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OPTIMUM SIZING AND ENHANCED CONNECTION SCHEME OF STANDALONE PV SYSTEM

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ABSTRACT:
With the depletion of fossil fuel resources and increase its prices as well as its high side effect on environment, all world marks the renewable energy resources as green energy replacement. The PV systems became the most popular energy resource in warm states. Precise sizing of PV systems either for grid connected or stand-alone became essential to minimize system cost and increase its life time. A new optimum sizing technique for stand-alone PV systems by equating the deficiency and surplus of PV power units to satisfy the load each quarter of hour for one day using a trial and error technique. The actual characteristic of daily PV power curve of the solar panels is practically obtained in lab. The minimum sizes of batteries that can be charged during the surplus power periods and discharged to feed loads for the deficiency periods are designed. In addition, the required PV modules and the corresponding required batteries for night load periods are also designed. Self-equalizing system is proposed to the battery system by connecting diodes with the batteries to prevent the circulating current and regulate the charging and the discharging process. Simulation of the system is represented to indicate the effectiveness of the proposed connections which increases the system efficiency and components lifetime.

KEYWORDS: Standalone PV systems, sizing PV system, Renewable energy, batteries connection.

INTRODUCTION:

Solar energy becomes the most attractive power source nowadays [1]. The earth faces the problems as a result of using the fossil fuels. These force the human body to find a clean energy source. The sun, which is the source of all energy on the earth, attracts the scientists' attention to exploit its energy to generate the energy needed. There are two types of energy coming from the sun; the thermal and photic energy. Photovoltaic solar systems are the most attractive power system in new projects in Egypt. There is a great interest to solar power systems in Egypt as it is one of the highest solar radiative countries. Fig. (1) Shows the mean annual solar energy radiated in Egypt [2,3].

By 2050, the Middle East and north Africa Energy Policy Plan aims to limit climate change by capping the global temperature rise to no more than 2°C [4]. For this reason, there is a possibility for a reduction of Green House Gas emissions in Egypt by establishing 43% of primary energy from renewable source by 2035became a goal [2]. In order to achieve this goal, the middle east and north Africa countries have developed specific technology roadmaps that will lead to the integration of low carbon energy technologies, and in particular the deployment of Concentrated Solar Power plants and Concentrated Photovoltaic installations in the energy economy [4].

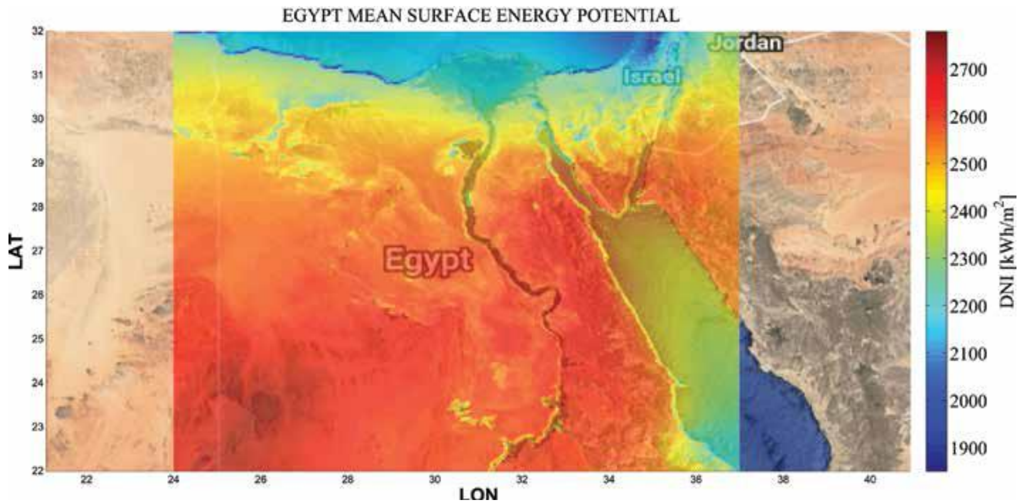

Fig. (1) Mean annual energy radiated in Egypt.

Egypt is located in the world's solar belt and has an excellent solar availability. The annual average total solar radiation over Egypt ranges from about 1950 kWh/m^2/year on the Mediterranean coast to more than 2600 kWh/m^2/year in Upper Egypt. About 90% of the Egyptian territory has an average total radiation greater than 2200 kWh/m^2/year [2-4].

Egypt has got an ambitious plan for village electrification. More than 98% of the villages were electrified through the utility grid. However, there are still some remote isolated small communities and settlements that are too far from the power grid and consequently will not be connected to it [2]. Sinai Peninsula is characterized by its high mountains and decentralized communities that are far from the power grid of Egypt. Most of those communities are still un-electrified. Where, the houses of those communities are characterized by poor inhabitants, low power demand, fixed load, and dispersed nature. They are beyond the economic boundary of the utility and are therefore not included in the future plan for electrification from the national grid [2-3].

There are two types of PV systems [5-7]. The first type is the grid connected system. This system is directly connected with the electrical power grid. This system doesn't need a storage system. It supports loads during daily hours and the excess energy will go to the grid. During night hours, the grid supports the loads. This system is supported by two-way metering devices. The second system is the off-grid or stand-alone PV system. It is designed to replace or supplement conventional mains power supply. This system is most commonly used in rural or remote areas where the utility grid is not available due to the high cost of grid extension. Stand-alone PV systems use solar power to charge batteries that store the power until it is needed for using.

Standalone PV system which shown in Fig. (2), is the best solution as a power supply for remote locations where the connection with the electrical grid cannot be easily achieved and where a good radiation of solar power is available. This system consists of the solar panels, a storage energy system, and DC/AC inverters to feed AC loads. The PV panels have many different types such as poly crystalline silicon, mono crystalline silicon, thin film, multi-layer panels, … etc. These types differ in cost and efficiency which varies from 9% for thin films to 48% for some types of multi-layer panels. Although, the high efficiency of multi-type solar panels, they are not used in systems because of high cost compared to other types. So that, they are recommended for aerospace applications. They will be used in PV applications on the earth when it will have a competitive cost. Silicon panels either mono crystalline or poly crystalline is the most popular panels all over the world [1], [5-7].

Storage systems are the most important part in the standalone PV systems as they can supply a sustainably power during the sun off periods such as hydraulic and battery systems. Hydraulic systems are not available for use in many applications specially in roof mounted small systems or in large systems but there is no availability of water. The batteries specially lead acid type is the most used storage system because of its availability. The battery system is the expensive part of the PV standalone system as all the other parts has a long lifetime except batteries which has a small lifetime. The battery systems have a special care in design and connection to increase its lifetime and increase the system efficiency.

As well known the solar radiation differs from month to month and differs through the day periods. The sizing of PV system requires sizing of PV modules, batteries, chargers and inverters. The classical method to size the PV system depends mainly on the energy consumed by the load and neglecting the load curve and the load characteristics. Also, it considers that the daily energy produced by the solar panel equals to the maximum energy produced by the same panel with $1000W/m^2$ insolation in a period of five hours (peak sun hours) with ignoring the actual energy produced and the power curve of the panels.

The Sizing of batteries is either determined by considering its energy equal the energy required to the load. The number of batteries is calculated by dividing the energy required for the load by the batteries rated voltages and a single battery ampere-hour taken its efficiency and the rate of discharge into consideration [8-11]. The PV modules are recommended to be connected in parallel and avoid the series connections which lead to under voltage problems if there is shadow of some panels. As a result, the batteries should be connected in parallel. The parallel connection of batteries has many problems. This is due to the unbalance of their emfs which depend on charging and discharging in different states for each battery. This leads to full charge of number of them while the others become completely discharge. Hence, the life time of the batteries are generally decreased. Circulating current moves from the high voltage string to the low voltage one. This current leads to excessive discharge of batteries. Hence, the equalizing systems is designed to solve these problems as in [12,13]. To avoid the connection of series batteries, DC/DC boost converters are used to raise the batteries voltage to match load voltage [10], [12]. To solve the parallel operation problem of batteries, many solutions is based on discharging each battery string through its own converter [12-15]. But this solution is very expensive. so that, parallel batteries are connected together through diodes grid as shown in Fig. (3.13) [16].

In this paper a trial and error method has been introduced to accurately size the PV system. The deficiency or surplus of power delivered from the solar panel output power is going to be calculated along the diurnal day against the corresponding load defined by the load curve each quarter of hour. The process is repeated by changing the size of the PV modules until the deficiency nearly equals the surplus of power to reach PV optimum sizing. The minimum sizing of batteries required to be charged during the surplus periods and to feed load during deficiency for diurnal periods is designed. Also, additional PV modules and batteries required for night periods are going to be calculated. Tailored Program through MATLAB is created. The actual characteristic of the used PV module is practically extracted at Mansura University, faculty of engineering energy lab.

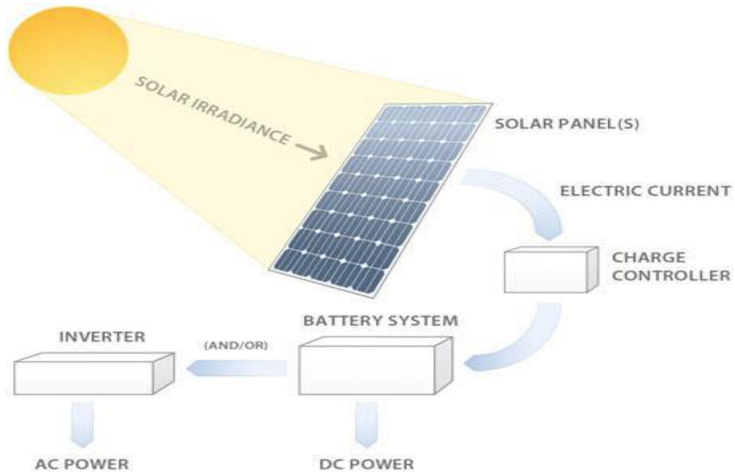

Fig. (2) The standalone PV system

The panel system connection is proposed to be connected in parallel not in series to avoid the under-voltage problems specially in case of partial shadow in series panel connection [17-18]. Another issue is the unbalance of parallel battery emf problem, which must be solved to increase the battery system life time. Self-equalizing system is proposed by connecting diodes with the batteries to prevent the circulating current and regulate the charging and the discharging process.

PROPOSED TECHNIQUE

The proposed technique can be described into two phases. The first phase is to design the optimum sizing of the PV module system. The second phase deals with how to enhance the PV System performance.

A. OPTIMUM SIZING OF PV SYSTEM

The main objective of the first phase of the proposed technique is to accurately determine the sizing of PV modules according to the quarter hourly produced power exerted by actual measurements at the solar energy lab at faculty of engineering, Mansoura University against the quarter hourly required load. The daily load curve is estimated and followed by determining of the PV modules daily output power. The surplus and deficiency energy of the sum of power delivered by the selected type of PV counter to the corresponding sum of energy consumed by the load along the day is calculated. Trial and error method is used to obtain the optimum PV size when the difference between the surplus and deficiency energy equals zero. On the other hand, optimum size of batteries is designed to be charged during the surplus energy periods and to feed the load during the deficiency energy periods during a day. Also, the night load periods are studied to economically design other PV modules and batteries capable to satisfy night load required energy in addition to the previously required for day periods.

Batteries, inverter, charger efficiencies and the battery discharge ratio are taken into design considerations. MATLAB package is utilized to deal with the explained proposal. The optimum design for the PV modules and batteries for day and night loads are explained in details as in figures (3-a) and (3-b) and as following:

1. Starting by determining the diurnal load curve.
2. Select a PV module and practically determine its daily power output curve at point of maximum power.
3. Divide the power required by the load with respect to the output of the module at starting time of the diurnal period of the day.
4. Step 3 is repeated for every quarter hour of the diurnal day.

5. Determine the number of square meters of PV required to supply the load at each point of the diurnal day.
6. Calculate the required average number of modules.
7. Compare the energy output of the average number of modules with the energy required by the load.
8. If the energy output of the average modules greater than the energy required by the load, then the average number of modules must be decreased and vice versa.
9. The surplus energy or the deficient energy is calculated.
10. Step 8 and 9 are repeated till the surplus energy equals deficiency energy along the diurnal period which leads to the best diurnal number of modules.
11. The batteries required to supply the load deficiency can be defined as following:

- ✓ Define the selected battery volt and ampere-hour.
- ✓ Number of batteries required to cover the daily deficiency of energy = daily deficiency of energy / (battery voltage*AH).

12. For night period, the accumulated load energy is only required to determine the sizing of PV modules and batteries sufficient to satisfy the load as following:

a. The required number of PV modules required equals to the ratio of the night energy divided by the energy output of one module during the diurnal period.
b. Number of batteries required to cover the night load energy = Night load energy / (battery voltage*AH).

13. The optimum number of PV modules required for the system equals the calculated diurnal number of modules and the calculated number of PV modules required for night loads.
14. The total number of batteries = number of batteries required for the diurnal load + number of batteries required for the night load.

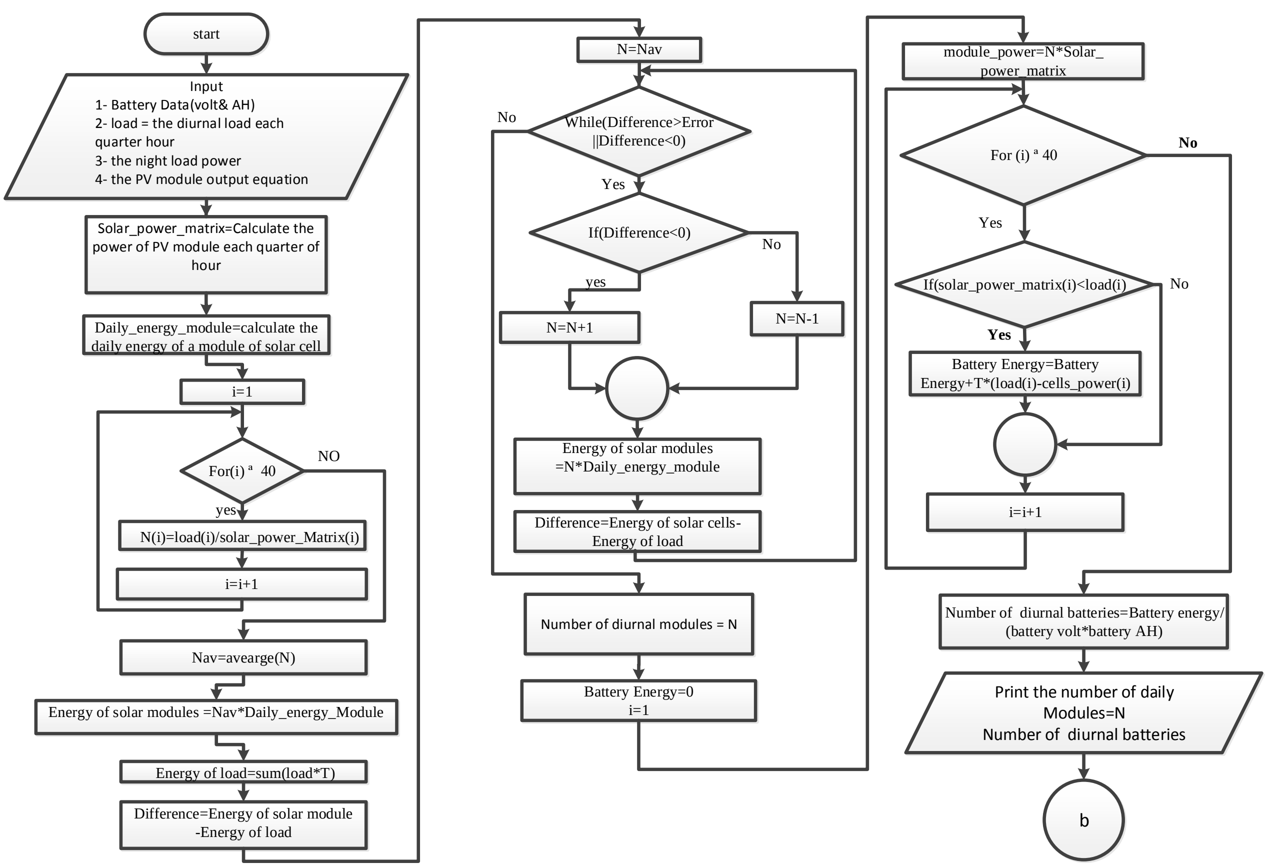

Fig. (3.a) the daily solar modules and batteries sizing

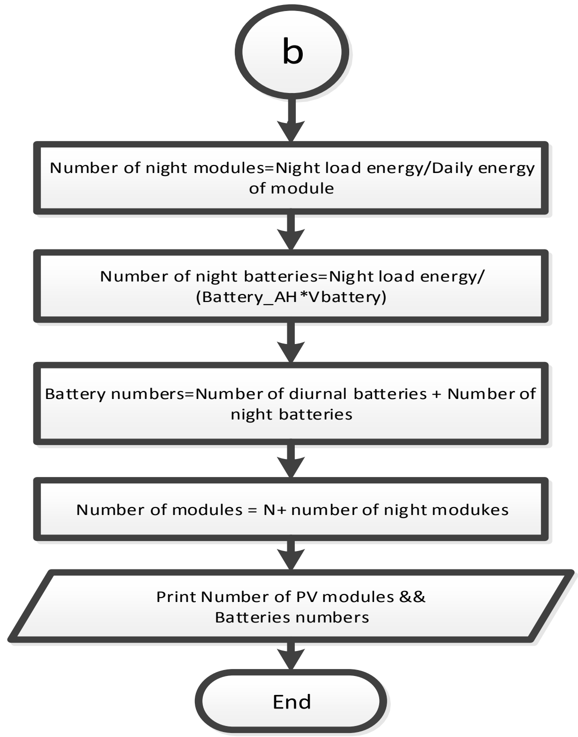

Fig. (3.b) The night solar modules and the night batteries followed by the system size

B. ENHANCEMENT OF THE PV SYSTEM PERFORMANCE

The main objective of the second phase of the proposed technique is to prevent the circulating current due to the unbalance of parallel batteries emfs and regulate the charging and discharging process. Self-equalizing system is proposed by connecting diodes with the batteries as in Fig. (4). the modules charge batteries and/ or supply loads through DC/DC step up converter and inverter in case of AC loads. The modules are connected in parallel with maximum power point voltage is nearly equal the batteries charging voltage (24-26 V). Reversed power diode is connected in series with each PV module to protect it from unwanted reverse current. The batteries are also connected in parallel strings; each one has two series batteries to reach 24 voltage levels. As illustrated in in Fig. (4), each battery string charges through separate charging diodes D1s, D2s and D3s respectively. On the other hand, each battery discharges lonely through the discharging diodes D1d, D2d, and D3d respectively. The fuses F1, F2, and F3 are used to protect batteries from the excessive current at short circuit conditions.

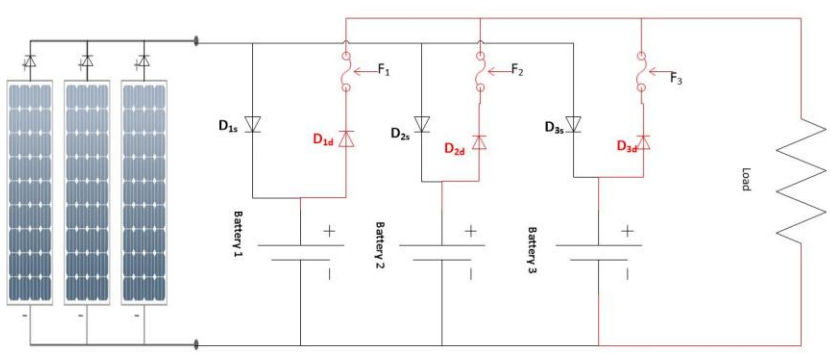

Fig. (4) Schematic diagram for the proposed connection of parallel batteries.

The proposed circuit connection does not only protect the batteries from circulating current but also regulates the charging and discharging between parallel battery strings. During charging periods, the low voltage (low charged) batteries is charged by a higher current. Conversely, the high voltage (high charged) batteries are charged by low currents. During discharging periods, the high charged batteries discharge high currents and the low charged batteries discharge low currents. This connection guarantees the self-equalizing to solve this problem with minimum cost and simple self-control.

APPLICATION

The proposed system was applied to a PV unit and loads present at Mansoura university, faculty of engineering. The data is indicated in the following section.

A. SYSTEM DATA

The load curve is estimated based on the Egyptian consumption domestic loads. A medium house is designed as an example load. The house has the electric devices which are rated in watts as per table (1).A PV solar cells array module of a poly crystalline type with of 250 W is used [9]. Each module is composed of 60 cells its dimensions are $(15.5\ cm \times 15.5\ cm)$ with an area 1m^2 $(167.5\ cm \times 96.1\ cm)$ and the maximum level of insolation is 1000W/m^2. The selected battery unit has 200Ah, 12V and 75% deep of discharge as a storage energy source.

Table. (1): The electric devices rated power.

Device	Watt	Device	Watt
Led lamp	9	Laptop	100
Led torch	60	Water heater	1000
Fan	120	Clothes washing	800
LCD-TV	200	Iron	700
Receiver	50	Mixer	300
Router	7	Water bump	750
Mobile charger	6	Ventilator	80
Refrigerator	110		

B. OPTIMUM PV SYSTEM CASE STUDY

The load curve of the medium house is firstly estimated by defining the individual load curve for each type of load as in Fig. (5.a) for twenty-four-hour period and sum them to deduce the predicted daily load curve of the total load as in Fig. (5.b).

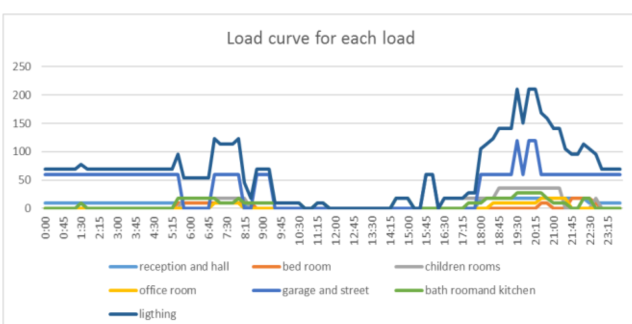

Fig. (5.a) The load curve for each type of load

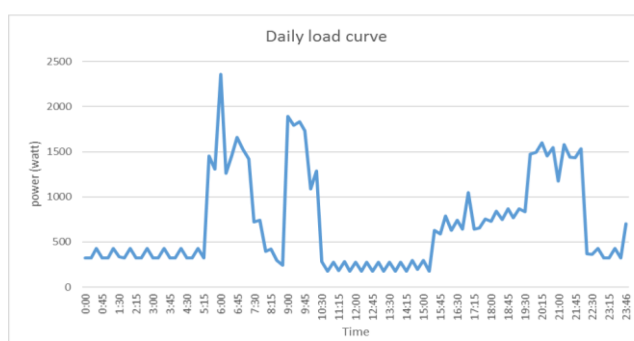

Fig. (5.b) the daily load curve

The I-V characteristics of the selected module are obtained from practical measurements at lab to obtain the maximum power points. The maximum power attained from the module is recorded referred to specific time and insolation level. Fig. (6) shows the relationship between the maximum power output of the module and the corresponding time during the sunshine period of a selected day.

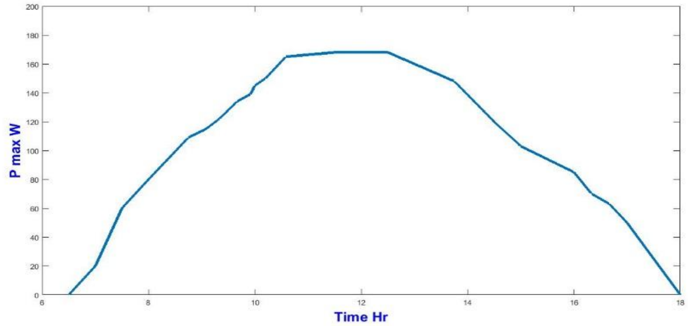

Fig. (6) the maximum power extracted from the PV solar module at one day

The area under the curve in fig. (6) is the maximum energy output from the module during the sunshine period per day. The maximum delivered energy is calculated using the developed program. The solar module used in the design has one-meter square area. The efficiency of the inverter, regulator and batteries are taken into the design consideration.

The proposed application results are shown in table (2) which illustrate the size of solar modules and batteries.

Table. (2): Optimum Sizing Results

Number of modules for daily load	9 modules
Number of modules for night load	15module
Total number of modules needed	24module
Number of batteries needed for night load	6 batteries
Number of batteries needed for daily load deficiencies	2 batteries
Total number of batteries needed	8 batteries

Moreover, the proposed method defines the daily periods of deficiencies and periods of surplus power originated from the daily solar panels. This can be used to manage loads by shifting the deficiency load periods to surplus periods which will lead to reduce the system size and reduce the cost. Fig. (7) displays the daily solar modules output power versus the daily load curve. As shown in Fig. (7.b) the periods of surplus and deficiency energy are determined.

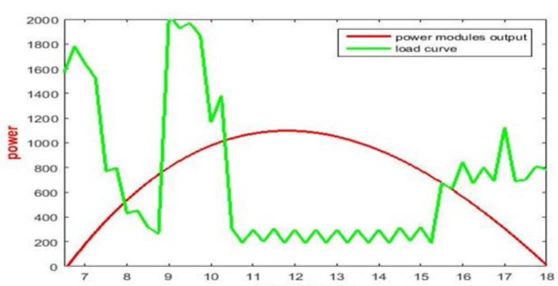

Fig. (7.a) comparison of the daily panels output power and the load curve.

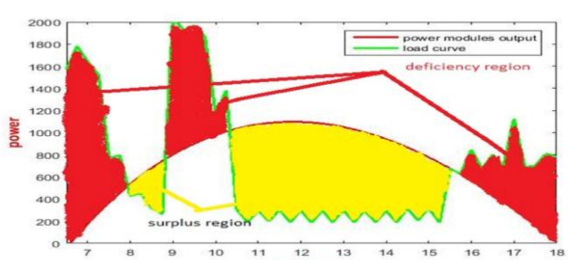

Fig. (7.b) the deficiencies and surplus regions

A. SIMULATION TEST FOR THE PROPOSED CONNECTION

To ensure the effectiveness of the proposed system connection, it is simulated using Proteus as in Fig. (8). Three states are studied; no load charging as in Fig. (8-a), discharging without connecting the source as in Fig. (8-b) and discharging with connecting the source as in Fig. (8-c). In case of no-load charging condition, the charging current is not the same for each battery which indicates 7.89, 4.06, 0.08 A respectively. In case of discharging without connecting the source condition, the discharging current from each battery has not the same value. In case of discharging with connecting the source condition, the batteries charging currents are 7.31, 4.56, 2.41 A respectively while the discharging currents are 1.88, 3.01,5.70 A respectively. It can be noticed from the previous three cases that the batteries with high charge discharge higher current as well as charge lower current and vice-versa. The system will reach a state of equalibrium between batteries and balance the battery emfs.

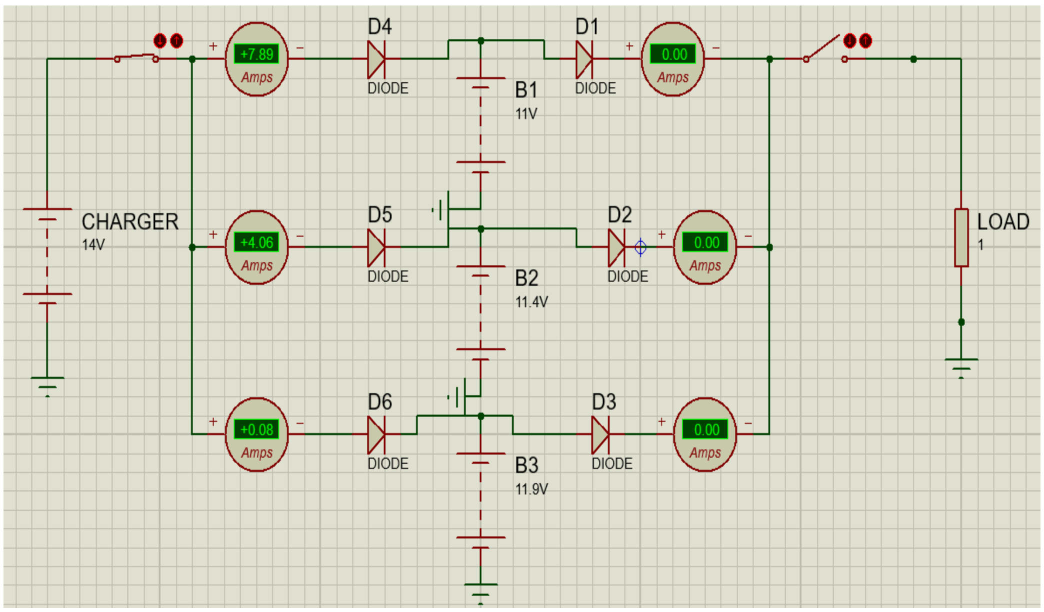

Fig.(8.a) The currents during charging periods.

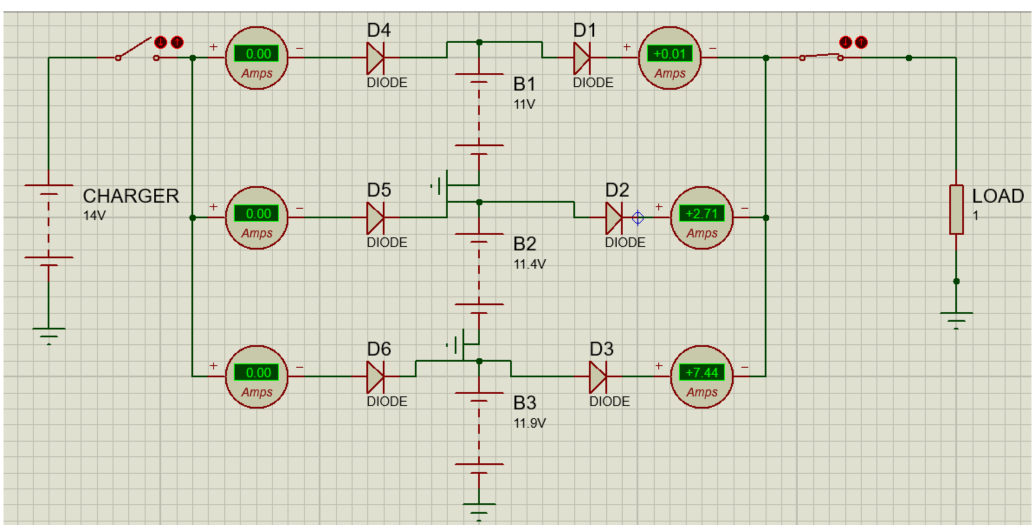

Fig. (8.b) The currents during discharging period.

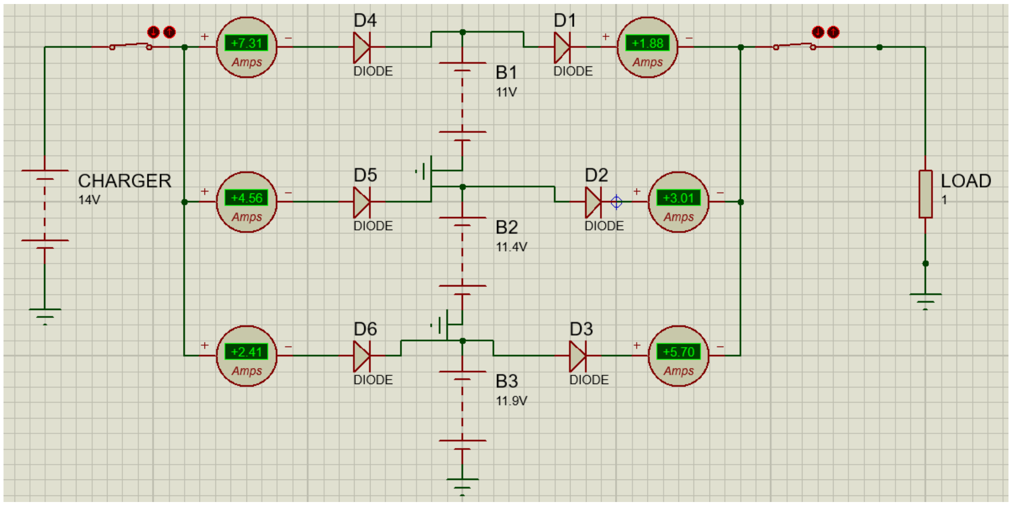

Fig. (8.c) The currents during the period when batteries charged and the load connected.

CONCLUSION

This paper proposed a new numerical technique based on the actual daily power curve of solar panels and the daily load curve of the burden. This technique could define the optimum size of PV modules and batteries by equating the deficiency and surplus of power for a day taking a calculation step each quarter of hour to have a precise result. For a load of energy 16.85 KWH/day, 24 PV modules and 8 batteries were selected when the deficiency equals surplus energy equals 4.36 KWH/day. This design got many advantages over the classical method as it could deal with the peak loads either in daily or night periods, it could define the precize sizing of PV modules and batteries leading to reduce the cost and could define periods of deffiency and surplus energy which can support in good mangement to the loads. On the other hand, the proposed connection scheme could prevent circulating current, self equalizing the batteries energy as the battery with a high charge will discharge more current faster than others and vice versa. It also protects batteries from high currents. To validate the proposed connection, a simulator was established using Proteus to test the batteries in different cases which proves efficient results.

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