# Sizing of A Large Isolated Solar Energy System for Bani Walid, Libya

Fathi Mosbah and Tariq Iqbal

***Abstract*—According to energy data from the General Electricity Company of Libya, electricity demand in Libya is growing at an annual rate of around 9%. An increasing number of power generators are therefore needed to meet both the current and projected growth in electricity demand and prevent power outages. In this paper, available renewable energy sources in Bani Walid, Libya, are studied, with the aim to design a hybrid power system for the region. HOMER (hybrid optimization model for multiple energy resources) software is used to perform financial calculations and simulation analyses. The components of the system include generator sets, photovoltaic (PV) modules, and an energy storage system. The average load in 2015 was 35.98 MW, with a peak load of 85 MW. Optimization results indicate the viability of a large-scale 76.8MW PV system. At the same time, Hoppecke 26 OPzS batteries for energy storage can provide reliable power in the Bani Walid area. The system design and location are studied in detail, with the results presented in this paper. The proposed large PV system with battery storage could easily be implemented in Libya as well as in neighboring countries.**

***Index Terms*—Renewable energy, PV systems, hybrid power systems, electricity production in Libya, data collection, system sizing.**

## I. Introduction

A hybrid power system is an independent grid that merges at least two different types of energy for power generation and distributes electricity to consumers. It functions as an autonomous entity and can provide almost the same service and quality as a national grid. Moreover, with appropriate arrangements, a hybrid power system can, in fact, be connected to a national grid [1].

Synergetic control of grid-connected photovoltaic (PV) systems was studied in [2], with the researchers demonstrating that this method does not require system linearization. Moreover, the reason electricity policy and competitive markets fail to use advanced PV systems to improve distribution power quality is that most project failures are caused by policy failures, as discovered in [3].

Recently, the price of solar panels has dropped by 45% or more, which makes the entire system much more affordable [4]. In addition, a study conducted in [5] shows that the installation capacity of large-scale PV systems reduces both the amount of generated electricity and subsequent $CO_2$ emissions. The researchers in [5] also discovered that the total electricity generation and $CO_2$ emission reduction by the installation capacity for their primary study area in Liaoning, China, was more 2.7 times larger than in other regions covered in the study [5].

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According to Solar Atlas data, North Africa has enormous potential for solar energy-powered resources. A comparison between measurements and Solar Atlas data in southern Algeria (Ghardaia region) shows that the relative error between the annual accumulated global solar radiation is only 0.6%, whereas it is about 2% for DNI solar radiation [6]. Both cloud cover and dust accumulation onto the surface of the solar module have a significant impact on PV solar performance. The effect of cloud cover is immediate, with a drop in global solar irradiance and subsequently in power output for a short time, while the effect of dust accumulation has a long-term effect [7].

The feasibility and optimal design of a stand-alone PV energy system for an orphanage was presented in [8]. In the study, the optimal design of a PV with a battery storage system was carried out, minimizing the net present cost by varying the size of the batteries until a configuration that produces the desired power needs of the orphanage was achieved. The components and generation sources selected for a hybrid power system will have a significant influence on the lifetime of the system and its affordability to end-users. To increase cost savings and efficiency, sizing the system appropriately should be a priority [1]. This paper presents an overview of the electricity situation in Libya, proposes a large hybrid power system, and shows that such a system could be the best solution for both Libya and neighbouring countries.

## II. Current Electricity State in Libya

Electricity generation in Libya relies entirely on fossil fuel. As shown in Fig. 1, the energy sector mainly uses natural gas, heavy fuel oil and light fuel, but the General Electricity Company of Libya (GECOL) recently increased the country’s reliance on natural gas as a means to reduce $CO_2$ emissions [9]. However, with only 0.06% renewable energy production in 2011, renewable energy has been negligible [10]. Despite being utilized in Libya since the 1970s, current renewable energy sources are mainly used only for powering small remote loads such as rural electrifications, water pumping, communication systems, and cathodic protection for oil pipelines in the desert [9].

By 2015, the total installed solar energy capacity in various applications was 5 MW. Table I shows total installed PV systems in Libya as of 2012. Some examples of projects under operation include the Wadi-Marsit centralized PV system (67.2 kWp at peak capacity), a grid-connected small-scale PV (42 kWp capacity), and communication repeater stations (950 kWp capacity) [10].

Outside the urban centers in Libya, remote areas and villages with small populations remain a challenge for

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GECOL to service. However, even though most of these areas are located far from central power plants and the national grid, 99.8% of Libyan people have access to electricity. Due to strong economic growth and increased investment in the oil and natural gas sectors, electricity generation more than doubled from 2000 to 2010. This is proving problematic, as the growing power demand has been greater than gains in installed generation capacity. As a result, electricity shortfalls are a normal occurrence in Libya [12]. For example, from 2011 to 2017, power outages ranging from 3 to 12 hours occurred daily due to load shedding, which increases during summer and winter seasons. In some remote areas, power outages last longer than 24 hours when there is a fault on the grid in addition to load shedding. To remedy this issue, GECOL schedules load shedding daily to maintain grid stability.

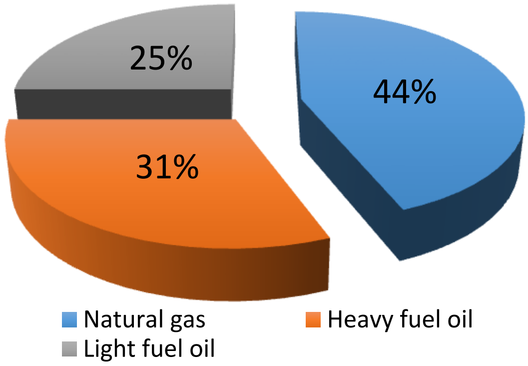



Fig. 1. Energy sectors with percentages of gas and fuel used in electricity generation as of 2012.

TABLE I: TOTAL INSTALLED PV SYSTEMS IN LIBYA AS OF 2012

| PV | kWp |
|---|---|
| General Post and Telecommunication Company (GPTC) | 850 |
| Almadar Company | 1500 |
| Libyana Company | 330 |
| Oil Company | 120 |
| Others | 10 |
| Total PV for communication systems | 2810 |
| PV for rural electrification | 725 |
| PV for water pumping | 120 |
| PV for street lighting | 1125 |
| Centralized PV system | 110 |
| PV for roof top systems | 30 |

## III. RENEWABLE ENERGY SOURCES IN BANI WALID

The renewable energy sector in Libya has planned a number of projects over the past decade. The proposed projects are mainly solar energy and wind energy systems, which are the alternative renewable energy forms best suited to Libya's climate, geography and meteorological conditions [9].


Fig. 2. Bani Walid location.

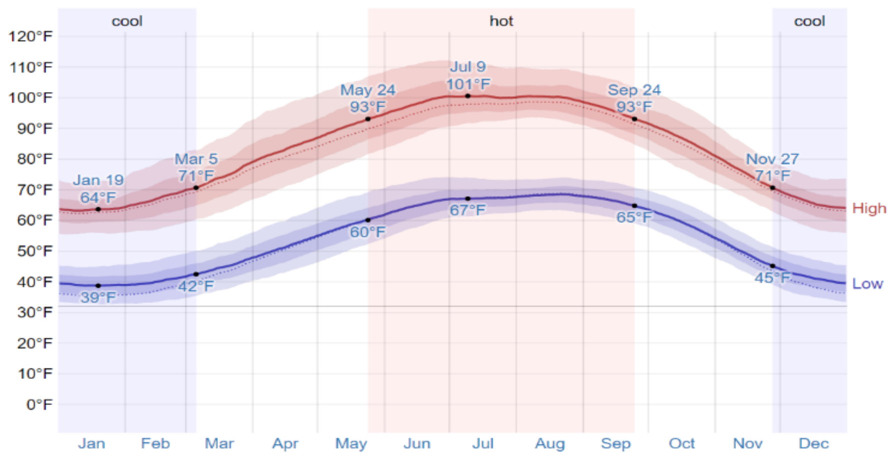



Fig. 3. Average high and low temperature in Bani Walid.

Bani Walid is situated about 180 km southeast of Tripoli at latitude 31°45’ N and longitude 13°59’ E, as shown in Fig. 2. The summers are long, arid, sweltering, and clear and the winters are cold, windy, dry, and mostly clear. During the year, the temperatures typically vary from 39 °F (3.8 °C) to 101 °F (38.3 °C), rarely falling below 33 °F (0.6 °C) or rising above 112 °F (44 °C). Fig. 3 shows average high and low annual temperatures in Bani Walid [13]. These data are important to the energy sector, as temperature has a significant effect on the electrical performance and power generation efficiency of PV modules. Online modelling and calculations for operating temperatures of silicon PV modules based on BP-ANN are presented in [11].

### A. *Wind Energy*

Average monthly wind speeds for the area under study are shown in Table II [14]. Overall, the average annual wind speed at latitude 31.8° N and longitude 14° E is 3.96 m/s. The windiest day usually occurs in February, with an average speed of 10.3 miles per hour (4.6 m/s.), as measured at 10 meters above the ground. The average hourly wind speed in Bani Walid experiences only mild seasonal variations during the year, as shown in Fig. 4 [13].

TABLE II: MONTHLY AVERAGED WIND SPEED AT 10 M ABOVE THE SURFACE OF THE EARTH FOR TERRAIN SIMILAR TO AIRPORTS (M/S)

| Jan. | Feb. | Mar. | Apr. | May | Jun. | Jul. | Aug. | Sep. | Oct. | Nov. | Dec. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 3.92 | 4.28 | 4.22 | 4.27 | 4.35 | 4.2 | 3.6 | 3.66 | 3.69 | 3.81 | 3.73 | 3.78 |

TABLE III: MONTHLY AVERAGED INSOLATION INCIDENT ON A HORIZONTAL SURFACE (KWH/M2/DAY) IN BANI WALID AT N31.8 °E14 °

| Jan. | Feb. | Mar. | Apr. | May | Jun. | Jul. | Aug. | Sep. | Oct. | Nov. | Dec. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 2.95 | 4.10 | 5.32 | 6.46 | 7.19 | 7.83 | 8.03 | 7.24 | 5.74 | 4.41 | 3.19 | 2.65 |

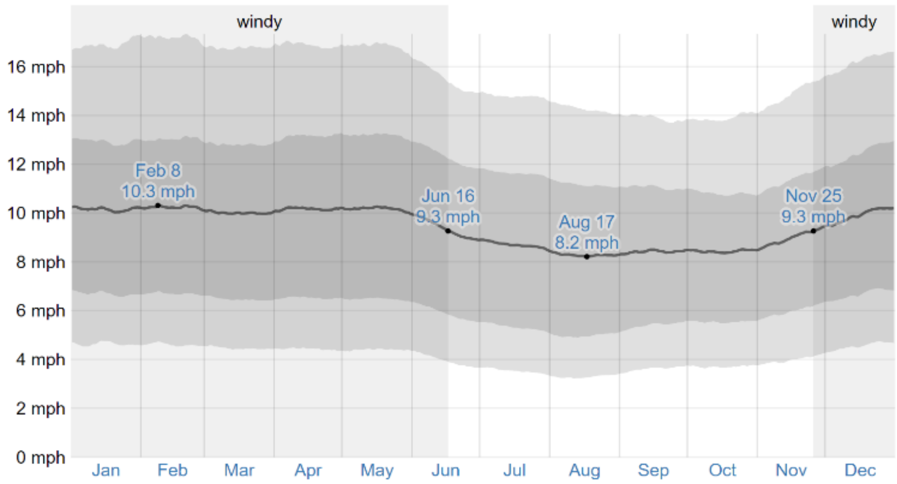



Fig. 4. Average wind speed in Bani Walid.

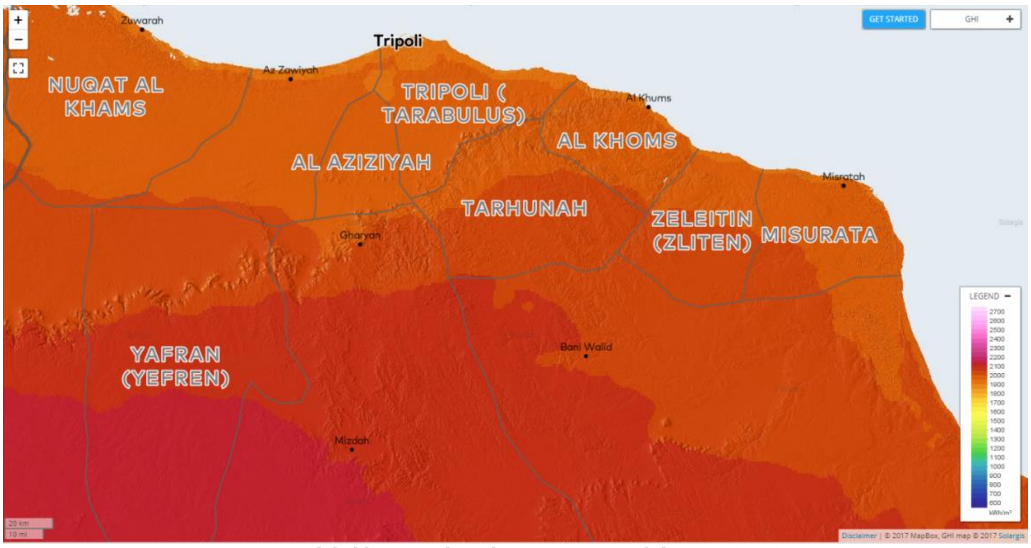



Fig. 5. Global horizontal irradiance in Bani Walid region (GHI).

### B. *Solar Energy*

According to data from NASA surface meteorology and the Solar Energy Corporation, the average insolation incident on a horizontal surface in July is 8.03 kWh/m$^2$/day for latitude 31.8° N and longitude 14° E, which is the area selected for a PV in Bani Walid. The data indicate that this location shows very good potential for solar energy production. Table III charts monthly averaged insolation incidents on a horizontal surface (kWh/m$^2$/day) [14], while Fig. 5 shows the global horizontal irradiance in the Bani Walid region (GHI) [15].

## IV. ELECTRICAL LOADS IN BANI WALID

Most loads in Bani Walid are residential. In 2015, the average load measured 35.98 MW. The maximum average load and peak load were 47.8 MW and 85 MW, respectively, in August, mainly due to the operation of air conditioners. Moreover, because the insulation system in homes in this region is generally inefficient, air conditioners are operated for most of the year. The minimum average load and minimum peak load in March were 26.2 MW and 46 MW, respectively, due to unusually warm weather, as shown in Fig. 6.

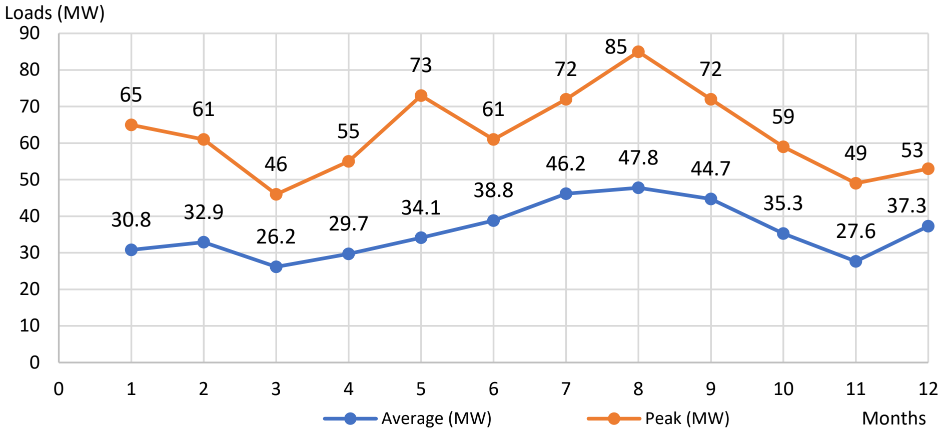



Fig. 6. Monthly average and peak loads in 2015 in Bani Walid.

## V. SYSTEM SIZING USING HOMER

Evaluation of the technical feasibility and economic of many technology options and accountability for variations in technology costs and energy resource availability, could easily be carried out using the hybrid optimization model for an electrical renewable (HOMER). A power system designer can use HOMER to provide an overview that not only compares the cost and feasibility of different configurations but also evaluates the potential technical performance of the proposed power system [16]. In this study HOMER ver 2.68 is used, which is free software from the National Renewable Energy Lab [nrel.gov].

### A. System Input Data

The system components for the sizing are photovoltaic system, diesel generator sets, and batteries for energy storage. System input data with costs are shown in Table IV.

TABLE IV: SYSTEM INPUT DATA

| PV System | | | |
|---|---|---|---|
| Size (kW) | Capital ($) | Replacement ($) | O&M ($/yr) |
| 12 | 22,473 | 13,620 | 150 |
| Generator | | | |
| Size (kW) | Capital ($) | Replacement ($) | O&M ($/hr) |
| 2,600 | 2,475,000 | 1,500,000 | 52 |
| Batteries | | | |
| Quantity | Capital ($) | Replacement ($) | O&M ($/yr) |
| 24 | 53,987 | 32,719 | 240 |
| Converter | | | |
| Size (kW) | Capital ($) | Replacement ($) | O&M ($/yr) |
| 100 | 31,755 | 19,246 | 120 |

The selected PV module is Panasonic HIT VBHN240SJ25, which features an output power of 240 W, solar efficiency of 19%, NOCT of 44 ℃, and a lifetime of 25 years. The effect of temperature is also considered in the system. The selected battery is Hoppecke 26 OPzS 4700 Ah, 9.4 kWh, with a life cycle of 20 years. Solar resources inputs and location are shown in Fig. 7.

### B. System Block Diagram

A block diagram of the designed system is shown in Fig. 8, where the primary load of 864 MWh/d is connected to the AC bus.

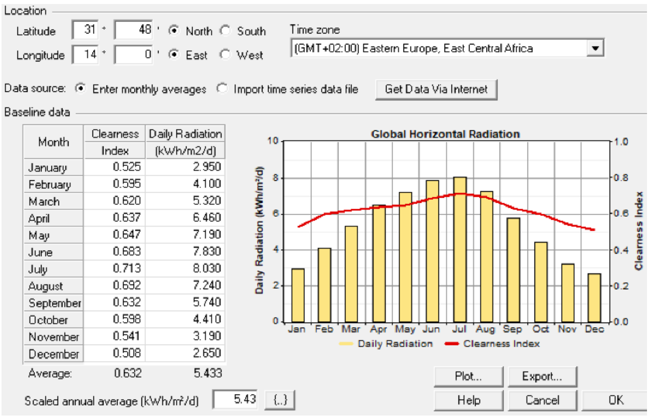



Fig. 7. Solar data resources.

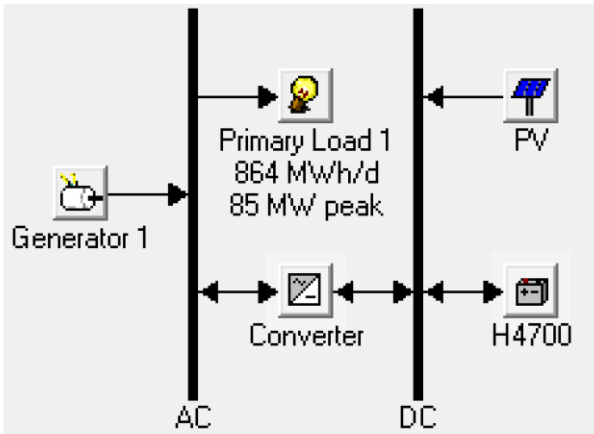
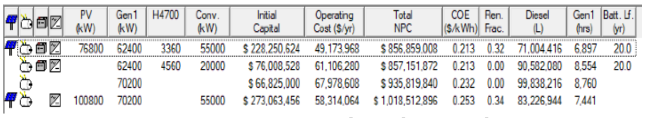



Fig. 8. Block diagram of system in HOMER.

### C. Optimized System

The optimization results show the ranking of optimized systems, the first ranking includes a large-scale 76.8 MW PV and all other power sources in the system. The levelized cost of energy (COE) is 0.213 $/kWh and the total net present cost (NPC) is $856,859,008. The highest cost in the ranking of the categorized system is for a system without battery storage, giving a COE of 0.253 $/kWh, as illustrated in Fig. 9. A list of system components is provided in Table V.



| | PV (kW) | Gen1 (kW) | H4700 | Conv. (kW) | Initial Capital | Operating Cost ($/yr) | Total NPC | COE ($/kWh) | Ren. Frac. | Diesel (L) | Gen1 (hrs) | Batt. Lf. (yr) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 76800 | 62400 | 3360 | 55000 | $ 228,250,624 | 49,173,968 | $ 856,859,008 | 0.213 | 0.32 | 71,004,416 | 6,897 | 20.0 |
| | | 62400 | 4560 | 20000 | $ 76,008,528 | 61,106,280 | $ 857,151,872 | 0.213 | 0.00 | 90,582,080 | 8,554 | 20.0 |
| | | 70200 | | | $ 66,825,000 | 67,978,608 | $ 935,819,840 | 0.232 | 0.00 | 99,838,216 | 8,760 | |
| | 100800 | 70200 | | 55000 | $ 273,063,456 | 58,314,064 | $ 1,018,512,896 | 0.253 | 0.34 | 83,226,944 | 7,441 | |

Fig. 9. Optimization results with cost rankings.

TABLE V: SELECTED SYSTEM COMPONENTS

| | |
|---|---|
| PV | 76,800 kW |
| Generator sets | 62,400 kW |
| Inverter | 55,000 kW |
| Rectifier | 55,000 kW |
| Batteries | 3,360 |

### D. Economic Optimization Results and Financial Analysis

Cost summary results for the optimized system are shown in Fig. 10 and Table VI. As can be seen, the highest net present cost is for generator sets throughout the lifetime of the system (25 years), while the lowest net present cost is for batteries. The total system cost is $856,859,328 with a COE of 0.213 $/kWh, while the case with only generator sets (base case system) gives a COE of 0.232 $/kWh. The difference between the net present costs indicates a present worth of $78,960,928 for the two cases. Thus, it can be seen that the optimized system saves money over the project's lifetime in comparison with the base case system. The simple payback period is 9.02 years, as illustrated in Table VII. Fig. 11 charts the cash flow (in $) for the two cases throughout the project lifetime, while Fig. 12 shows cash flow details for the optimized system.

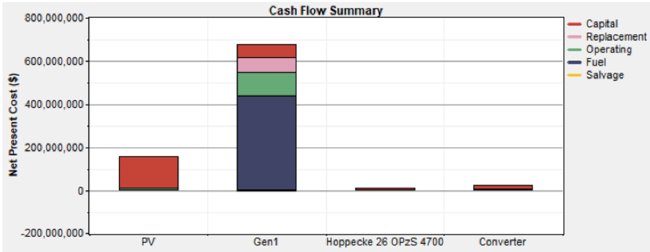



Fig. 10. Cash flow summary.

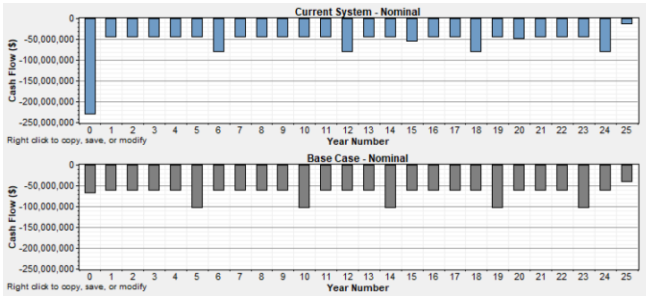



Fig. 11. Comparison between the current case system and the base case system.

TABLE VI: COST SUMMARY

| Component | Capital ($) | Replacement ($) | O&M ($) | Fuel ($) | Salvage ($) | Total ($) |
|---|---|---|---|---|---|---|
| PV | 143,827,200 | 0 | 12,272,030 | 0 | 0 | 156,099,232 |
| Generator 1 | 59,400,000 | 66,368,568 | 110,032,224 | 440,222,464 | -5,782,452 | 670,240,960 |
| Hoppecke 26 OPzS 4700 | 7,558,180 | 1,428,273 | 429,521 | 0 | -800,467 | 8,615,506 |
| Converter | 17,465,250 | 4,416,880 | 843,702 | 0 | -822,121 | 21,903,710 |
| System | 228,250,624 | 72,213,720 | 123,577,496 | 440,222,464 | -7,405,040 | 856,859,328 |

TABLE VII: ECONOMIC COMPARISON BETWEEN CURRENT CASE SYSTEM AND BASE CASE SYSTEM

| Metric | Value |
|---|---|
| Present worth | $ 78,960,928 |
| Annual worth | $ 6,176,854/yr |
| Return on investment | 11.6 % |
| Internal rate of return | 10.8 % |
| Simple payback | 9.02 yrs |
| Metric | Value |

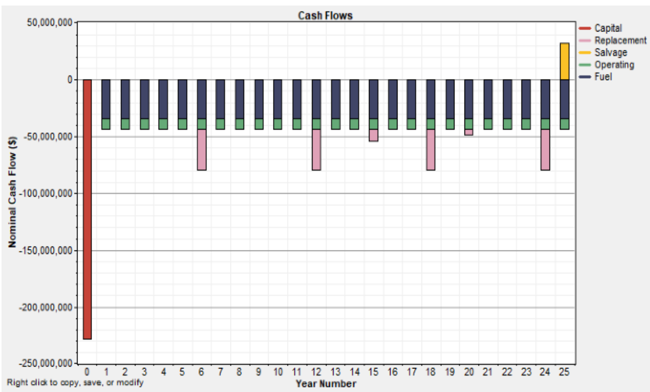



Fig. 12. Cash flows.

TABLE VIII: EXPECTED ELECTRICAL OUTPUT RESULTS

| Production | kWh/yr | % |
|---|---|---|
| PV array | 128,497,000 | 32 |
| Generator 1 | 278,850,944 | 68 |
| Total | 407,347,936 | 100 |
| | | |
| Quantity | kWh/yr | % |
| Excess electricity | 89,393,936 | 21.9 |
| Unmet electric load | 35,640 | 0.0 |
| Capacity shortage | 186,770 | 0.1 |

### F. Electrical and System Simulation Results

Simulation results show that PV energy production is 32%, with a penetration of 40.8%. The system's excess energy is 21.9%, which could be sold to the grid. The unmet electrical load is 0%, as illustrated in Table VIII. Table IX shows the expected PV output results. Average electric production from the PV modules and the generator sets are high during the summer season to meet the load demand, as shown in Fig. 13. Fig. 14 shows PV output in kW. As can be seen, maximum PV production occurs around noon time, because the modules have no tracking system. The maximum generator set production occurs during the nighttime in summer and winter, whereas production during the daytime is less due to the PV system and batteries having supplied plenty of energy to the loads, as demonstrated in Fig. 15. Since the generator sets supply most of the load during the night, the inverters work mainly during the day. The rectifiers work mainly during the night to charge batteries, as illustrated in Fig. 16. The state of charge for the batteries ranges between 86% to 100% for most of the year, as illustrated in Fig. 17.

TABLE IX: EXPECTED PV OUTPUT RESULTS

| Quantity | Value | Units |
|---|---|---|
| Rated capacity | 76,800 | kW |
| Mean output | 14,669 | kW |
| Mean output | 352,047 | kWh/d |
| Capacity factor | 19.1 | % |
| Total production | 128,497,000 | kWh/yr |
| | | |
| Quantity | Value | Units |
| Minimum output | 0 | kW |
| Maximum output | 74,559 | kW |
| PV penetration | 40.8 | % |
| Hours of operation | 4,385 | hr/yr |
| Levelized cost | 0.0950 | $/kWh |

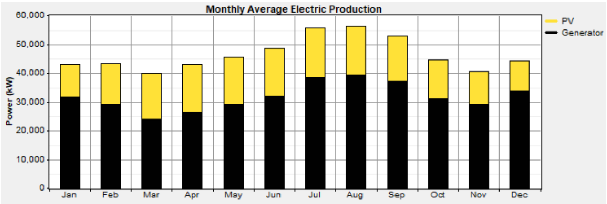


Fig. 13. Monthly average electric production.

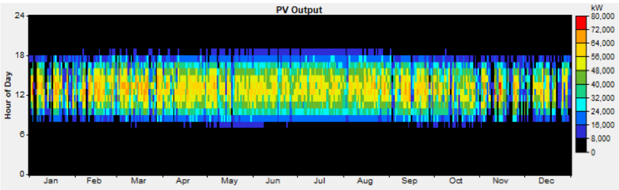


Fig. 14. PV output.

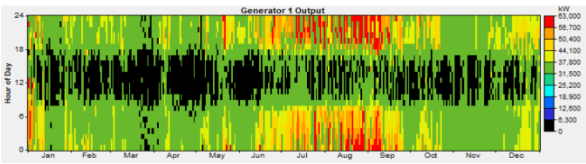


Fig. 15. Generator sets output.

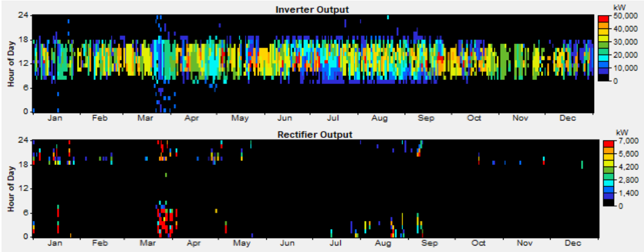


Fig. 16. Inverter and rectifier output.

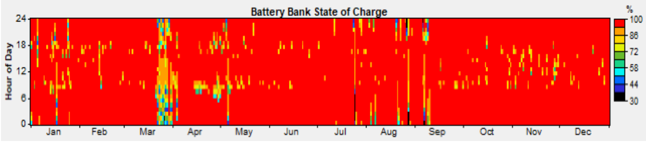


Fig. 17. Battery bank state of charge.

### G. *Sensitivity Analysis*

The optimization results are affected by variable inputs such as solar radiation, increasing loads and component price. Therefore, the design approach can be scaled or translated for different cases. The considered sensitivity variables for this study are shown in Table X.

TABLE X: SENSITIVITY VARIABLE INPUTS

| | | | | |
|---|---|---|---|---|
| Diesel price | 0% | 10% | 20% | 30% |
| Load | 0% | 10% | 20% | |
| Solar radiation | -5% | 0% | 5% | |

#### 1) *Levelized Cost of Energy (COE)*

The levelized cost of energy is important for designing a power system, as it is impractical to design a power system with a very high COE. Fig. 19 (a), (b), (c), and (d) demonstrate that levelized COE rises with increasing loads and decreasing irradiance. COE also rises with increasing diesel prices but decreases with decreasing loads and increasing irradiance.

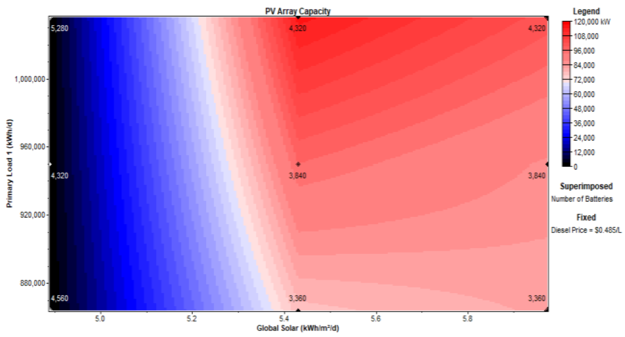
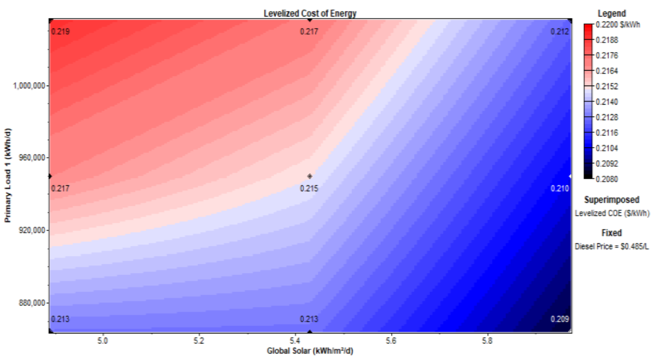
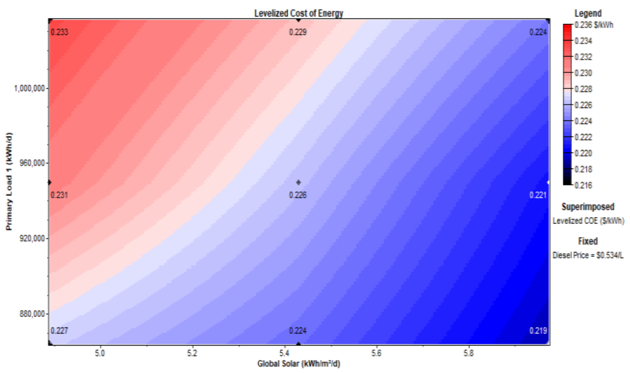


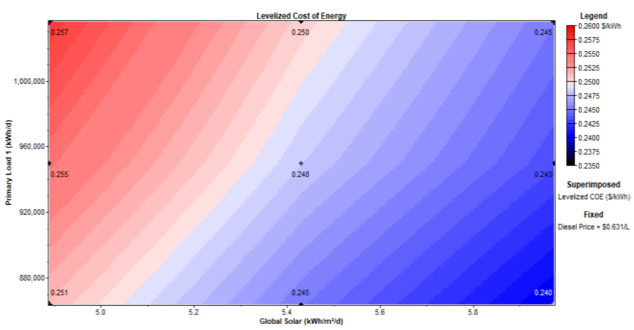
Fig. 18. Optimal PV and battery system sizing at a diesel sensitivity of 0%.



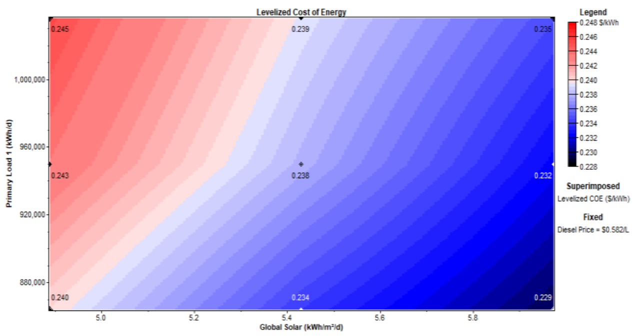
(a). COE at load sensitivities (0, 10, and 20%) and diesel price 0%



(b). COE at load sensitivities (0, 10, and 20%) diesel price 10%



(c). COE at load sensitivities (0, 10, and 20%) and diesel price 20%



(d). COE at load sensitivities (0, 10, and 20%) and diesel price 30%

Fig. 19. Levelized cost of energy (COE).

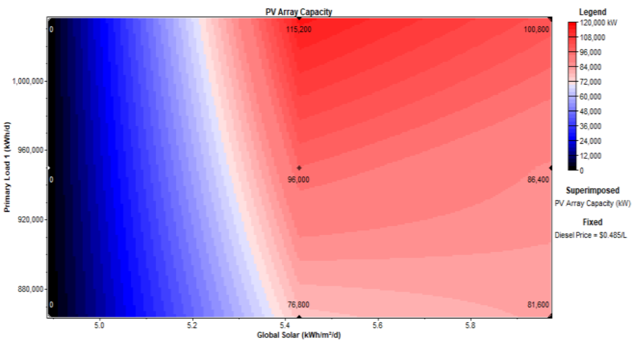
### 2) *Optimal systems*

#### *a) Optimal PV system*

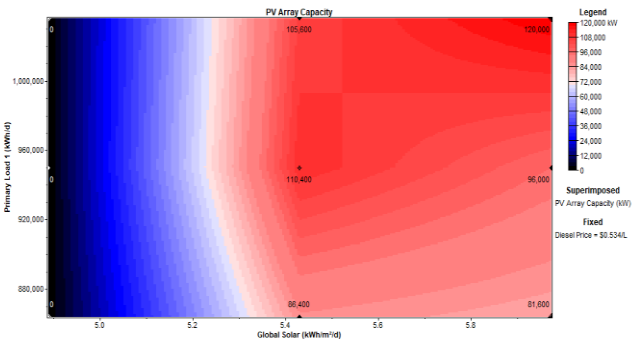
The results for an optimal PV system using variable sensitivity inputs can be seen in Figs. 20 (a), (b), (c), and (d). At diesel price sensitivities of 0% and 10%, the PV system capacity decreases significantly with a decreasing irradiance of -5%. Furthermore, with increasing diesel prices of 20% and 30%, the sizing shows that using a PV system is preferable at all irradiance sensitivities. The highest capacity of PV occurs at high loads and low irradiance, after increasing diesel prices to 30%, as shown in Fig. 20 (d),

#### *b) Optimal battery storage*

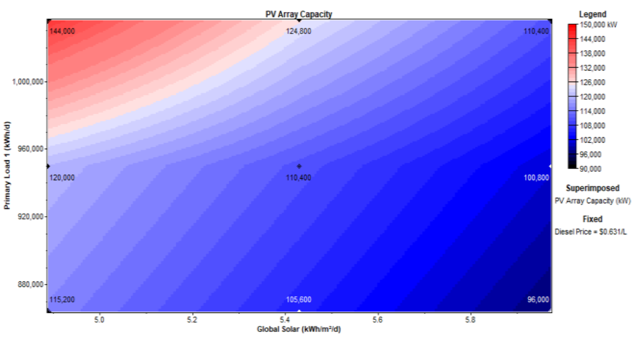
The sensitivity analysis shows that the hybrid power system requires more batteries at very low capacity of the PV system, as shown in Fig. 18. The irradiance sensitivities of 0% and 5% do not have much effect on battery sizing. However, as shown in Fig. 21 (d), for a diesel price sensitivity of 30%, load growth does in fact affect battery sizing. On the other hand, irradiance sensitivities do not affect battery sizing in such a large power system, due to the high price jump of a large battery string.



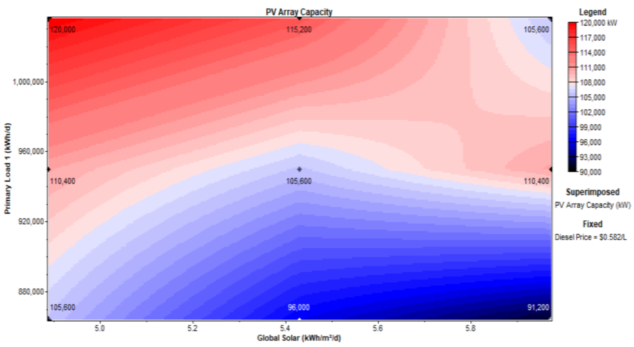
(a). Load sensitivities (0, 10, and 20%) and diesel price 0%



(b). Load sensitivities (0, 10, and 20%) and diesel price 10%

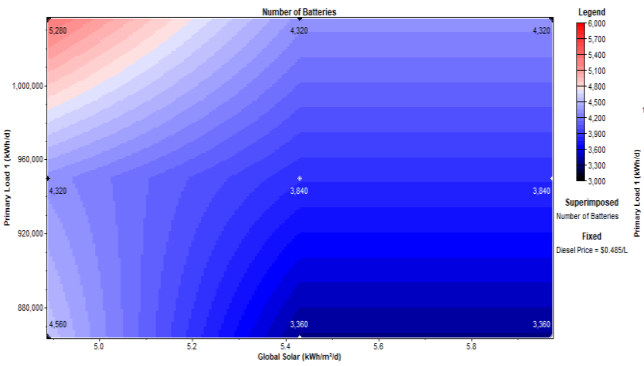


(c): Load sensitivities (0, 10, and 20%) and diesel price 20%

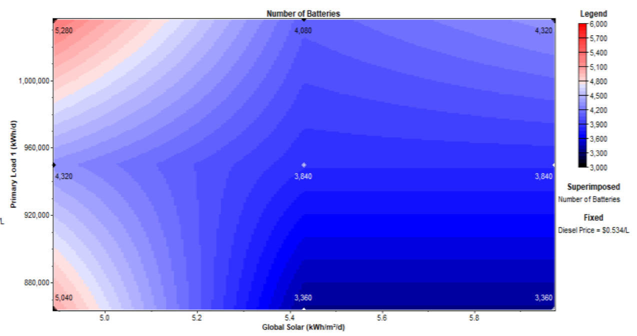


(d): Load sensitivities (0, 10, and 20%) and diesel price 30%

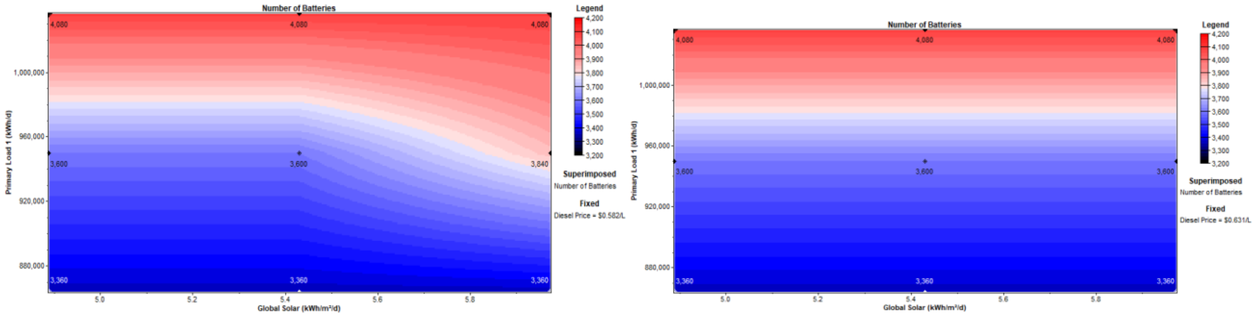
Fig. 20. Optimal PV system sizing.



(a). Load sensitivities (0, 10, and 20%) and diesel price 0%



(b). Load sensitivities (0, 10, and 20%) and diesel price 10%




(c). Load sensitivities (0, 10, and 20%) and diesel price 20% (d). Load sensitivities (0, 10, and 20%) and diesel price 30%

Fig. 21. Optimal battery storage sizing.

## VI. Required Area for PV Module and the Proposed Location

Since a fixed array is used in this study, only the sun's apparent motion across the sky needs to be considered to optimize the distance between the rows of modules. An adaptive PV topology for overcoming the shadowing effect in PV systems is presented in [17]. As illustrated in Fig. 22 (a), arrays should be spaced at distance "*d*" in relation to module width "*a* " to avoid excessive shadowing [18]. Fig. 22 (b) shows the configuration of fixed PV arrays.

$$\frac{d}{a} = \cos\beta + \frac{\sin\beta}{\tan\varepsilon} \qquad (1)$$

where $\varepsilon$ can be calculated by the geographical latitude $\emptyset$ and the ecliptic angle $\delta = 23.5^{\circ}$

$$\varepsilon = 90° - \delta - \emptyset \qquad (2)$$

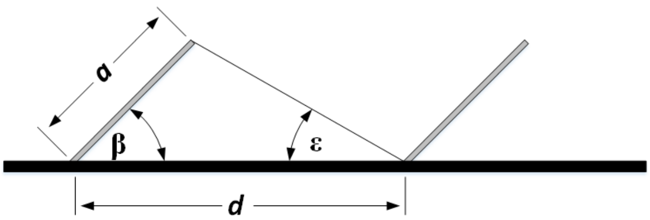



Fig. 22 (a). Arrangement of several rows of fixed modules.

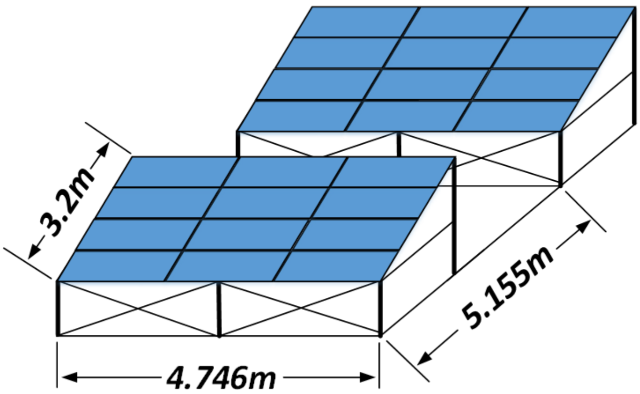



Fig. 22 (b). Configuration of fixed PV array.

The required area for 2741.76 kW arrays is 12371.24 m$^2$, while the required area for one PV substation, 2741.76 kW, including the land, is 24980.56 m$^2$.

As shown in Fig. 23, the proposed location is latitude 31.8° N and longitude 14° E, which is the northern portion of the Bani Walid valley. That the area is very close to a distribution station will help prevent losses in transmission lines. Moreover, because the station is positioned nearly at the center of most loads, overload on existing transmission lines is avoided, as demonstrated in the results of the PowerWorld tool tests. It is also worth noting that this area is characterized by high altitude and is mostly rock-covered. Therefore, it has less dust compared to southern cities in Libya. The red lines in Fig. 23 represent existing 66kV transmission lines.

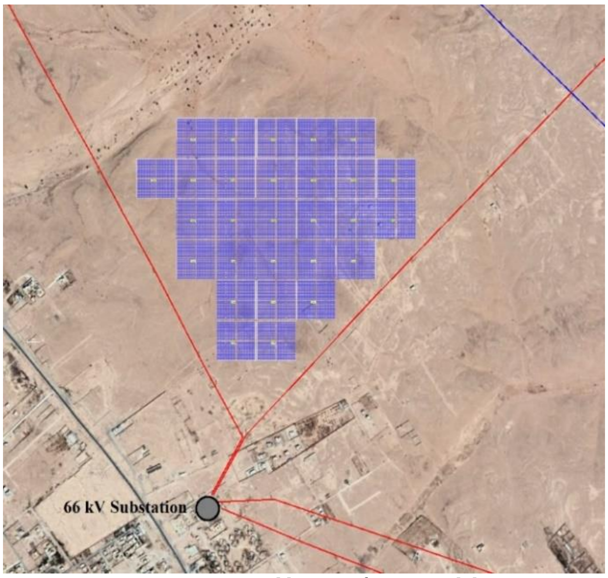



Fig. 23. Proposed location for PV modules.

## VII. Conclusion

In designing a feasible hybrid power system that utilizes a variety of renewable energy sources, the availability of the energy sources at the desired location as well as the price of the components should be taken into consideration.

Libya has significant potential for solar and wind power production, but only certain areas are suitable for wind energy. The main goal of this study was to investigate the available renewable energy sources in Bani Walid and optimize the hybrid grid power system, considering the effect of temperature in that area. The design approach was scaled for different cases. Based on this study, Bani Walid was shown to have great potential for solar energy. Wind energy would, however, be less reliable, given that an annual average wind speed is only 3.96 m/s.

The optimized system indicates that the lowest COE of 0.213 $/kWh occurred with a PV, generator sets, and battery storage, while the COE with only generator sets was 0.232 $/kWh. A comparison between these two cases shows a present worth of $78,960,928. Meanwhile, the simple payback was 9.02 years and the annual worth is $6,176,854. The payback indicates how long it would take to recover the difference in investment costs between the optimized system with renewable energy (optimized system) and the case with only generator sets (base case system). In addition, emissions were reduced by 29% compared to the optimized system.

The optimization results illustrate that using renewable energy in a hybrid power system could lower the COE, given that prices for renewable energy components have decreased recently. Such a system also reduces emissions up to 29% during the project's lifetime. Furthermore, the study shows that backup batteries play a major role in lowering COE, with the optimized system demonstrating that a setup without battery storage has the highest COE.

The designed approach was scaled for different cases, as the optimization results were affected by variable inputs such as solar radiation and increasing loads. From the sensitivity analysis, it can be concluded that load growth and decreasing irradiance raise the COE. The sensitivity analysis also demonstrated the effect of load growth on PV and battery sizing, showing that while irradiance sensitivities affect PV sizing, they do not significantly affect battery sizing. In our case, for a sensitivity diesel price of 30%, irradiance sensitivities did not affect battery sizing due to a jump in the large string price for such a large-size hybrid power system.

Overall, the study outcomes demonstrate that this innovative design could be implemented in Libya as well as in neighboring countries towards the successful production of renewable energy.

## VIII. Conflicts of Interest

The authors of this manuscript declare that the devices and software applications used in this research were selected solely on a professional basis. There is no direct financial relation whatsoever with the trademarks mentioned in this manuscript that might lead to conflicts of interest.

## IX. Data Availability Statement

Some of the data collected for this research are presented in Table I, Table II, and Table III. Data collected from the General Electricity Company of Libya are presented in Fig. 6. The full data sets used to support the findings of this study were supplied by the General Electricity Company of Libya and are made freely available by the company. Requests for access to these data should be made to Fathi Mosbah (fsmm27@mun.ca).

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