisch, "Distributed secondary frequency control in microgrids: Robustness and steady-state performance in the presence of clock drifts," *Eur. J. Control*, vol. 51, pp. 135–145, Jan. 2020.

[8] M. Carpintero-Rentería, D. Santos-Martín, and J. M. Guerrero, "Microgrids literature review through a layers structure," *Energies*, vol. 12, no. 22, p. 4381, Nov. 2019.

[9] L. Ahmethodzic and M. Music, "Comprehensive review of trends in microgrid control," *Renew. Energy Focus*, vol. 38, pp. 84–96, Sep. 2021.

[10] J. Machowski, Z. Lubosny, J. W. Bialek, and J. R. Bumby, *Power System Dynamics: Stability and Control*, 3rd ed. Hoboken, NJ, USA: Wiley, 2020.

[11] A. Ahmad Khan, M. Naeem, M. Iqbal, S. Qaisar, and A. Anpalagan, "A compendium of optimization objectives, constraints, tools and algorithms for energy management in microgrids," *Renew. Sustain. Energy Rev.*, vol. 58, pp. 1664–1683, May 2016.

[12] H. Shayeghi, E. Shahryari, M. Moradzadeh, and P. Siano, "A survey on microgrid energy management considering flexible energy sources," *Energies*, vol. 12, no. 11, p. 2156, Jun. 2019.

[13] A. K. Basu, S. P. Chowdhury, S. Chowdhury, and S. Paul, "Microgrids: Energy management by strategic deployment of DERs—A comprehensive survey," *Renew. Sustain. Energy Rev.*, vol. 15, no. 9, pp. 4348–4356, Dec. 2011.

[14] A. Molderink, V. Bakker, M. G. C. Bosman, J. L. Hurink, and G. J. M. Smit, "Management and control of domestic smart grid technology," *IEEE Trans. Smart Grid*, vol. 1, no. 2, pp. 109–119, Sep. 2010.

[15] S. Ali, Z. Zheng, M. Aillerie, J.-P. Sawicki, M.-C. Péra, and D. Hissel, "A review of DC microgrid energy management systems dedicated to residential applications," *Energies*, vol. 14, no. 14, p. 4308, Jul. 2021.

[16] J. M. Lujano-Rojas, C. Monteiro, R. Dufo-López, and J. L. Bernal-Agustín, "Optimum load management strategy for wind/diesel/battery hybrid power systems," *Renew. Energy*, vol. 44, pp. 288–295, Aug. 2012.

[17] F. C. Robert, G. S. Sisodia, and S. Gopalan, "A critical review on the utilization of storage and demand response for the implementation of renewable energy microgrids," *Sustain. Cities Soc.*, vol. 40, pp. 735–745, Jul. 2018.

[18] L. Olatomiwa, S. Mekhilef, M. S. Ismail, and M. Moghavvemi, "Energy management strategies in hybrid renewable energy systems: A review," *Renew. Sustain. Energy Rev.*, vol. 62, pp. 821–835, Sep. 2016.

[19] L. Meng, E. R. Sanseverino, A. Luna, T. Dragicevic, J. C. Vasquez, and J. M. Guerrero, "Microgrid supervisory controllers and energy management systems: A literature review," *Renew. Sustain. Energy Rev.*, vol. 60, pp. 1263–1273, Jul. 2016.

[20] E. S. Oda, M. Ebeed, A. M. Abd El Hamed, A. Ali, A. A. Elbaset, and M. Abdelsattar, "Optimal allocation of a hybrid photovoltaic-based DG and DSTATCOM under the load and irradiance variability," *Int. Trans. Electr. Energy Syst.*, vol. 31, no. 11, pp. 1–25, Sep. 2021.

[21] M. Faccio, M. Gamberi, M. Bortolini, and M. Nedaei, "State-of-art review of the optimization methods to design the configuration of hybrid renewable energy systems (HRESs)," *Frontiers Energy*, vol. 12, no. 4, pp. 591–622, Dec. 2018.

[22] P. Nema, R. K. Nema, and S. Rangnekar, "A current and future state of art development of hybrid energy system using wind and PV-solar: A review," *Renew. Sustain. Energy Rev.*, vol. 13, no. 8, pp. 2096–2103, Oct. 2009.

[23] A. A. Elbaset, H. Ali, and M. A. El Sattar, *Performance Analysis of Grid-Connected Photovoltaic Power Systems*. London, U.K.: Lambert Academic Publishing, Nov. 2015, p. 176.

[24] I. R. Cristóbal-Monreal and R. Dufo-López, "Optimisation of photovoltaic–diesel–battery stand-alone systems minimising system weight," *Energy Convers. Manage.*, vol. 119, pp. 279–288, Jul. 2016.

[25] Y. J. Reddy, Y. V. P. Kumar, S. Kumar, and K. P. Raju, "Distributed ANNs in a layered architecture for energy management and maintenance scheduling of renewable energy HPS microgrids," in *Proc. Int. Conf. Adv. Power Convers. Energy Technol. (APCET)*, Mylavaram, India, Aug. 2012, pp. 1–6.

[26] P. Stluka, D. Godbole, and T. Samad, "Energy management for buildings and microgrids," in *Proc. 50th IEEE Conf. Decis. Control Eur. Control Conf.*, Orlando, FL, USA, Dec. 2011, pp. 5150–5157.

[27] D. K. Lal, B. B. Dash, and A. K. Akella, "Optimization of PV/wind/micro-hydro/diesel hybrid power system in Homer for the study area," *Int. J. Electr. Eng. Informat.*, vol. 3, no. 3, pp. 307–325, Sep. 2011.

[28] NASA. (Jun. 2018). *Surface Meteorology and Solar Energy*. [Online]. Available: http://eosweb.larc.nasa.gov/sse/

[29] A. A. Elbaset, H. Ali, and M. Abd-El Sattar, "Novel seven-parameter model for photovoltaic modules," *Sol. Energy Mater. Sol. Cells*, vol. 130, pp. 442–455, Nov. 2014.

[30] M. A. El Sattar, W. A. Hafez, A. A. Elbaset, and A. H. K. Alaboudy, "Economic valuation of electrical wind energy in Egypt based on levelized cost of energy," *Int. J. Renew. Energy Res.*, vol. 10, no. 4, pp. 1879–1891, Dec. 2020.

[31] M. Castañeda, E. I. Gutiérrez-Velásquez, C. E. Aguilar, S. N. Monteiro, A. A. Amell, and H. A. Colorado, "Sustainability and circular economy perspectives of materials for thermoelectric modules," *Sustainability*, vol. 14, no. 10, p. 5987, May 2022.

[32] R. Nazir, H. D. Laksono, E. P. Waldi, E. Ekaputra, and P. Coveria, "Renewable energy sources optimization: A micro-grid model design," *Energy Proc.*, vol. 52, pp. 316–327, 2014.

[33] H. Shayeghi and M. Alilou, "3—Distributed generation and microgrids," in *Hybrid Renewable Energy Systems and Microgrids*, E. Kabalci Ed. New York, NY, USA: Academic Press, 2021, pp. 73–102.

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