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Experimental Based Method for Sizing Photovoltaic Power System Suitable for Cooling Greenhouses.

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EXPERIMENTAL BASED METHOD FOR SIZING PHOTOVOLTAIC POWER SYSTEM SUITABLE FOR COOLING GREENHOUSES

"طريقة عملية لتحديد منظومة فوتوفولتيه (خلايا شمسية) مناسبة لتبريد البيوت المحمية"

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هذا البحث يعرض طريقة جديدة مقترحة لتصميم نظام فوتوفولتي مناسب لتبريد البيوت المحمية. ولقد تم تركيب النظام الفوتوفولتي المصمم بالطريقة المقترحة في محطة بحوث السرو الزراعية بدمياط، بغرض إمداد منظومة التبريد بالطاقة الكهربية اللازمة لها من أجل تبريد بيت محمي (صوبه) منشأ لإنتاج محاصيل الخضر وخاصة محصول الخيار، والأبعاد الهندسية للبيت المحمي المراد تبريده هي 6 متر طول، 4 متر عرض، 2 متر ارتفاع. كانت درجة الحرارة داخل هذا البيت قبل تشغيل منظومة التبريد حوالي 50°، ويعتبر هذا المستوى من الحرارة داخل الصوبه ضار جدا بعملية إنتاج المحصول داخل البيت المحمي، وبالتالي يصبح من الضروري تصميم وإنشاء نظام فوتوفولتي لازم لإمداد منظومة التبريد بالطاقة بغرض تخفيض درجة الحرارة داخل البيت المحمي وذلك من أجل الحفاظ على المحصول وزيادة إنتاجه. ومنظومة التبريد التي تم اقتراحها من أجل تبريد البيت المحمي تتكون من مروحة وشفاط يتم تثبيتهم أعلى البيت المحمي في مستوى أفقي واحد ومقدار الطاقة اللازمة لتشغيلهم عبارة عن 1.7 كيلو وات ساعة يتم خلال اربع ساعات إنتاجها من النظام الفوتوفولتي الذي يتم تصميمه بالطريقة المقترحة.

هذا البحث يعرض طريقة جديدة وبسيطة لتصميم أي نظام فوتوفولتي يغذي أي حمل. وهذه الطريقة تقوم على نتائج معملية لدراسة الأداء الكهربي لمنظومة خلايا شمسية عبارة عن لوح واحد يتم اختباره في المعمل ويؤخذ كعينة يتم اختبارها وأيضا الأداء الكهربي لبطارية واحده من نوع البطاريات التي سيتم ربطها بالخلايا الفوتوفولتيه. وتعتمد هذه الطريقة أساسا على مبدأ بقاء الطاقة. يحتوي هذا البحث على الخطوات التفصيلية المقترحة وأيضا خريطة السريان اللازمين لتصميم أي منظومة فوتوفولتيه تغذي أي حمل.

ويحتوي هذا البحث أيضا على خرائط بيانية توضح نتائج الطريقة المقترحة وعن طريقها يتم استنتاج كلا من حجم الخلايا الشمسية المطلوبة وأيضا عدد البطاريات اللازمين للنظام الفوتوفولتي لتغذية أي حمل. ولقد تم نمذجة الخرائط البيانية رياضيا ووضعها في صورة نماذج رياضية وعن طريقها يتم أيضا الحصول على حجم الخلايا وعدد البطاريات المطلوبة لتغذية أي حمل. هذا وقد تم مقارنة النتائج المتحصل عليها بالطريقة المقترحة ومقارنتها بتلك المتحصل عليها بطريقة ناسا لتقييم الطريقة المقترحة ولقد وجد من النتائج أن تلك الطريقتين متطابقتين تماما. ولقد تم تحديد حجم الخلايا وعدد البطاريات اللازمين لإدارة منظومة تبريد البيت المحمي تحت الاختبار والقائم بمحطة بحوث السرو على النحو الآتي:

لوحين من الخلايا الشمسية كل منهم 75 وات، اثنان بطارية 80 أمبير ساعة من النوع الرصاص الحامضية.

Abstract

This paper presents new method for designing photovoltaic power system (PVPS) suitable for cooling the greenhouses. The designed PVPS is installed at Serw station at Domietta for cooling cucumber crop. The greenhouse, under test has the geometrical configuration of, 6m length, 4m width and 2m height. The indoor temperature of the greenhouse is 50°c before cooling. This level of temperature has a harmful effect upon the cucumber. Hence, the cooling system must be installed for increasing the mass production of the crop within the greenhouse. PVPS is designed to operate the cooling system contains one blower and a fan, they require electrical energy of 1.7KWhr. This paper illustrates new method for designing the PVPS. The proposed method is based upon the experimental behavior of one module of solar cells array and lead acid battery. The method strategy depends upon the energy balance principle. An algorithm and flow chart illustrate the design steps are built up. Graphical charts and mathematical model are obtained to determine the array and battery size required for supplying the previous load (1.7 kWhr). Consequently, the charts obtained can be used for designing any small PVPS system provides desired load. The results obtained by the proposed method are compared with that obtained by the famous method (NASA method). The paper presents that the two methods are approximately identical. The tested greenhouse requires PVPS of 2 modules 75 W peak each and two batteries of 80 Ahr lead acid battery.

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1- Introduction

A typical PVPS consists of SCA, battery storage, power conditioner and load [1]. The optimum design of PVPS components is very important for economic considerations.

The sizing procedure for PV systems by simulating the system operation allows one to optimize the size of the PV generator [2]. Another method for optimizing the sizes of PV array and the battery in PV systems with short-term energy storage is based on maximizing the utilization of the array output energy, and minimizing losses associated with charging and discharging the battery [3]. The designed PVPS has wide applications in greenhouses. In these houses the cooling system has a significant effect in mass production especially in summer season. The PVPS can be designed for supplying cooling system interconnected as a load with the PVPS. Tow typical methods of cooling are used in summer. The first method is to reduce the light intensity passing through the greenhouse. The second and most effective method of greenhouse cooling is accomplished by using an evaporate cooler [4]. Another method used or cooling the greenhouse is the ventilation process. Ventilation means the exchange of inside air for outside to control temperature, remove moisture or replenish carbon dioxide (CO_2) [5]. The ventilation system can be loaded in the designed PVPS with suitable size. In this paper new accurate approach for sizing SCA, and energy storage elements of PVPS based upon experimental measurements of maximum power output of a sample of SCA module is represented. Comparison between this approach and NASA method is illustrated [6]. The new approach can be used in different sites for all sizes of PVPS. This new method is more economic because it has not any proposed factors and only depends on experimental measurements. Suitable design of PVPS is applied for cooling greenhouse located at El-Serw research station in Domitta, Egypt. The cooling system gives an important effect in the mass production.

2- The Proposed Method for Sizing Solar Cells Array

For obtaining the optimum size of SCA required for supplying a specific load, a proposed plane for measurements is built up. The required measurements are the maximum power output of a sample of SCA represented by one module. The determination of SCA size depends upon the last measurements.

2.1. Experimental Measurements

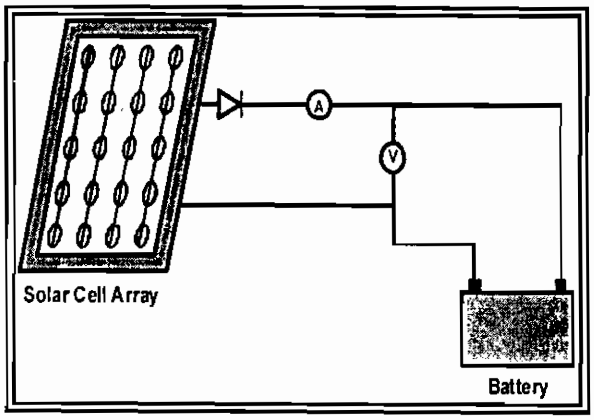

Figure 1-Connection Diagram of Testing System.

The experimental measurements required for accurate sizing of SCA supplying load are carried out in solar energy laboratory of faculty of engineering, Mansoura University. *Figure 1* represents the connection diagram of the elements used in the experiment. The, first of all is the obtaining of the I-V characteristics of the tested module of PVPS. The figure declares that, the maximum power output of the module is at 12.5 volt. Consequently, lead acid battery of 12 volt is selected with any capacity to connect with the system. The battery is connected across solar cells module terminal and the battery charging current and voltage are recorded at different insolation during sunshine period of a specific day. The module output (I, V) represents the current and voltage as shown in Fig. 3. Then, the module output power and the voltage at different levels of insolation are calculated and illustrated in Figure 2.

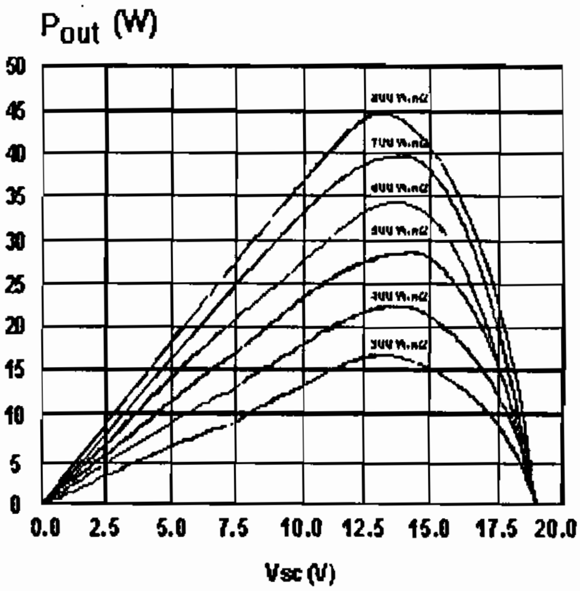

Figure 2- Variation of Output Power against Voltage of SCA.

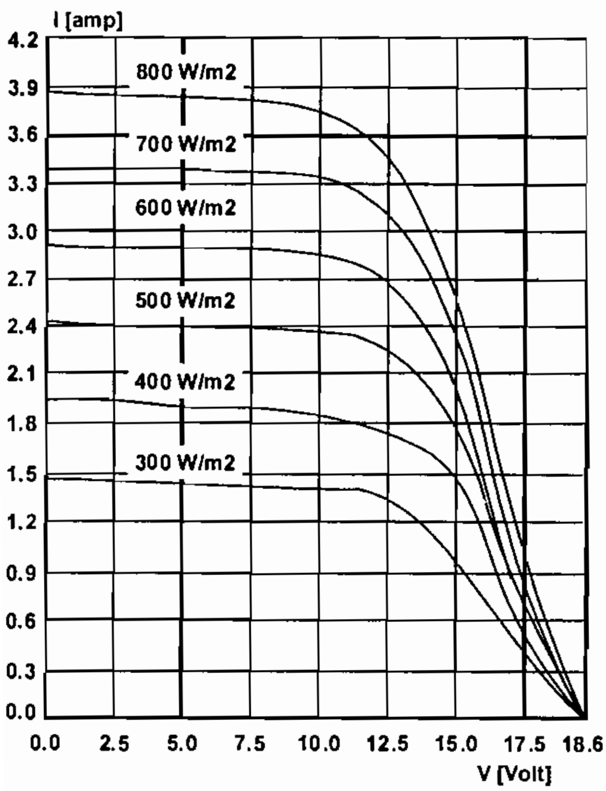

Figure 3-I-V Characteristics of SCA under Test.

The SCA coupled with the PV system is tested in the laboratory. Its behaviors are investigated in Figures 4, 5.

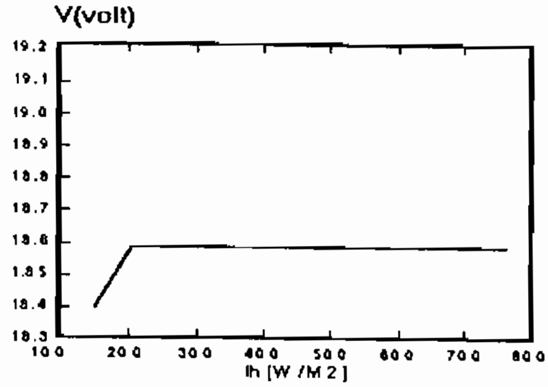

Figure 4- Open circuit voltage of SCA against insolation level.

Figure 4 illustrates the relationship between the open circuit voltage of SCA and the insolation level of the array under test while the array short circuit current and the intensity of the insolation incident upon the SCA is shown in *Figure 5.*

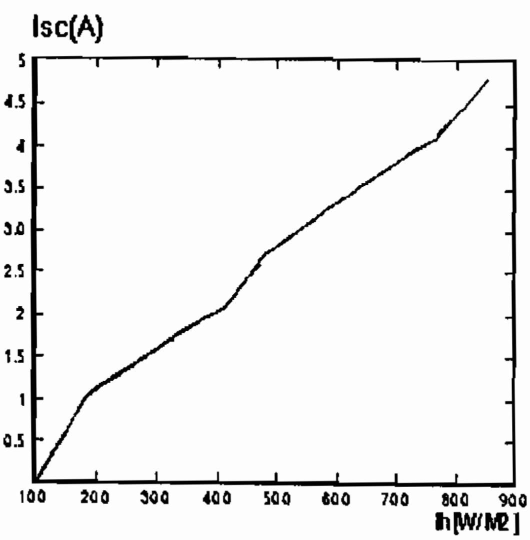

Figure 5-Array Short Circuit Current against Intensity of Insolation

3. Algorithm of the New Approach

The first step of array sizing is a selection of a load. A constant load is used of P_L kw but this method can be used with variable loads. The designed SCA is divided into two parts, the diurnal and night arrays.

The diurnal arrays are those supplying load during sunshine period. These arrays are directly supplied load during some of time of sunshine periods and providing load through storage during the remaining time. On the other hand, the night arrays supplied battery storage during sunshine period. The flowchart represents the algorithm steps are shown in Figure 6.

Algorithm steps:

1) The input data to the computer is the maximum output power of the tested module at different insolation levels.
2) Load data during 24 hours.

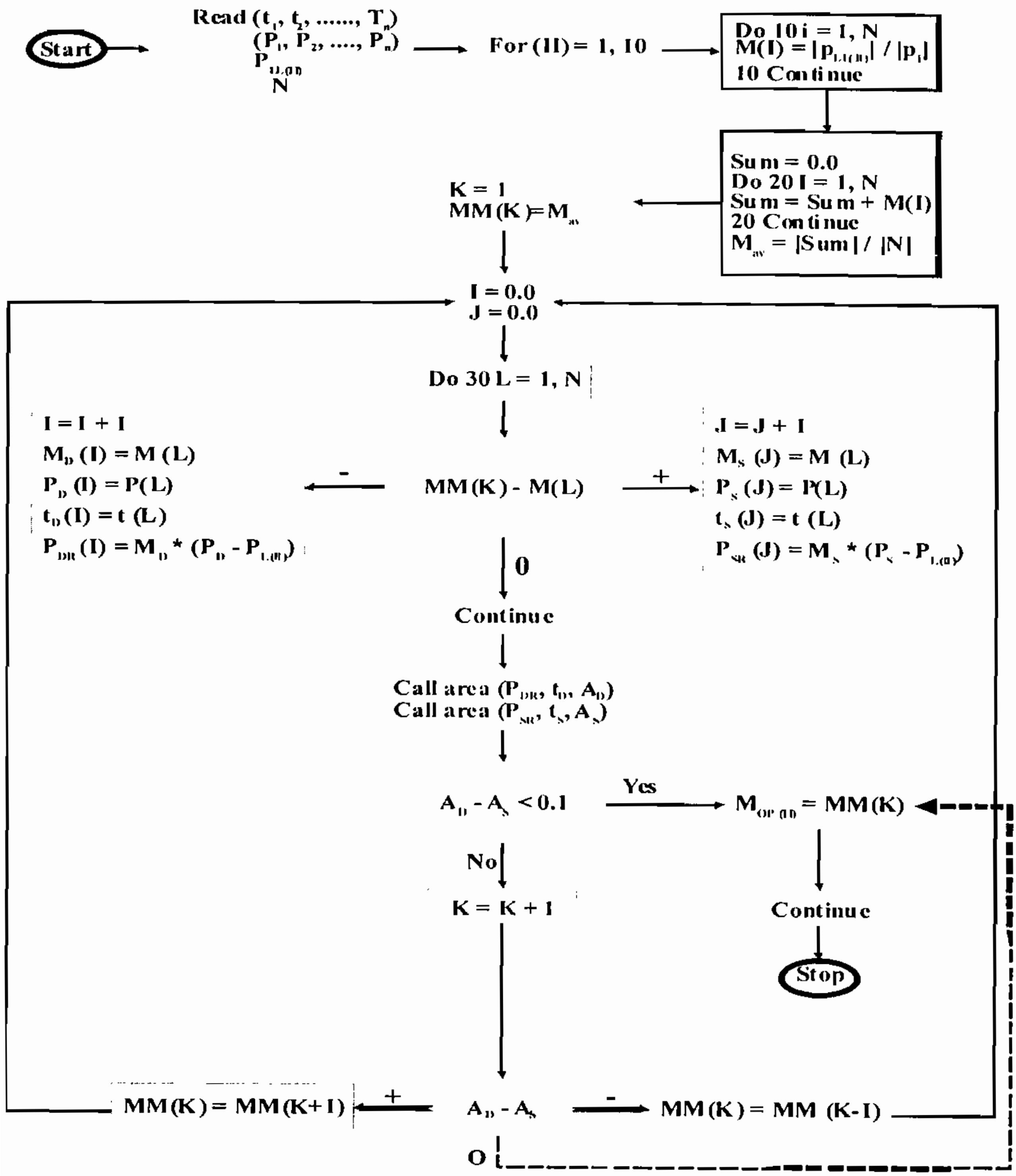

Figure 6-Flow Chart of PVPS Sizing.

3) Estimate the required number of modules (similar to the tested module) at different instants during sunshine period.
4) Obtain the average number of modules.
5) Determine the surplus and deficit energy.
6) Compare between the two energies (surplus and deficit).
7) Increase or decrease the number of modules according to the result of the previous steps.
8) Repeat step "7" until the surplus energy equals to the deficit.
9) Obtain the optimum number of modules achieves the last step.
10) The total number of modules equal to the optimum number obtained plus the required number supplying the load during the night periods.
11) The optimum short term battery capacity equals the energy deficit or surplus.
12) The capacity of the whole energy storage system is equal to the short term capacity and long term battery capacity where the long term battery capacity is referred to the battery required for feeding the load at night which equal to the energy required by the load at the night.

4. Sizing of Diurnal Arrays

The proposed procedure used for obtaining the optimum size of SCA depending upon the previous data is illustrated in the following items;

4.1. Obtaining of Instantaneous Size (Mi).

The instantaneous size of SCA represents as the number of modules similar to the tested one. These modules are required to feed directly the load at each instant of sunshine period. At instant (i), the number of modules Mi required is,

$Mi = (P_L) / [(P_{mi}) * (\zeta_B) * (\zeta_{P.C}) * (DoD)]$ (Module) (1)

For i = 1, 2, 3 ...n

Where;

P_{mi} : is the maximum power output of SCA referred to instant i (calculated),

n : is the number of instants at which P_{mi} are measured.

P_L : is the power required by the load, during calculations P_L represents constant value at each instant t,

ζ_B : is the battery efficiency and is equal to 80%,

$\zeta_{P.C}$: is the power conditioner efficiency and is equal to 90%.

DoD : is the battery depth of discharge and is equal to 5%.

The required modules are calculated for each instant i, then the average one, Mav, is determined.

$$Mav = (\sum Mi) / (n) \quad (2)$$

If the average size of SCA is installed at the site, there will be deficit of energy during some instants. And surplus during the remaining instants. The surplus one does not equal to the deficit of energy.

4.2. Obtaining of Optimum Size.

The comparison between energy deficit and the surplus one gives an indication for increasing or decreasing the SCA size from its average, Mav. If the deficit of energy becomes more than the surplus energy, the SCA size must be increases by an amount to reach the optimum one. The optimum size achieves that the energy deficit equals to the surplus energy. On the other hand, if the energy surplus is more than the energy deficit, the SCA size must be decrease to reach the last condition.

4.3. Diurnal Battery Size Bd

Because of the shortage of surplus energy during sunshine period, the existence of diurnal energy storage system becomes very important. The capacity of this storage must be equal to the amount of surplus or deficit of energy (energy deficit = surplus energy).

5. Sizing of Night Array

The determination of array size that is required to storage energy at night. This size can be calculated as follows;

$$M_n = (P_L * t_n) / (E_m * \zeta_B * DoD * \zeta_{P.C}) \quad (3)$$

Where;

M_n : number of modules (similar to sampled module) that will be used to storage energy at night,

P_L : load in w,

E_m : output energy of sampled module during the selected day,

t_n : number of night hours (number of hours during night period + number of hours through which low levels of insolation are obtained).

5.1. Sizing of Night Battery

The battery required for feeding night load must be selected to satisfy the following equation;

$$B_n = (P_L * t_n) / (\zeta_B * \zeta_{P.C} * DoD) \quad (4)$$

5.2. Sizing of Photovoltaic System

The total size of SCA is;

$$M_{to} = M_D + M_n \quad (5)$$

Where; M_{to} : is the optimum size of SCA supplies the load during all day period (24 hours).

M_D: is the optimum number of modules output from the program.

$$Bt_{oe} = B_n + B_d \quad (6)$$

Where;

Bt_{oe} : represents the optimum capacity of energy storage required for supplying the load during all periods.

6. Nasa Method

The sizing of SCA is achieved also by NASA method [10]. Then the comparison between the two methods is obtained.

The NASA method depends upon tables contain average monthly insolations, $\bar{I}$, and the ratio between standard insolation, S, and average insolation, $\bar{I}$, at specific clearness factors KH, at different latitude angles from zero to 60°. While array tilt angle either equal to the latitude or equal to latitude plus 10°. The design procedure using the method is described as follows:

1-Select the clearness factor for the selected month KHm. Adjust the tilt angle of the array equal to the latitude angle of the mounted site.

2- Select two clearness factors from tables one of which greater than KHm, KH_{mg} and the other is lower than KH_m, KH_{mL}. The average insolation at KH_{mg} and KH_{mL} is obtained as follows;

$$\bar{I}_{KH\,mg} = \{\bar{I}_{LL} + (I_{Lg} - I_{LL}) * (L^\circ - L^\circ_L)\} / \{L^\circ_g - L^\circ_L\} \quad (7)$$

$$\bar{I}_{KH\,mL} = \{\bar{I}_{LL} + (I_{Lg} - I_{LL}) * (L^\circ - L^\circ_L)\} / \{L^\circ_g - L^\circ_L\} \quad (8)$$

Where;

KH_{mg}, maximum clearness factor of the selected month.

KH_{ml}, is the lower clearness factor of the month.

$\bar{I}KH_{mg}$, $\bar{I}KH_{ml}$, are the average monthly insolation referred to the greater clearness factor and the lower one respectively.

Lg and LL are the greater and lower latitude angle.

The average daily insolation at selected clearness factor, KHm is;

$$\bar{I}_{KHm} = \bar{I}_{KH\,mL} + (\bar{I}_{KH\,mg} - \bar{I}_{KH\,mL})(KH_m - KH_{mL}) / (KH_{mg} - KH_{mL}) \quad (9)$$

3. The ratio R is also obtained by the NASA tables as follows;

$$\acute{R}_{KH\,mg} = \{\acute{R}L_L + (\acute{R}L_g - \acute{R}L_L) * (L^\circ - L^\circ_L)\} / \{(L^\circ_g - L^\circ_L)\} \quad (10)$$

$$\acute{R}_{KH\,mL} = \{\acute{R}L_L + (\acute{R}L_g - \acute{R}L_L) * (L^\circ - L^\circ_L)\} / \{(L^\circ_g - L^\circ_L)\} \quad (11)$$

Where;

$\acute{R}_{KH\ mg}$, $\acute{R}_{KH\ mL}$ are the ratios at greater and lower clearness factor.

The ratio $\acute{R}_{KH\ m}$ at the selected clearness factor is;

$$\acute{R}_{KH\ m} = \{\acute{R}_{KH\ mL} + (\acute{R}_{KH\ mg} - \acute{R}_{KH\ mL})\ (KH_m - KH_{mL})\} / \{(KH_{mg} - KH_{mL})\} \quad (12)$$

4. The standard deviations, for the selected month is obtained as;

$$S = \bar{I}_{KH\ m} * R_{KH\ m} \quad (13)$$

5. The array area feeds specific load P_L becomes;

$$A = \{(P_L * 24)\} / \{(\zeta_{PV} * (\bar{I}_{KH\ m} - M * S)\} \quad (14)$$

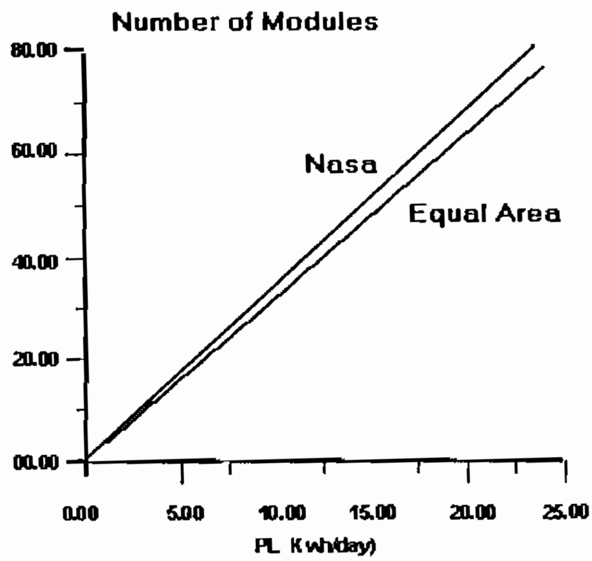

Figure 7-Optimum Number of Modules against Load.

ζ_A: is the solar cell array efficiency and M is constant selected as 0.33.

6. The number of modules (similar to the tested one is determined as);

$$M_{to} = (A) / (\text{area of tested module}) \quad (15)$$

7. The capacity of energy storage system is determined by obtaining the storage time, C, this time is determined from NASA *Figure* by the aid of M and $R_{KH\ m}$ thus;

$$Bt_{on} = (C) / (P_L * 24) \quad (16)$$

Where;

ζ_{PV} : is the efficiency of PV system which is obtained as;

$$\zeta_{PV} = \zeta_A * \zeta_B * \zeta_{P.C}$$

Where;

7. Comparison between the Two Methods

The results obtained by the two methods are represented in the following figures.

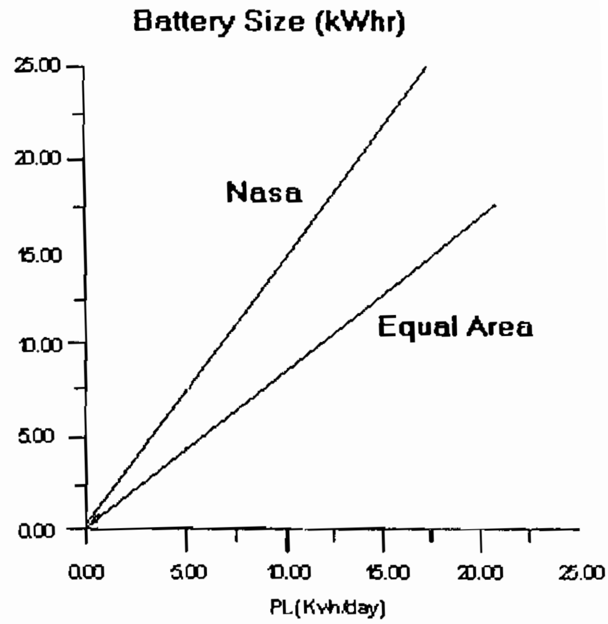

Figure 8-Optimum Battery Size against Load

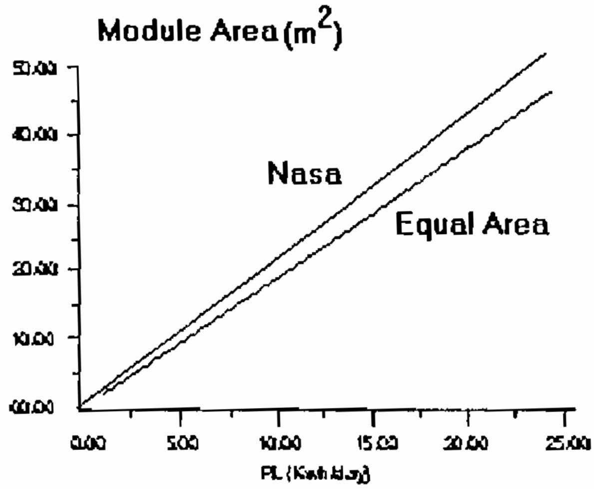

Figure 9-Tested Module Areas against Load.

The calculated data obtained by the proposed are graphically presented and mathematical models are obtained.

Figure 7 illustrates the optimum number of modules required for supplying different load size for specific month. The selected month used for the comparison between the two methods is August. The Figure shows that the number of modules required for supplying specific load by equal area less than that obtained by using NASA method. For instance, the number of modules obtained by equal area method required for supplying the load of 24KWhr is 77 modules. On the other hand, the number of modules required for feeding the same previous load designed by NASA method is 84 modules.

Figure 7 which shows the relationships between the optimum numbers of tested modules against load in kWh can be modeled mathematically in the following form.

$$MtOe = 3.19689 * PL + 0.0991679 \quad (17)$$

Where;

PL : is the load inKWhr and Mto is the optimum number of modules similar to the tested one obtained by the equal area method. The relationships between the number of modules obtained by NASA method and the load are in the form of;

$$Mt_{On} = 3.46856\, P_L + 0.0111535 \quad (18)$$

The two equations show that the slope of the equation (18) is greater than that of equation (17). So, NASA method is not economic. The tested module has an area of 0.6 m2. Figure 9 gives the optimum area of SCA in m^2 required for supplying specific loads obtained by equal area and NASA methods.

The battery size which is required for supplying the load during night and periods of low insolation is determined also by equal area and NASA method. Figure 8 gives the relationship between the optimum size of battery and the load in kWhr. The slope of the line represents equal area method is less than that illustrated by Nasa method.

The mathematical models describe the battery size by equal area and Nasa method are written as:

$$Bt_{oe} = 1.84858 * P_L + 0.00390099 \quad (19)$$

$$Bt_{on} = 2.042113 * P_L + 0.000497 \quad (20)$$

Where Bt_{oe}, and B_{ton} are the optimum battery size required for feeding the diurnal and night loads.

There is a slight difference of the slope of the two models.. The equal area method depends upon actual data obtained from the test of one module of SCA. Conversely, the NASA method depends upon tables and Figures and an interpolation for obtaining the data required for the design. Besidly, the average daily insolation incident upon the tilted module by 31.2° and oriented towards the equators at Mansoura city measured as 4.587 kWh / m2. Conversely its calculated value by NASA method is 6.48. This means that the results obtained by the two methods are quite different from each other.

8. Practical Application of the Proposed Sizing Method

In serw research station, there is a problem in the electricity supply required for cooling greenhouses under research. The greenhouse is used for producing some vegetables crops (tomato, paper and cucumber). The using of greenhouses technology is very important for mass production. On the other hand, the greenhouses suffer from a large problem. This problem is related to the cooling phenomena, especially in the summer season. Hence, the greenhouses need suitable energy source required for cooling it especially in summer season. The most suitable energy supply connected with the cooling system of the greenhouses is the photovoltaic power system. The proposed method is used for sizing the PVPS supplying cooling system required for a greenhouse located in serw research station. The greenhouse under test has geometrical configuration of 6 m long, 4 m width and 2 m height.

The cooling system is composed of one blower of 30 cm diameter with 5.1A, 12V and 8000 rpm and one circular fan of 30 cm diameter, 6 fins, 1/2HP and 10000rpm.

The fane and blower are located in the same horizontal plane within the tested greenhouse as shown in Figure 13. The photovoltaic system required to supply the greenhouse cooling system is designed from the models of the proposed method according to the cooling system load is 434.2w. The system is operated from the noon instant to 4 hours after the noon instant. Hence, the energy required for the cooling system is 1.7368KWhr.

Consequentially, the number of modules required is two modules. The required energy storage system (battery) is sized from fig. (9) as (2.7KWhr).

The solar cells array designed for cooling the greenhouses contains two modules each of which contains 36 grided solar cells single crystalline silicon of 75 WP. The WP of the module means that WP= V_{oc} * I_{sc} mx.

Where;

V_{oc}mx and Iscmx are the maximum module open circuit voltage and short circuit current at maximum insolation level received by the module (1000 w/m^2). On the other hand, the battery used within the designed PVPS required for cooling process of the greenhouses has specification of, lead acid type, 12V, 80 Ahr.

The cooling system is operated and the temperature inside the greenhouses is recorded as shown in Figure (10). The figure shows that a very large decreasing in the temperature inside the greenhouse occurs during the first 20 minutes, after that the temperature remains constant such that the indoor temperature becomes larger than that the outdoor by only 1°c. Hence, the cooling system achieves the purpose of constructing it.

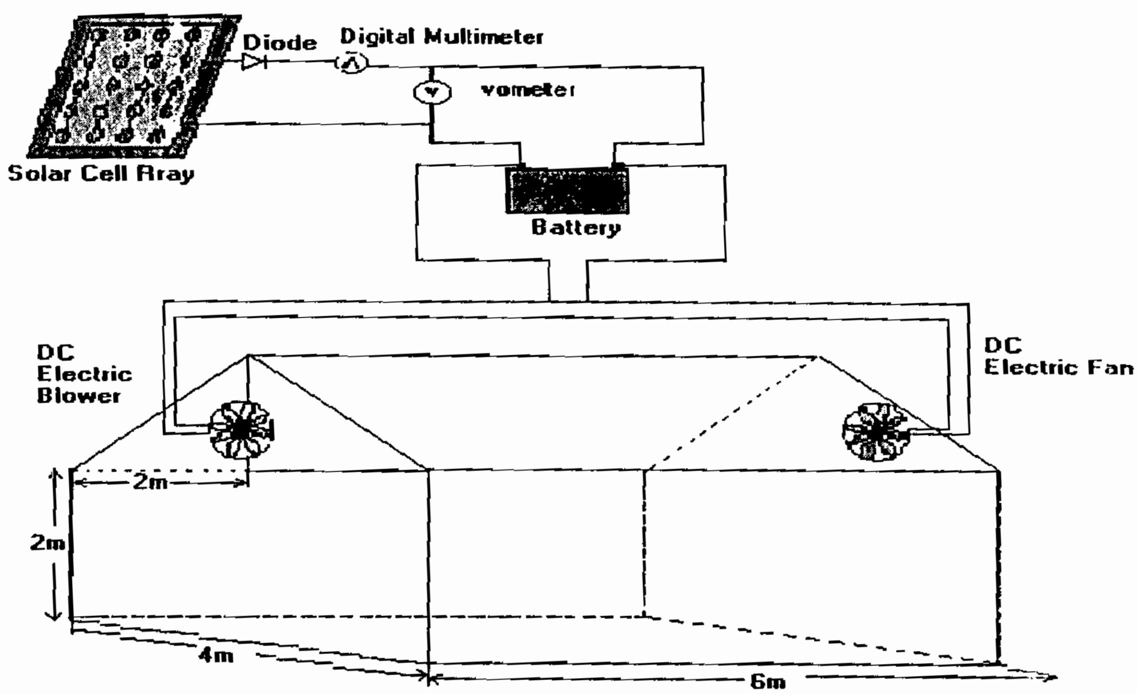

Figure 14-Relationship Between the temperature inside greenhouses and the time measured from Noon instant