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Supplying DC Auxiliary System in Power Station by Using a DC Microgrid

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ABSTRACT

Electrical power generation is the first and most important step in producing electricity. Internally, the generation station has an essential sub-system that is called the DC auxiliary system, which is considered the soul of the station and helps in supplying electricity to the essential components in the power station, such as protection elements, monitoring systems, alarms, and control equipment. So, it needs a main and backup source of electrical supply. A challenging problem is discussed in this paper, which is increasing the reliability of the system through the transition to the DC microgrid. This paper aims to provide two different scenarios using renewable energy sources (RESs) for better reliability and economic operation. Both scenarios use photovoltaic (PV) systems with battery energy storage systems (BESSs) to supply the DC auxiliary system in the generation power station. The first scenario supplies the DC loads for 24 hours and the other one only for 8 hours; then, the loads would be supplied by the grid the rest of the day. As a result, both proposed scenarios use DC microgrid, which is applicable, more efficient, reliable, and cost-effective than the conventional source of supply. In addition to choosing, either one of the two scenarios has its own considerations. The first one is more costly than the other, but it is more sustainable over time. Cairo North Power Station Combined Cycle 750 MW in Shoubra, Egypt, is selected in this paper as the case study. Simulation and results are gained using the PVsyst program. The results are manually checked and compared to the simulation report. Also, the economic study over 25 years for the proposed system is added.

1. Introduction

It is well known that the whole world takes a magnificent step towards green energy, as per the Paris Agreement, which offers a strong foundation that will direct international efforts for many years to come. It signals the start of the transition to a world with net-zero emissions, as stated in the previous study [1,2]. The Paris Agreement makes it clear that increasing the use of renewable energy sources will lower CO_2 emissions, as shown in the earlier study [3,4]. This is where micro-grids come in. They are defined as a small-scale, self-contained energy system that may function both as a controllable entity in relation to the main power grid in on-grid mode and independently of it in off-grid mode, as declared in the preceding study [5,6]. Distributed energy resources (DERs), including solar photovoltaic plants, wind turbines, batteries, and conventional generators, are among them.

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These DERs are interconnected and managed by sophisticated software tools and communication technologies. Microgrids strive to improve, build resilience, and reduce carbon emissions, as mentioned in the previous study [7,8], particularly solar energy, which has grown significantly in the last decade. It is also an infinite source of energy that is non-polluting to the environment. Researchers examined several considerations that must be made during this phase of transition from the existing conventional power systems to the new smart grids that involve DC microgrids, as taken from the prior study [9]. There are various compelling arguments against implementing DC. These justifications come under the heading of load, source, and storage system explanations. These days, consumer loads are frequently supplied in DC – like in the paper`s case study- Supplying these loads via conventional AC distribution networks necessitates additional conversion processes, which reduces the efficiency of the delivery process. To put it another way, the amount of energy lost varies and usually ranges from 10% to 25%. This paper will examine the analysis and design of a DC microgrid in order to be involved in industrial services. Because DC microgrids require fewer components for installation, they can help boost the energy efficiency of applications while also lowering installation costs. It is possible to maximize efficiency, resilience, and the percentage of energy self-consumption by keeping an eye on the microgrid's energy storage system.

DC auxiliary systems are primarily used to supply a dependable power source for the protection of the power system. DC systems supply the electricity needed to run monitoring devices, protective relays, and circuits that run power circuit breakers or other fault-isolating devices. When the power systems are operational and during outages, the DC systems are intended to supply power for these protective measures in the prior study [10], Dib et al.,2020 in the earlier study [11], added a renewable energy source and batteries, studying their effect on the electric system at a transformer substation. Research focuses on design and energy management optimization in order to decrease electrical losses, but further simulations, technical, and economic studies are required to assess this reinforced system supplying the AC and DC in the substation. A comparison between the conventional method and the new method of optimization-based selection of lead-acid batteries for supplying the DC auxiliary system in which it shows that the new one satisfies the technical criterion and also maintenance tasks and associated reliability of operation, is shown in [12].

The economic performance of Li-ion vs. lead-acid batteries has been compared in the previous study [13]. In five case studies, two sets of simulations are run for every case. Using both a PV-diesel hybrid and a 100% PV system, the absolute optimum was achieved with Li-ion batteries in three of them and lead-acid batteries in seven. And to attain the economic optimum when changing the type of battery, the complete system must be downsized. In all cases of this study, Li-ion batteries have shown a longer lifetime, but the Li-ion battery also has a lower capacity than the lead-acid battery in their optimum systems. Li-ion batteries outperform lead-acid batteries in terms of economy in hybrid systems as opposed to PV ones. Li-ion batteries perform better in PV systems when exposed to more solar radiation, but poorly in hybrid systems. Research was done in the prior study [14] to overcome the problem of Messias substation using a reliable and clean solution, which is PV systems and BESS in place of the diesel generators (DGs), - which emit pollutants, and take longer to start up - to supply the AC auxiliary system for a longer time and a higher quality of energy as a primary source, but concerning emergencies for a short time or power outages during the night, DGs are advised to be employed if the primary source is an energy storage system or DGs.

This paper provides two scenarios that help in increasing the reliability of feeding such a critical system, which is the DC auxiliary system in the generation station. One of them is using the PV systems plus BESS as the main source for supplying the DC loads all day, and the second is using PV plus BESS during sun hours, then the utility source supplies the loads for the remaining hours of the day. This study assumes the second scenario to have more than one option in case the ministry of electricity prefers to supply the DC loads in the power station from the DC microgrid for only 8 hours per day and from the utility grid for the remaining hours of the day to save on initial costs. Here is a short presentation of the paper's sections. Section 2 gives a description of the paper's case study of Cairo North power station, discussing the DC auxiliary system in the power station and the PVsyst program and its simulation steps. In Section 3, the system verification was done with equations that matched the PVsyst report. The comparison between the results of the two proposed scenarios is shown in Section 4. Section 5 of the paper studies the effect of increasing the temperature of the batteries due to an outage of the air conditioning system in the battery room at different temperatures. together with a detailed economic study for the two proposed scenarios over 25 years in Section 6. Finally, Section 7 contains the conclusions of the research, which show that in the long-term using renewable energy, especially PV systems in addition to the BESS leads to more reliability and saves on the cost of the project.

2. Case Study

2.1 The Case Study, "Cairo North Power Station "

Cairo North Power Station Combined Cycle 750 MW in Shoubra, Egypt. It has two modules; each consists of two gas turbines and one steam turbine with 46% efficiency. It lies between 30.14 °N latitude and 31.25 °E longitude. Figure 1 shows the single line diagram (SLD) of feeding the DC Auxiliary System of the combined cycle power station, which includes the DC loads that are considered crucial loads since they are necessary for the power station to achieve the correctly, dependable, and safely operation for supporting the control circuits for circuit breakers and disconnect switches and also the solid-state protection relaying for all the station electrical equipment such as tripping and closing coils of circuit breakers.

The DC auxiliary system also supports various systems like fire alarms, access control, communication, emergency exit signs, and lights. Some loads, like monitoring devices and PCs, are fed by the UPS, which is supplied by the DC auxiliary system to ensure the continuity of supply, as mentioned in the earlier study [15].

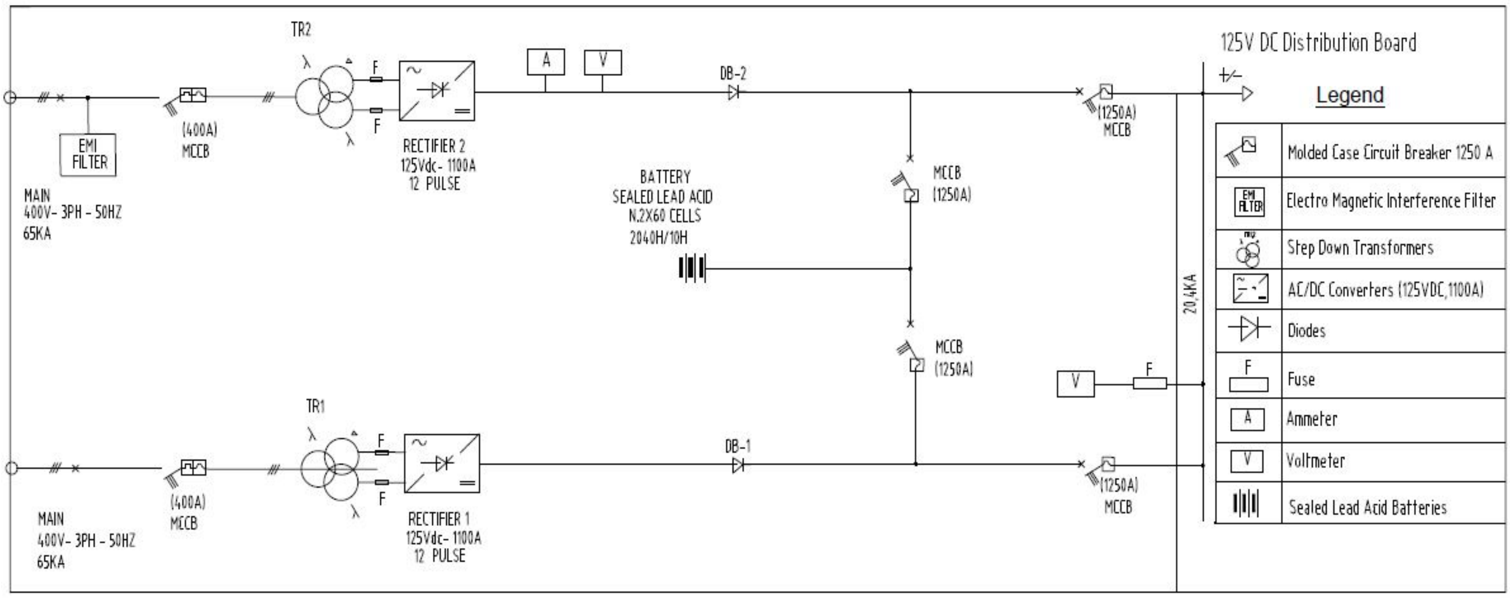

Fig. 1. Single line diagram of DC auxiliary system

Figure 2 shows the SLD of all DC and UPS loads. The voltage level that is required for the DC auxiliary system is 125 volts and it is supplied by two sources from the grid by two rectifiers (chargers). One of them is primary, and the other is redundancy- in case the primary line faces an outage- and there is the battery bank if the outage of both sources occurs. Also, there is a backup diesel generator in case of emergency, i.e. AC bus loses the supply or if a blackout occurs.

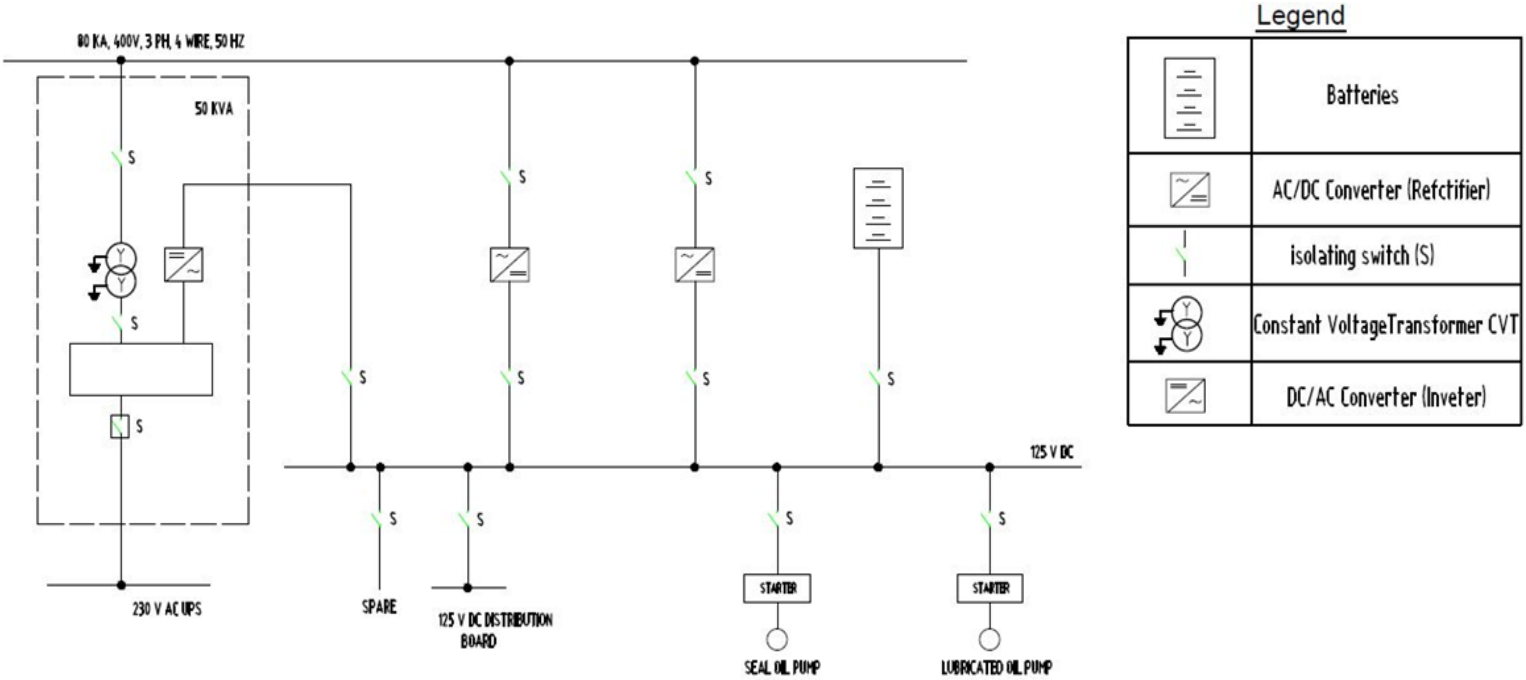

Fig. 2. Single line diagram of DC auxiliary system and UPS system loads of Shoubra power station

2.2 PVsyst. Simulation Steps and the Factors & Data of the DC Load and the System

PVsyst is one of the most efficient tools for sizing, simulating, and assessing various kinds of solar energy systems. It can also model the orientation of the solar panels, the site's location, the temperature, and the patterns of electrical load and its consumption, as taken from the prior study [16]. It is renowned for its precision in analyzing the overall performance of PV systems either on grid or off grid, as well as providing a detailed loss diagram of the system. Figure 3 shows the off-grid layout that is generated by PVsyst software from the page "Simplified Sketch" and the following points show the simulation steps as shown in the earlier study [17]:

- Determining the geographical location and meteorological data of Shoubra power station.
- Specifying the orientation of the PV array (the tilt and azimuth angles) and the optimization period is chosen that the irradiance is per year.
- Outlining the total DC auxiliary loads that needed to be supplied from the page "user's need".
- Outlining the configuration of the modules from the page "PV Array" and choosing a PV module model from the database and its details as shown in Table 1. Figure 4 shows the current vs. voltage curve, including incident irradiance, of Trina PV modules.
- Defining the system parameters, such as choosing a battery model and its details as shown in Table 2, and the number of batteries in series and in parallel from the page "Storage".

- Selecting the control mode (DC-DC converter) and its details, as shown in Table 3.
- Defining the number of modules in series and parallel according to battery voltage and required PV power.
- Finally, running the simulation and getting the report.

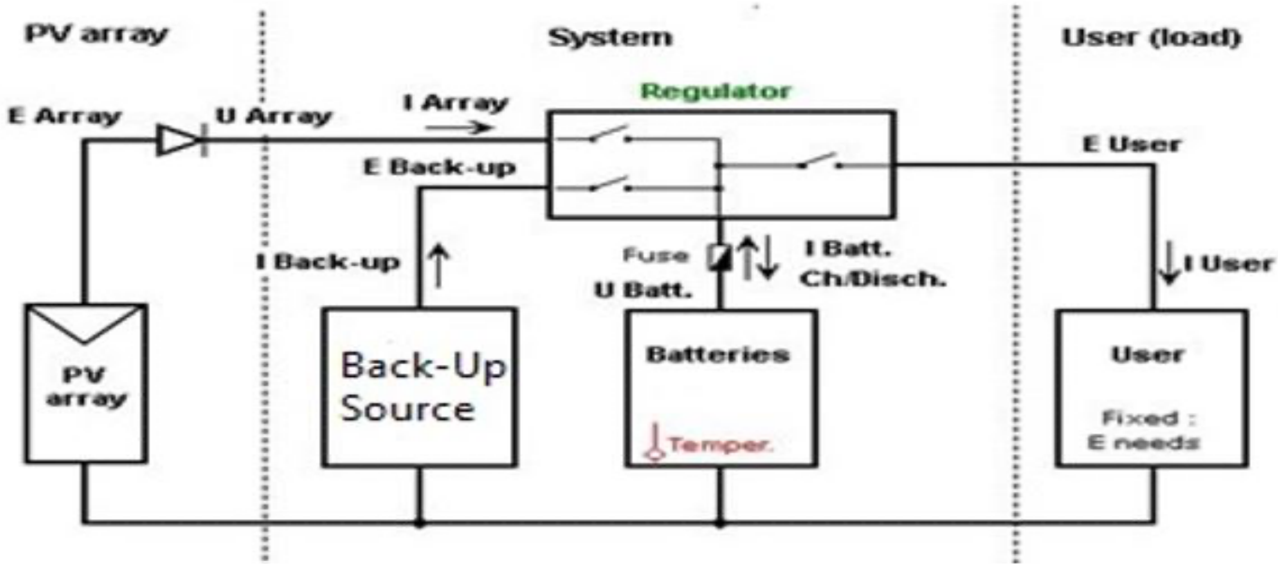

Fig. 3. Off-grid layout generated by PVsyst software simulation

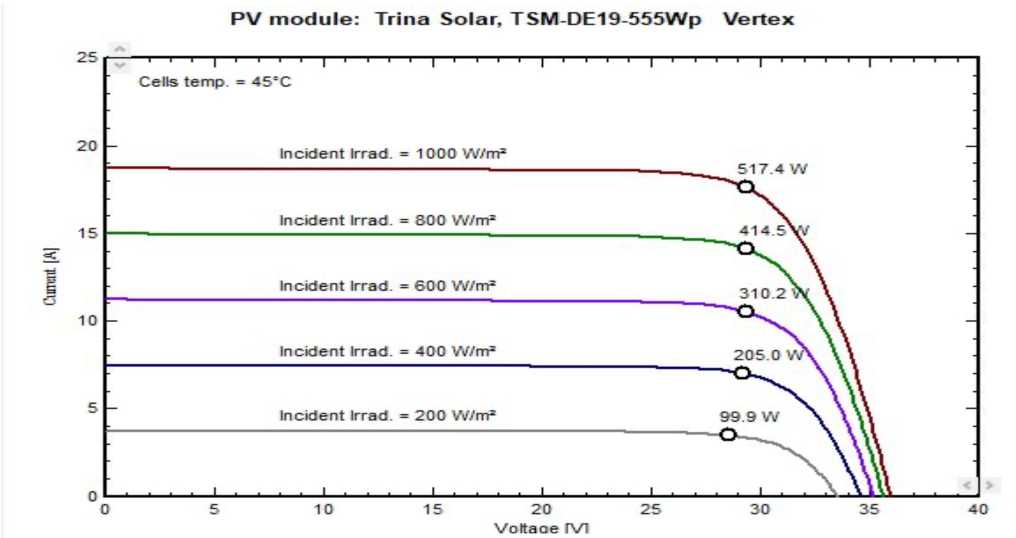

Fig. 4. Current vs Voltage of Trina modules

Table 1
The PV modules data

PV Modules	Values
Reference condition Gref	1000 W/m^2
Nom Power at STC	555 Wp
Short- circuit current Isc	18.560 A
Current at mpp	17.450 A
Voltage at mpp	31.80 V
Open Circuit Voltage Voc	38.10 V
Nb cells in series	55 *2
Module Area	2.613 m^2

Table 2
The battery model data

Battery Set	Values
Nominal Voltage	25.6 V
Capacity at C10	180 Ah
Battery pack voltage	128 V
Stored energy (80% DOD)	4101 kWh
Number of cycles at 80% DOD	2000
Total stored energy during the battery life	7213 MWh

Table 3
The DC-DC converter data

DC Converter	Values
Max. Charging Current	4350 A
Max. Discharging Current	8700 A
Max. back-up Current	1171.9 A
Converter nom. power	108000 W

2.3 Data to Be Considered While Using PVsyst

The Azimuth (Orientation) angle describes the position of the modules in terms of how many degrees the array is from the north, considering that north is 0 degree and south is 180 degree as mentioned in the preceding study [18,19], while the tilt angle is the angle formed between the horizontal plane and the pitch of a solar panel, and the panels should be tilted to get the most of the sun light to be absorbed as declared in the prior study [20,21].

Figure 5 shows the difference between the two angles. In the case study the tilt and azimuth are 25° and 0°, respectively and from the meteorological data of Shoubra power station from PVsyst, the yearly irradiance is 2070 kWh/m^2, as shown in Figure 6.

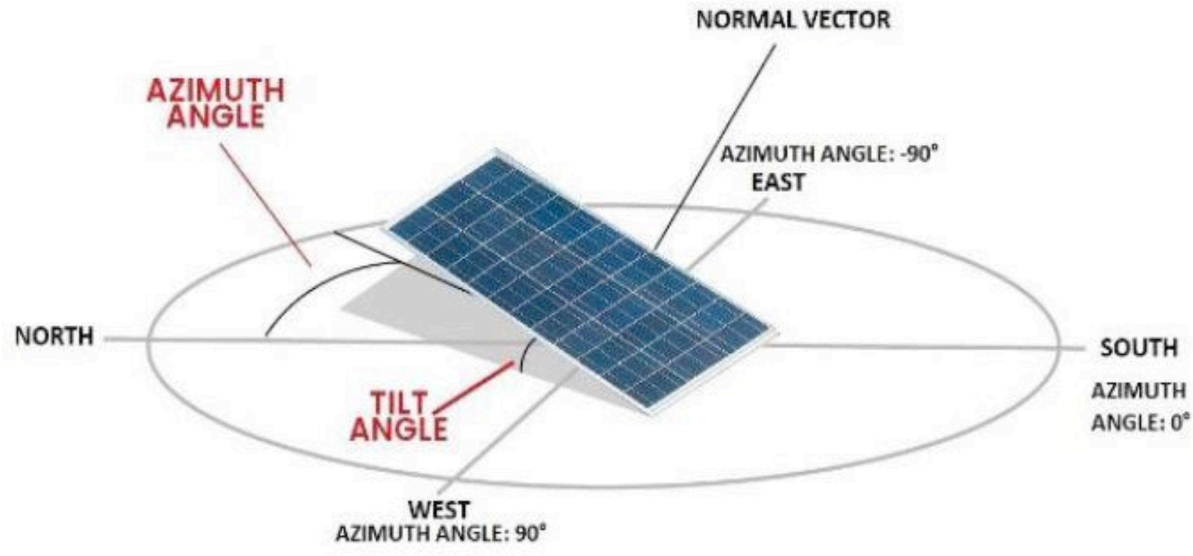

Fig. 5. Difference between azimuth and tilt angles is taken from the previous study [22]

2.4 The Proposed Two Scenarios for Supplying the DC Auxiliary System

This paper proposes two different scenarios to supply the DC auxiliary system in the power station using both conventional and renewable energy sources by making use of the PV systems with BESS. The first scenario supplies the DC loads from the PV and BESS for 24 hours, and the other one supplies the loads only for 8 hours, then the loads would be supplied by the grid. Figure 7 shows the proposed configuration for both scenarios

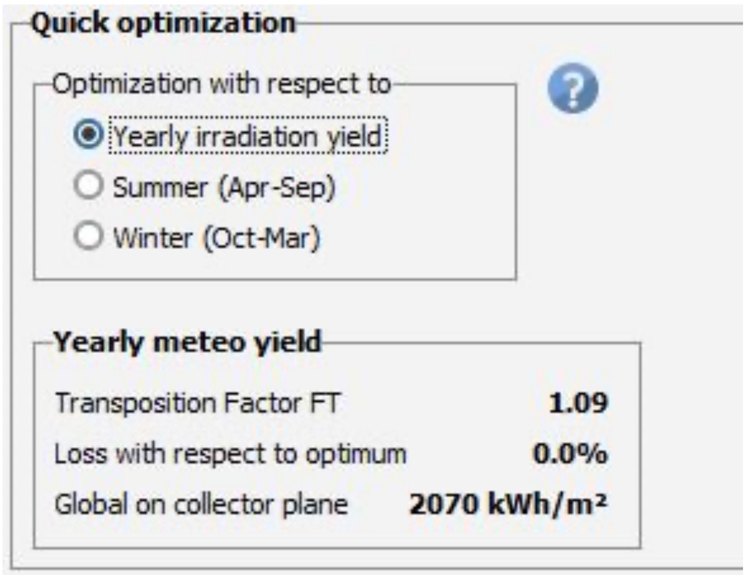

Fig. 6. The yearly irradiance of Shoubra power station

Fig. 7. Block diagram of the proposed configuration

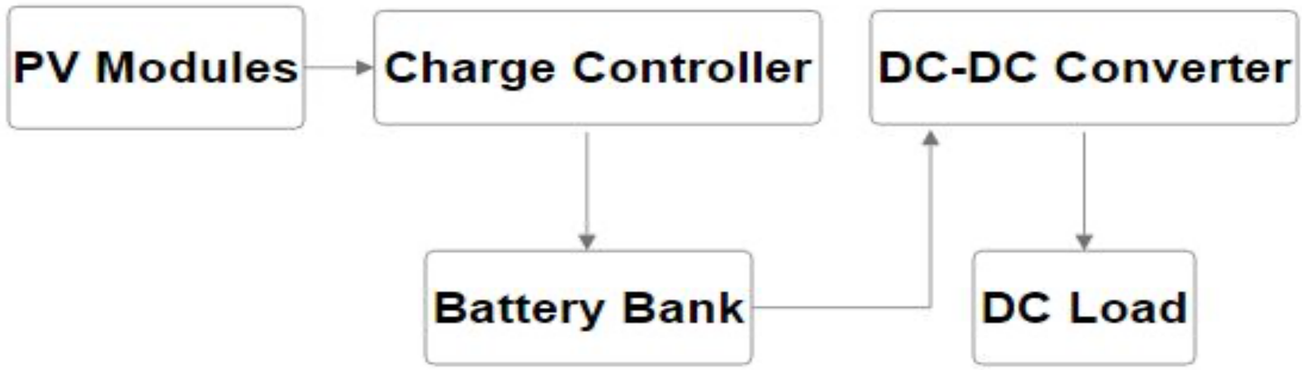

Fig. 7. Block diagram of the proposed configuration

3. System Verification with Equations

The DC auxiliary loads are not only continuous loads but also critical loads that need to be supplied without any drop in continuity of supply. The 125 volts DC distribution board loads are 55 kw, and as mentioned in the paper above, there are two modules of turbine, so the critical loads are doubled to be 110 kw while keeping in consideration the safety factor, so the total loads will be 150 kw. The PV system with BESS is designed to supply the critical loads in the two scenarios that are proposed in this paper. In the following paragraphs, the steps of the hand check are matched with the PVSYST results.

A. The load needed to be supplied is 150 kw, so energy is needed per day to supply that load, as calculated in Eq. (1) for the first scenario for 24 hours, and Eq. (2) for the second one for only 8 hours.

$$\boldsymbol{E = P * 24} \tag{1}$$

$$\boldsymbol{E = P * 8} \tag{2}$$

Where E is the energy needed per day that PV modules would provide, and P is the load power.

B. According to PVsyst, the coordination of the location of the Shoubra power station indicates the year of plane irradiation is 2070 kWh/m^2, so Eq. (3) calculates the sun peak hour.

$$\boldsymbol{SPH = \frac{Irr}{365}} \tag{3}$$

Where SPH is the sun peak hour, Irr is irradiance (kWh/ m^2), and SPH is calculated per 365 days.

C. To calculate the power of the PV power plant (PV PP), Eq. (4) shows as follows:

$$\boldsymbol{PV\ PP = \frac{E}{\mu * SPH}} \tag{4}$$

Where μ is the off-grid efficiency.

D. PV modules used in the simulation of PVsyst were Trina module TSM-DE19-555WP, Si-Mono, 27 volts, so the number of series modules (NS) equals the module number in one string = 4, and the number of parallel modules (NP) equals the string number as Eq. (5) shows:

$$\boldsymbol{NP} = \frac{\boldsymbol{NT}}{\mathbf{NS}} \tag{5}$$

E. Batteries used in the simulation have the voltage VB = 25.6 volts, battery capacity (IB) = 180 Ampere Hour, Vectron energy, and Depth of Discharge = 80 %, so to calculate the battery number (NB), Eq. (6) shows the following:

$$\boldsymbol{NB} = \frac{\boldsymbol{E}}{(\boldsymbol{VB} * \boldsymbol{IB}) * \boldsymbol{DOD}} \tag{6}$$

F. To calculate the number of series batteries (NSB), Eq. (7) shows as follows:

$$\boldsymbol{NSB} = \frac{\boldsymbol{VS}}{\mathbf{VB}} \tag{7}$$

Where VS is the system voltage and VB is the battery voltage.

G. To calculate the number of parallel batteries (NPB), Eq. (8) shows as follows:

$$\boldsymbol{NPB} = \frac{\boldsymbol{NPT}}{\boldsymbol{NSB}} \tag{8}$$

H. We choose a converter to be 100 kw, and hence the NB is 990, so the number of converters is 9 for the first scenario. For the second scenario, NB and the number of converters would be 330 and 3, respectively, so the number of batteries connected to the converters (BTC) is given by Eq. (9).

$$\boldsymbol{BTC} = \frac{\boldsymbol{NB}}{\boldsymbol{NC}} \tag{9}$$

Where NC is the number of the converters.

Figures 8 and 9 show the whole of the energy flow by expressing the losses for the two proposed scenarios, starting from solar energy and striking the solar modules, then going through all the components of the mentioned PV plant, thus converting to electrical output energy. Each diagram contains the upper part expressed in terms of solar energy and the lower part in terms of electrical energy. The ratio between the two scales is due to the collector area and the PV module efficiency.

It is concluded from the loss diagrams that the energy that can be generated by the systems of 1765452 kWh for the first scenario and 588484 kWh for the second one has decreased to 1314009 kWh and 438009 kWh, respectively, due to losses in the systems. Figures 10 and 11 show the normalized production and the performance ratio. Figures 12 and 13 show the following diagrams: daily input/output diagram, daily array output energy, array power distribution, and finally, array temperature vs. effective irradiance.

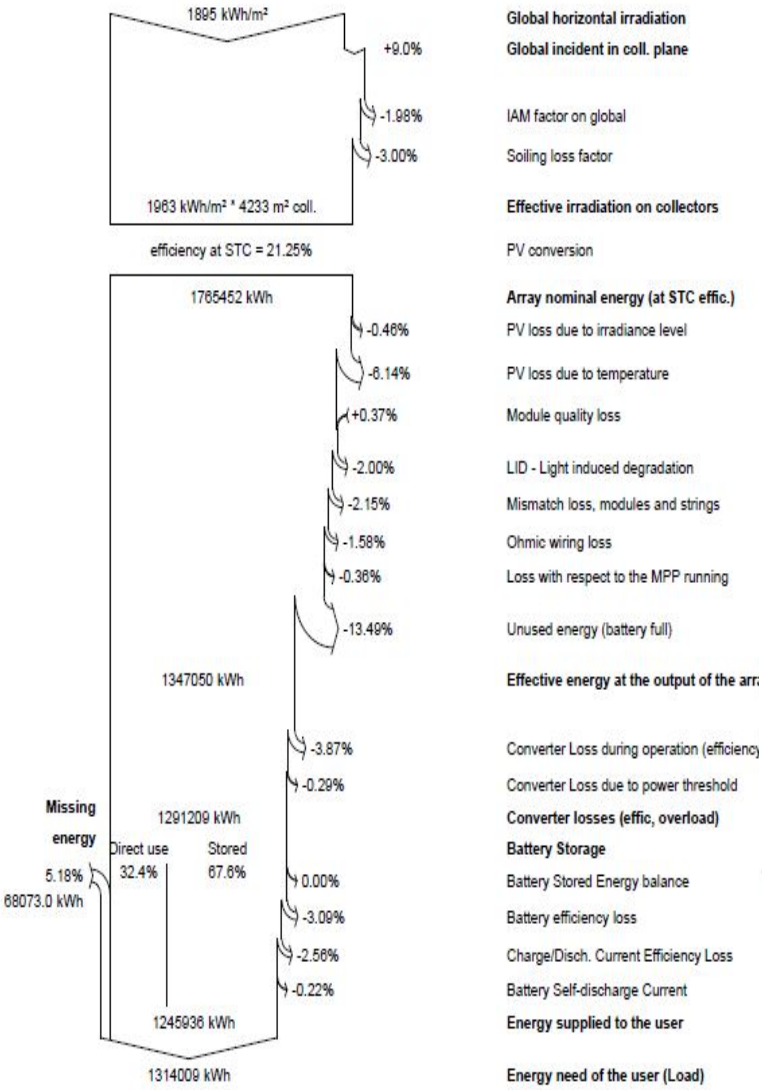

Fig. 8. The loss diagram of 1st scenario

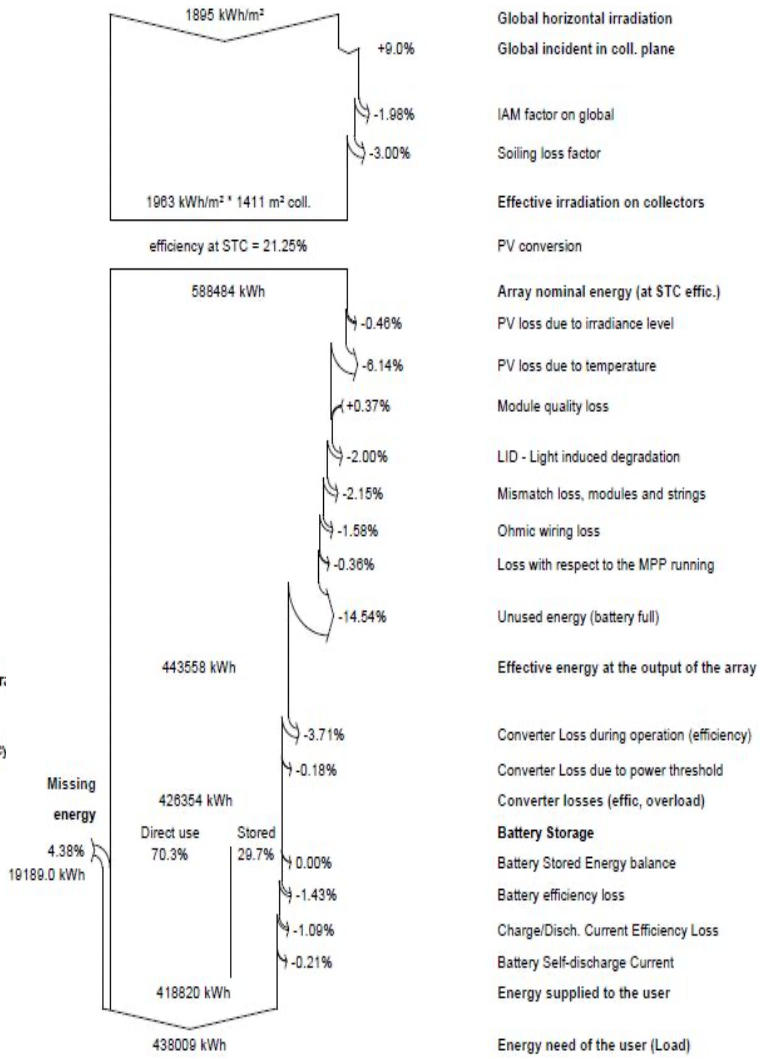

Fig. 9. The loss diagram of 2nd scenario

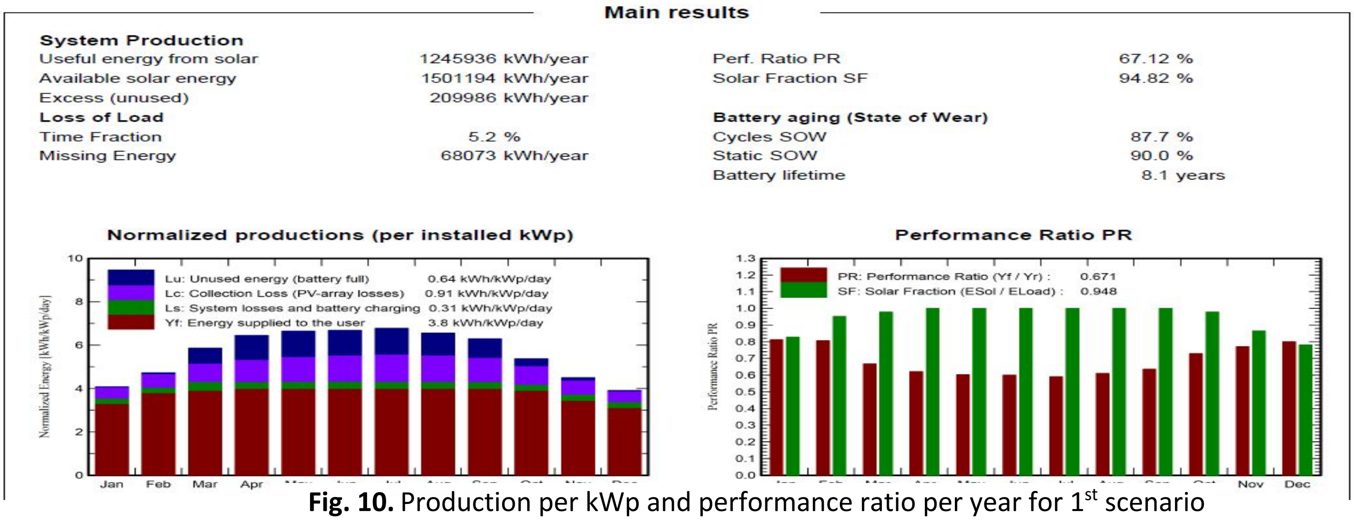

Fig. 10. Production per kWp and performance ratio per year for 1st scenario

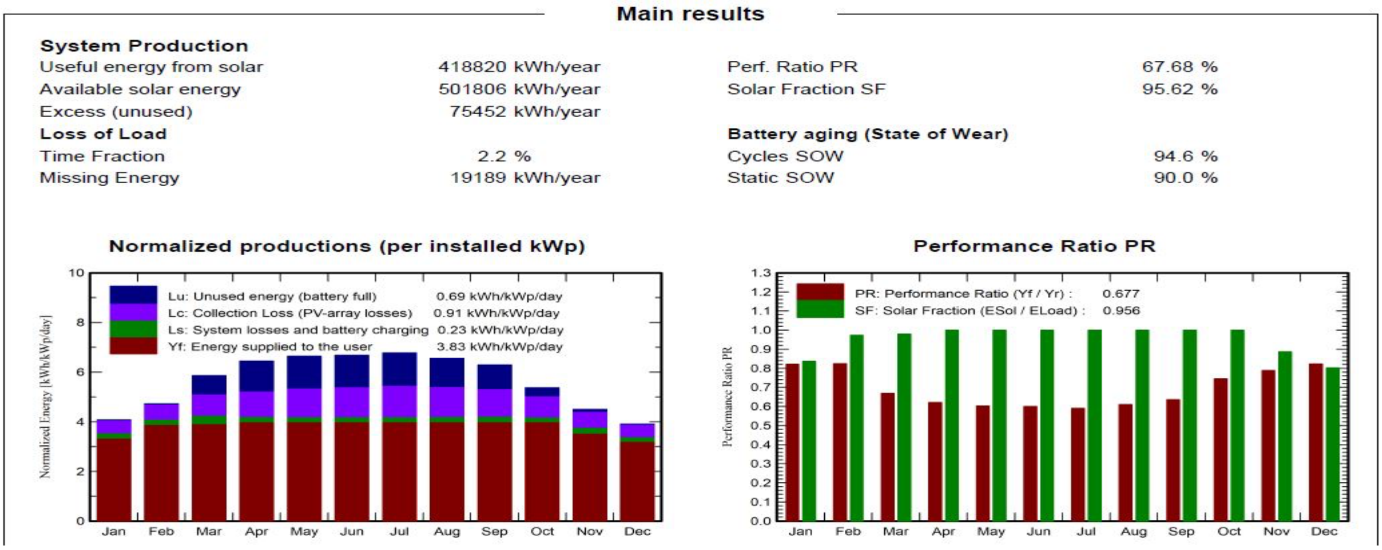

Fig. 11. Production per kWp and performance ratio per year for 2nd scenario

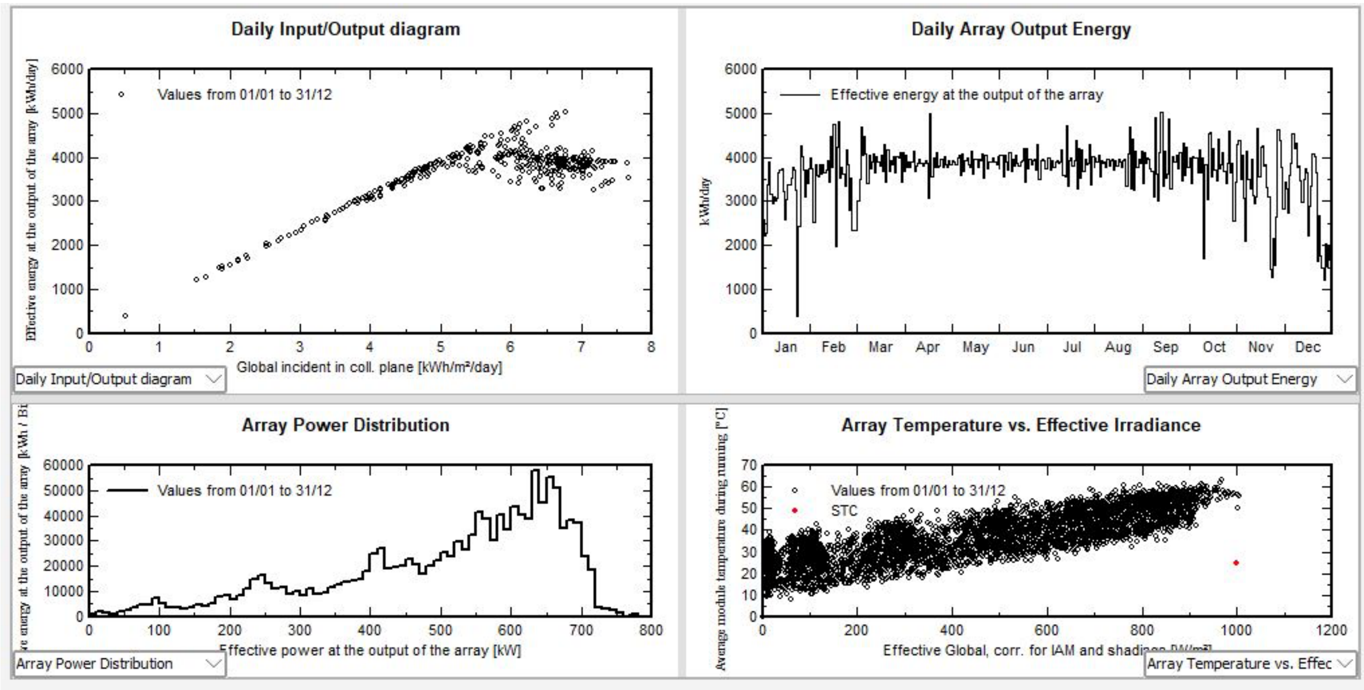

Fig. 12. The PVsyst primary diagrams of 1st scenario

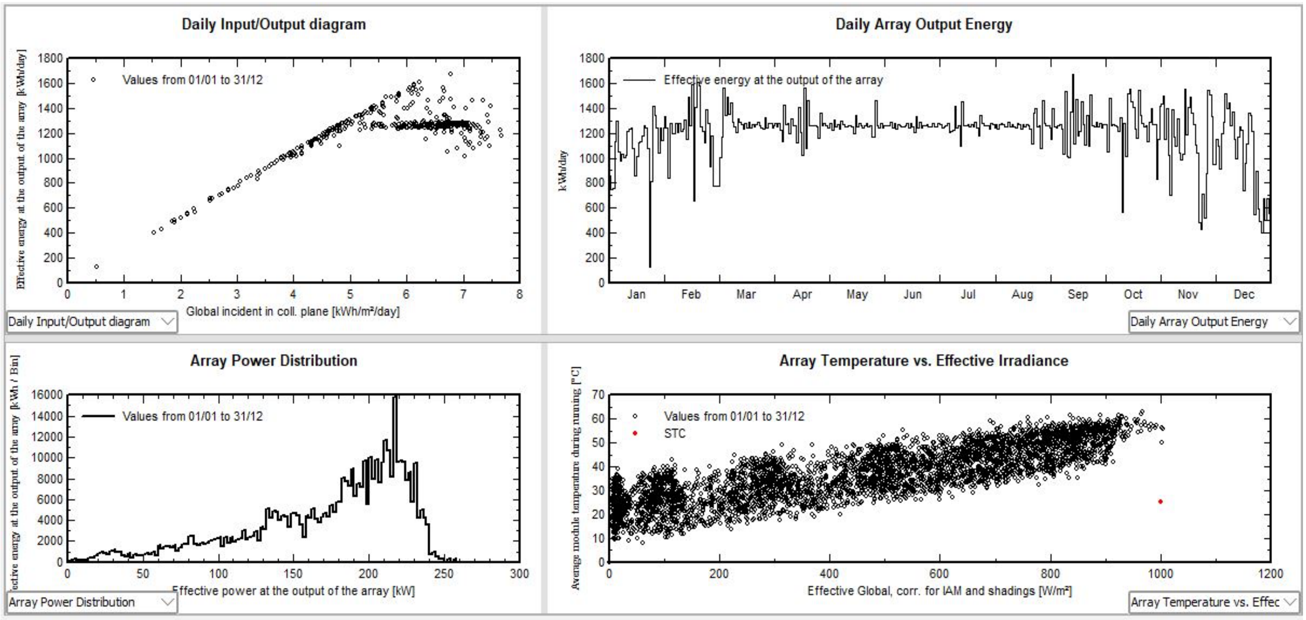

Fig. 13. The PVsyst primary diagrams of 2nd scenario

4. Result

As mentioned in Section 3 the verification equations of the system, Table 4 shows the hand-check results according to the previous equations for both scenarios, the first of which is supplying the DC load for 24 hours with the help of PV modules and batteries, and the second scenario is supplying the DC load only for 8 hours and the rest of the day switching to the backup supply of the grid.

Table 4
The results of hand check equations

Comparison Aspects		First Scenario (24 hours)	Second Scenario (8 hours)
$E = P * 24$ $E = P * 8$	(1) (2)	3600 kWh / day	1200 kWh / day
$SPH = \frac{Irr}{365}$	(3)	5.67 hrs	5.67 hrs
$PV\ PP = \frac{E}{\mu * SPH}$	(4)	900 kw	300 kw
$NP = \frac{NT}{NS}$	(5)	405	135
$NB = \frac{E}{(VB*IB)*DOD}$	(6)	990	330
$NSB = \frac{system\ voltage\ 128}{battery\ voltage 25.6}$	(7)	5	5
$NPB = \frac{NB}{NSB}$	(8)	198	66
$BTC = \frac{NB}{NC}$	(9)	110	110

5. Studying the Effect of Increasing the Temperature upon the Losses of the Battery

The battery bank room in the station is covered by MCC panel that is responsible for controlling the air-conditioning devices in the room to maintain the batteries at a suitable temperature to gain the highest performance, so in this section, the effect of increasing the temperature of the batteries - due to the outage of the air conditioning system in the battery bank room- is reviewed at 30° and 40°, as the temperature in Cairo reaches that range of high temperature, especially in summer.

Figures 14 and 15 show the loss diagrams for the first scenario at two different temperatures. The figures show that the missing energy for both scenarios in the case of 30° is 5.11% and in the case of 40° is 5.35%, which reflects that providing good coverage of air in the battery room leads to fewer losses, which provides more reliable performance for the batteries in the long term, which in turn leads to higher reliability for the overall system.

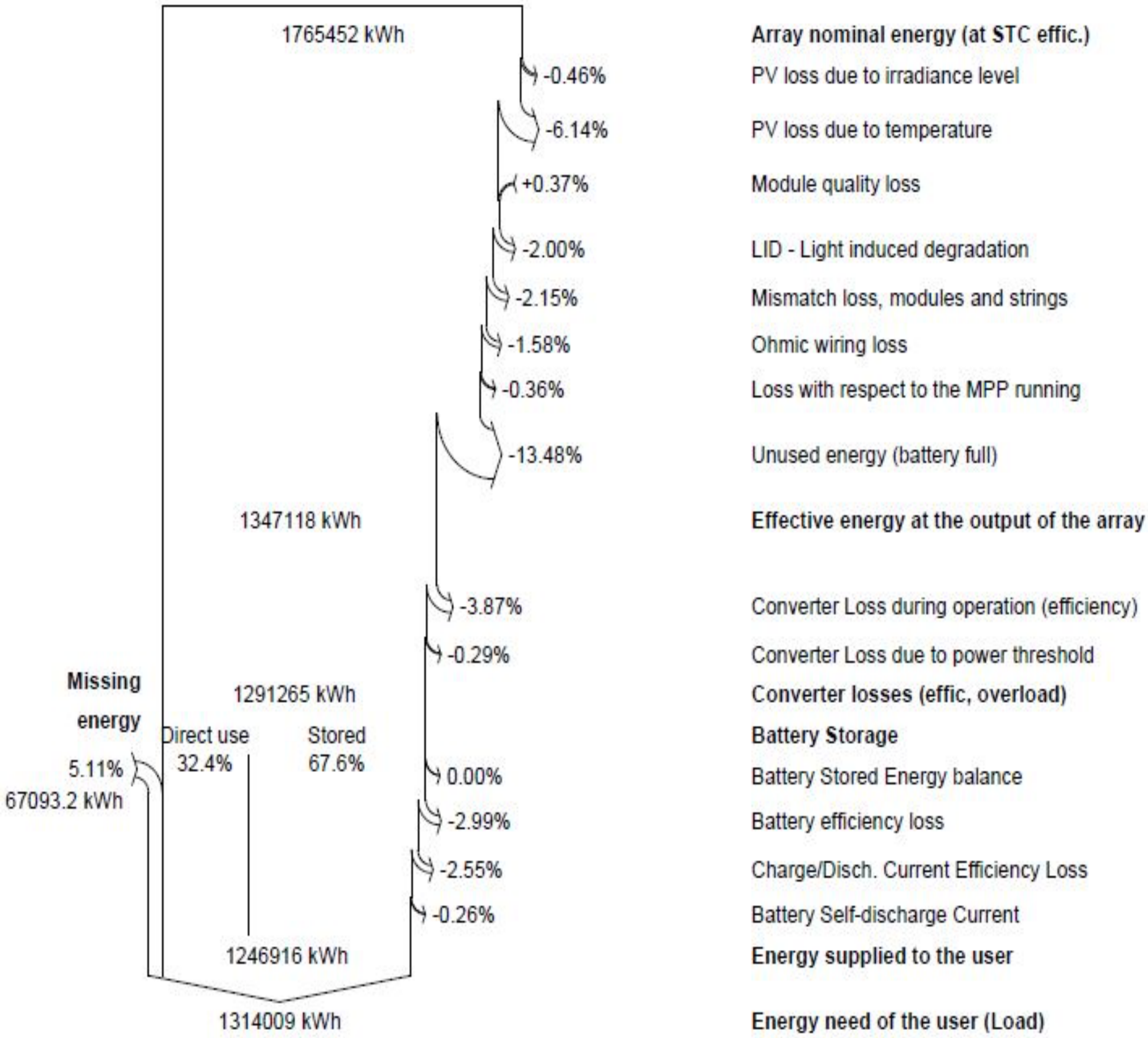

Fig. 14. Loss Diagram for a 30° Temperature Case

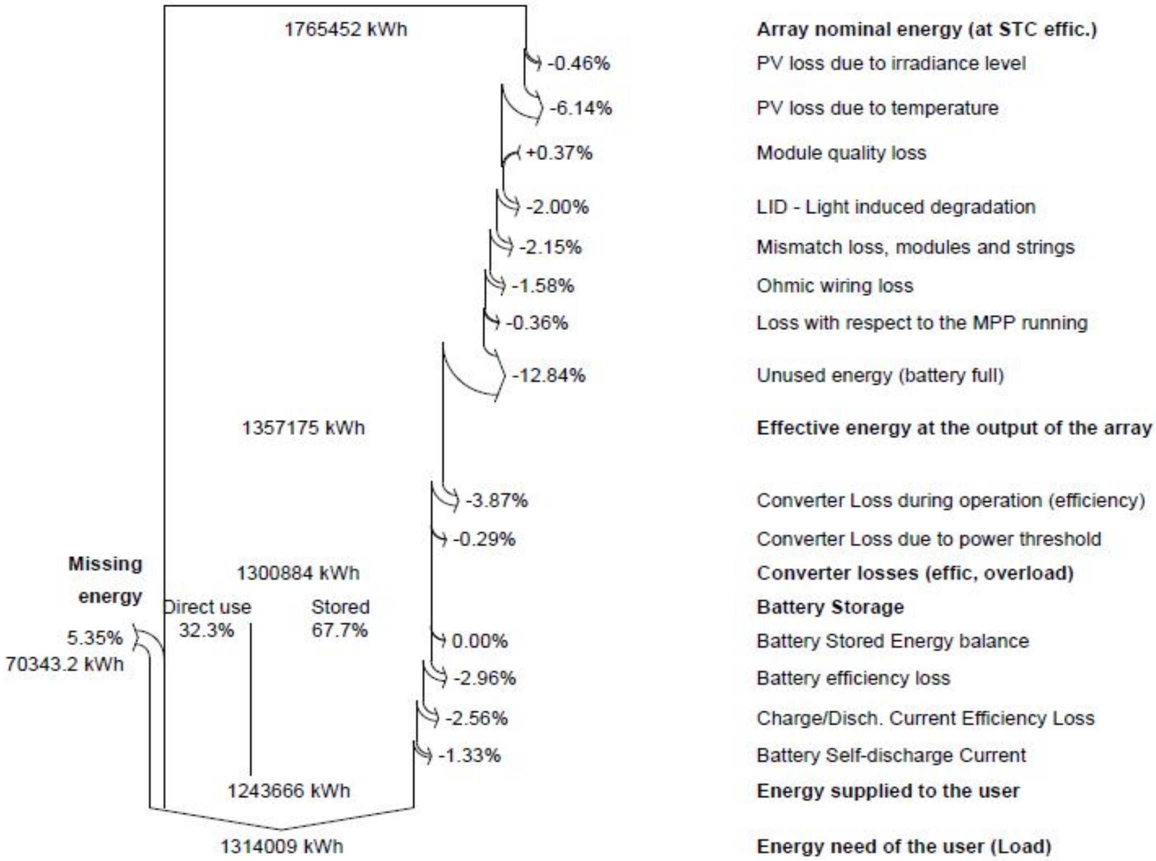

Fig. 15. Loss Diagram for a 40° Temperature Case

6. The Economic Study

6.1 Cost Estimation of the Project

The economic survey is done by reviewing the average prices from the Egyptian market, which are approximate indicative prices, to estimate the values of all the project components and applying that study to the two scenarios that have been assumed, as illustrated in this paper. Table 5 shows the share percentage of the project items, and Table 6 shows the battery bank cost in USD. These cost estimations are obtained from the New and Renewable Energy Authority in Egypt [23], based on the average market energy prices survey and the ongoing projects, they are also obtained from the global petrol prices platform, which shows the approximate electricity prices around the world [24].

Table 5
The share percentage of the project items

Item	Share	Price (1st scenario) USD	Price (2nd scenario) USD
PV Modules	%50	285000	95000
DC-Converter	%25	142500	47500
Structure	%10	57000	19000
Cables & Panels	%15	85500	28500
Sum		570000	190000

Table 6
The battery bank cost in USD

Item	Price USD	1st scenario Battery No.	2nd scenario Battery No.
Battery Cost	1800	990	330
Total Price USD		1782000	594000

6.1.1 First Scenario

Hence the cost of 1 kw = 30000 Egyptian Pounds (EGP). So, for 900 kw, the total price will be 27000000 EGP, hence the USD = 47.37 EGP. Then the cost of the components (PV modules, DC converter, structure, cables, and panels) equals approximately 570000 $. And from Table 6, the price of the battery bank equals 1782000 $ so the total price of the components of the first scenario would be 2352000 $.

6.1.2 Energy Estimation for the First Scenario

Energy for the First Year = 1314009 kWh Energy need of the user (load) in Figure 8, keeping in mind that the degradation factor is 0.994 Figure 16 from the datasheet of the Trina solar module. So, the total energy after 25 years will be approximately 30590307 kWh.

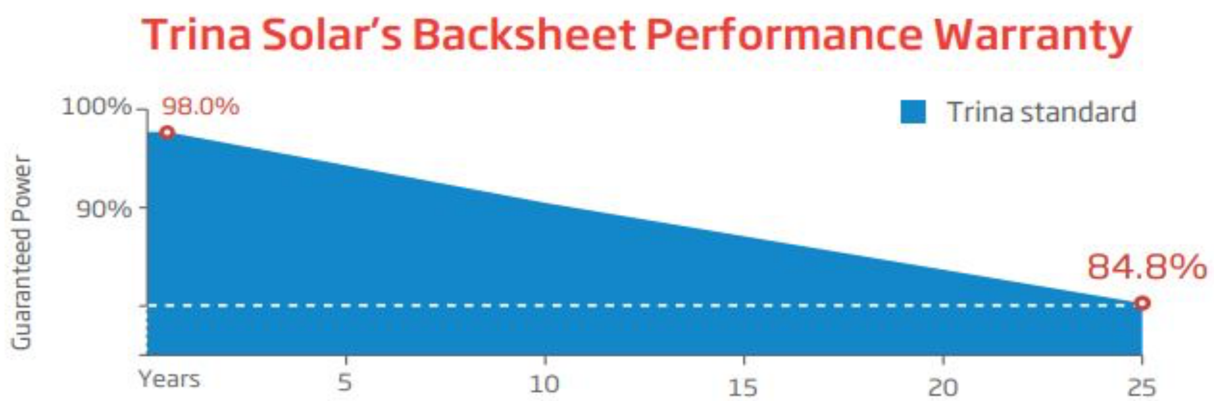

Fig. 16. The degradation of the PV modules along 25 years

6.1.3 Second Scenario

For 300 kw, the total price will be 9000000 EGP, so the cost of the components (PV modules, DC converter, structure, cables, and panels) equals approximately 190000 $. And from Table 6, the price of the battery bank equals 594000 $ so the total price of the component of the second scenario would be 784000 $.

6.1.4 Energy Estimation for the Second Scenario

Energy for the First Year = 438009 kWh Energy need of the user (load) in Figure 9, keeping in mind that the degradation factor is 0.994 in Figure 16 from the data sheet of the Trina solar module, so the total energy after 25 years will be approximately 10196909 kWh.

6.2 Energy Tariff Calculations

The tariff could be calculated by dividing the total energy after 25 years in both cases by the total price of the scenarios, which gives 0.076 cent.

7. Discussion and Conclusion

This paper discusses the two proposed scenarios that are feeding the DC auxiliary system in Shoubra power station. The first scenario is that the PV modules and battery storage system are the primary supply for the DC auxiliary system for 24 hours instead of the current mode of the power station – which is being fed by two lines from the grid, one is the backup for the other– and in case of contingency or total loss for the system, the current redundant grid line would be the energy supply. The second scenario is to supply the DC loads for only 8 hours, and then comes the role of the line from the grid to supply the loads the rest of the day. This paper also reviewed the effect of increasing the temperature of the battery pack room on the losses, which is considered an important parameter for aging the batteries, and the economic cost of the scenarios showed that the proposed scenarios achieve more reliability than the conventional methods in the power stations.

This paper reaches the fact that green energy penetration using a PV system in addition to the BESSs is a clean and sustainable solution due to its ability to reduce the emissions that come out of ordinary stations, which is recommended by the government nowadays, because it provides self-sufficiency by feeding such a critical DC auxiliary system in the power plant and also by saving the energy of the grid to supply other load demands. Also, cost-wise, using (PV+BESS) is better over time. Finally, choosing between the proposed 1st and 2nd scenarios depends on the decision of the Ministry of Electricity and Renewable Energy to afford the higher fixed installation cost of the 1st scenario while keeping in mind its much greater reliability over the 25 years compared to the 2nd scenario.

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