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OPERATING WIND GENERATOR WITH ALTERNATIVE RENEWABLE ENERGY SOURCES TO SUPPLY ISOLATED LOADS

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ABSTRACT

The energy output of a wind generator (WG) variable due to the variation of wind speed at the installation site through the day hours and year months. Therefore, a back-up power supply (BUPS) is necessary for operating WG to supply isolated loads. This BUPS may be diesel generator or/ and alternative sources of renewable energy system (RES) which are available at the installation site. The diesel generator as a BUPS with WG to supply isolated loads had been studied in previous publication.

In this work, alternative of RESs are studied and assessed as a BUPS for operating with WG to supply isolated loads. These alternatives are photovoltaic power system (PVPS) or/ and battery storage (BS). So, a hybrid model is presented here incorporates the added futures of dynamic modeling and graphic user interface in the power system block set and matlap program to assess the capacity of these BUPSs for operating with WG to supply isolated loads. Also, an economical model has been introduced to optimize the considered BUPSs from economical point of view. These models are applied numerically to estimate the capacity of alternative of WG/ BS and WG/ PVPS/ BS generation systems to supply an isolated load of a tourist village on the Egyptian coast of Red Sea. Also, these alternatives are optimized economically to supply the load study.

تتغير الطاقة الناتجة من مولدات طاقة الرياح نظرا لتغير سرعات الرياح خلال ساعات اليوم وفي شهور السنة المختلفة لذلك يحتاج مولد طاقة الرياح إلى مولدات أخرى لتوليد الطاقة الكهربية لتغذية الأحمال المطلوبة. وتشمل هذه المولدات مولدات الكهرباء التي تعمل بالديزل ومصدر أو عدة مصادر من مولدات الطاقة المتجددة. وقد تم في هذا البحث دراسة استخدام مصدر الطاقة الشمسية الفوتوفولية والبطاريات التي يتم شحنها من هذا المصدر أو من مولدات طاقة الرياح لتعمل مع مولدات طاقة الرياح لتغذية الأحمال المنفردة, لذا تم اقتراح نموذج راضى يعتمد على المتغيرات في معادلة توليد الطاقة الكهربية من مولدات طاقة الرياح و الطاقة الشمسية الفوتوفولية بالإضافة إلي منحنى الحمل المراد تغذيته من هذه المولدات لتصميم منظومات منها لتغذية الأحمال المنفردة. كما تم اقتراح نموذج اقتصادي لحساب تكلفة الطاقة من هذه المنظومات. وبتطبيق النماذج المقترحة تم تصميم منظومتي توليد، الأولى تحتوى على مولدات طاقة الرياح وبطاريات يتم شحنها من هذه المولدات، والثانية تحتوى على مولدات طاقة الرياح ومولدات الطاقة الشمسية الفوتوفولية مع البطاريات وذلك لتغذية حمل كهربى لقرية سياحية على شاطيء البحر الأحمر في مصر (الغردقة). كما تم حساب تكلفة وحدة الطاقة الكهربية الناتجة من هاتين المنظومتين وذلك لاستخدامهما في تغذية أحمال هذه القرية، وذلك لعمل مفاضلة اقتصادية بينهما وبين تكلفة الطاقة الناتجة من مولد كهربي يعمل بالديزل ويستخدم في تغذية هذه القرية الآن.

1. INTRODUCTION

Egypt is endowed by huge wind energy potentials where the coastal areas particularly the Red Sea Coast and the South Western parts of the country have high wind velocities reaching 10 m/s and 7 m/s respectively. Wind resources in coastal areas of Egypt have proven to be feasible both for mechanical pumping and electricity generation. Several organizations have directed efforts towards utilization of such resource [2,3].

However, for small single village applications hybrid photovoltaic power systems (PVPSs) may play an economical role, particularly when used in combination with other technologies in a hybrid scheme and when adequate power storage is available. PVPS in hybrid systems can be the most cost-effective solution in some situations, such as when the costs of diesel fuel delivery increase fuel prices by 15–50% [4,5].

Correct sizing of remote area power system (RAPS) systems is very important, particularly if wind or solar energy is used. If the system is too small, power shortages will be experienced and the batteries may be damaged by excessive discharge. If the system is too large it will be unnecessarily expensive. The size of the system is dependent on the electrical load. The availability of wind and solar energy will also determine the size and type of system used. Suppliers of RAPS systems generally have methods of designing a system to meet each user's specific needs [6, 7].

In this work, hybrid system of wind generator, photovoltaic power system or/and battery storage has been designed and operated to supply isolated load at an site of Egypt using a suggested design model. Also, an economical model is presented to optimize different alternatives of this hybrid generation system.

2. OPERATING WG WITH ALTERNATIVE RESs:

Many of renewable energy sources (RESs) may be used with wind generators (WGs) as a backup power source (BUPS). The most convient types of these RESs are photovoltaic power system and storage batteries. So, alternative generation systems of WGs and these resources may be installed to supply isolated loads. These systems are:

Alternative I: Wind generator /BS generation system, Figure (1).

Alternative II: Wind generator / PVPS / BS generation system, Figure (2).

The WG generation curve can be used with the load curve at the study site to assess the capacity of BS and sizing the photovoltaic array for PVPS.

Alternative I:

In this case the battery charged from WG when; $P_{WG}(i) > P_L(i)$. Also, the capacity and charge / discharge cycle of BS are depending on both of wind generation and load curves.

To assess the capacity of these BUPS, the following load balance equation may be stated:

$$P_{WG}(i) \pm P_B(i) = P_L(i) \quad (1)$$

Where; $P_{WG}(i)$, $P_B(i)$ are the hourly power supplied by WG and BS, and $P_L(i)$ is the hourly load demand.

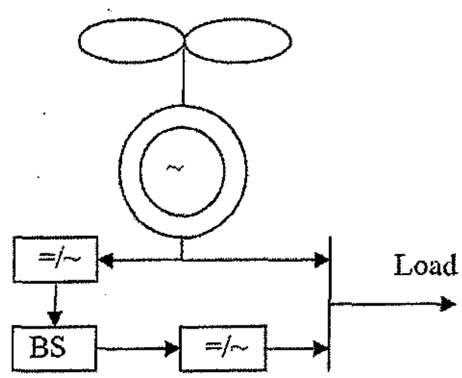


Fig (1) Line diagram of WG/BS generation system.

Hence, the energy supplied to the load by this battery (E_{BS}) is:

$$E_{BS} = E_{GW} - E_L \quad (2)$$

Where, E_{WG} and E_L are the output energy of WG and energy requirement for the load respectively. At the –ve sign of E_{BS}, the BS is in discharge case and +ve sign it is charged.

The capacity of BS in this case is given as a function of overall efficiency of BS (η_{BS}) and consists of long-term BS capacity (LTBS) and short-term BS capacity (STBS). These capacities are developed as following:

$$STBS = E_{def}(m)_{max} / \left[N_{cd}(m) * \eta_{BS}\right] \quad (3)$$

$$LTBS = \left[\sum^{m} E_{def}(m) \Big/ \eta_{BS}\right] - STBS \quad (4)$$

$$BS = STBS + LTBS \quad (5)$$

Where:

$E_{def}(m) = E_{WG}(m) - E_L(m)$ at $E_L(m) > E_{WG}(m)$, and

$E_{WG}(m)_{max}$, $E_{WG}(m)_{min}$: the monthly maximum and minimum output of WG

$[E_{WG}(m) - E_L(m)]_{max}$: the maximum difference between WG output and load demand through the month m of the year ($E_{def}(m)_{max}$).

$N_{cd}(m)$: the number of charge-discharge cycles through the month m.

The unit energy cost (UEC_1) of WG/ BS generation system may be developed as a function of economy of WG and BS. These economies are developed as followings:

The annual capital cost (ACC_1) of this system is:

$$ACC_1 = ACC_{WG} + ACC_{BS} \quad (6)$$

Where; $ACC_{WG} = DR_{WG} * C_{WG} * P_{WG} \quad (7)$

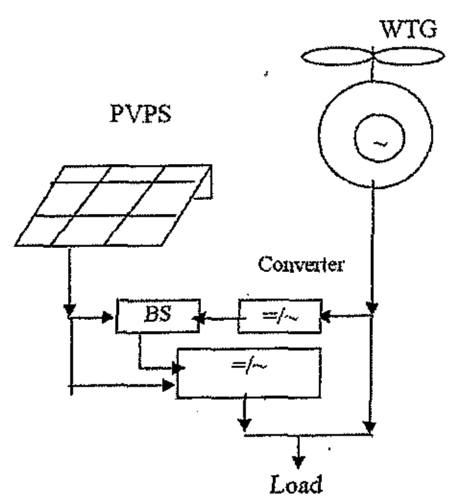


Fig (2) Line diagram of WG /PVPS/BS generation system.

$$ACC_{BS} = DR_b * C_b * CB \quad (8)$$

, and P_{WG} is the rated power of WG, CB is the capacity of BS, C_{WG} is the capital cost of 1 kW of P_{WG} ,C_B is the capital cost of 1 kWh of BS, and DR is the annual discount rate which is depend on the interest rate (r) and life time(n) of both of WG and SB. This DR is given by [8]:

$$DR = r(1+r)^n / \left[(1+r)^n - 1\right] \quad (9)$$

The annual operation cost (AOC_1) of WG/BS system is stated as:

$$AOC_1 = AOC_{WG} + AOC_{BS} \quad (10)$$

Where; $AOC_{WG} = b_W E_{WG}$ (11)

$$AOC_{BS} = m * ACC_{BS} \quad (12)$$

Where; b_w is the operation cost per 1 kWh of E_{wg} , and m is a percentage of capital cost of storage battery. Thus, the total annual cost (TAC_1) and UEC_1 of this system are:

$$TAC_1 = ACC_1 + AOC_1 \quad (13)$$

$$UEC_1 = TAC_1 / E_L \quad (14)$$

Where;

$$E_L = \sum_{i=1}^{8760} P_L(i)$$

Alternative II : At deficit generation of WG through the sunshine periods, the load is supplied from a PVPS in this case. While the battery storage is charged by either of WG or/and PVPS. So, Eqn. (1) is modified as:

$$P_{WG}(i) + P_{pv}(i) + P_{bs}(i) = P_L(i) \quad (16)$$

Also, the annual energy supplied of PVPS ($E_{pv}(a)$) is developed as a function of the annual electric generation of WG and load demand during the sunshine periods as :

$$E_{pv}(a) = \sum^{t_s} P'_L(i) - P'_{WG}(i) \quad (17)$$

Where:

$$E_{pv}(a) = E_{pv(d)}(a) + E_{pv(s)}(a) \quad (18)$$

, and *$E_{pv(d)}(a)$ and $E_{pv(s)}(a)$ are the annual energy* supplied directly to the load and from BS charged by PVPS. $P'_L(i)$ and $P'_{WG}(i)$ are the hourly load demand and wind generation through the annual sunshine hours t_s.

The array size of PVPS to generate $E_{pv}(a)$ is developed from the deficit generation of WG to satisfy the energy requirement through the sunshine periods of the year months, monthly solar radiation received on this array, $H_t(m)$, at the installation site and the efficiencies of PV array (η_c) and power conditioner (η_{pc}). The monthly $S_v(m)$ is given as:

$$S_v(m) = \left[E_L(m) - E_{WG}(m)\right] / H_t(m) * \eta_c * \eta_{pc} \quad (19)$$

,and the global PV array size (S_{pv}) is:

$$S_{pv} = \sum^{m} S_{pv}(m) \Big/ N_m \quad (20)$$

Where $[E_L(m) - E_{WG}(m)]_{sp}$ is the difference between E_L and E_{WG} through the sunshine periods of the month m and N_m is the number of the months have this difference.

Corresponding to S_{PV}, the monthly generation of *PVPS, $E_{pv}(m)$*, is given by:

$$E_{pv}(m) = S_{pv} * H_t(m) * \eta_c * \eta_{pc} \quad (21)$$

The LTBS and STBS are developed in this case as following:

$$STBS = \left[E_{WG}(m) + E_{pv}(m) - E_L(m)\right]_{max} / \left[N_{cd}(m) * \eta_{BS}\right] \quad (22)$$

$$LTBS = \sum^{m} \left\{\left[E_{WG}(m) + E_{pv}(m)\right]_{max} - E_L(m)_{min}\right\} / \eta_{BS} \quad (23)$$

To assess the unit energy cost (UEC_2) of this system, the economy of WG, PVPS *and* BS are determined. This economy is developed in terms of ACC, AOC and TAC. These costs are determined for WG and BS as in alternative I. While these costs are *evaluated for PVPS as following:*

1. Chosen the PV module used, the number of PV modules, N(m), and peak power of PVPS, P_{pv}, are given as:

$$N(m) = S_{pv} / S_{pv}(m) \quad (24)$$

$$P_{pv} = N(m) * P_{pv}(m) \quad (25)$$

Where, $S_{pv(m)}$ and $P_{pv(m)}$ are the net area and peak power of the PV module respectively.

2. The ACC, AOC and TAC of PVPS are given by:

$$ACC_{pv} = DR_v * C_{pv} * P_{pv} \quad (26)$$

$$AOC_{pv} = C_{opv} * E_{pv}(a) \quad (27)$$

$$TAC_{pv} = ACC_{pv} + AOC_{pv} \quad (28)$$

Where; C_{pv} and C_{opv} are the capital cost of 1kW of Ppv *and operation* cost per 1kWh of the annual energy supplied by PVPS, Epv(a), respectively. Thus, the total annual cost (TAC2) and unit energy cost (UEC2) of WG /BS /PVPS generation system are:

$$TAC_2 = TAC_{WG} + TAC_{BS} + TAC_{pv} \quad (29)$$

$$UEC_2 = TAC_2 / E_L(a) \quad (30)$$

UEC_1 and UEC_2 are compared to define the optimal BUPS of RES_s study may be used with WG to supply the isolated load at the considered site.

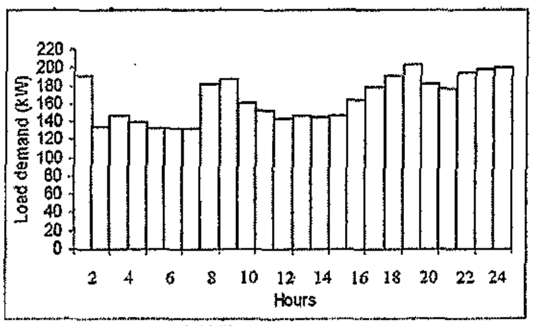
3. OPTIMIZING ALTERNATIVE RESs WITH WG TO SUPPLY THE ISOLATED LOAD STUDY:

The proposed generation and cost models, section 2, are applied here using Matlab program (MLP) to optimize different WGMs and alternative RESs used to supply an isolated load of a tourist village on the Egyptian coast of Red Sea (Hurghada). These WGMs have a rated of 100, 300 and 600 kW. The average daily load curve of this tourist village is shown in Figure (3). This Figure gives the average hourly load demand through a day of Winter and summer seasons. Using the methodology of Ref. [9] the hourly generation curve of different WGMs are determined and shown in Figure (4) for a day of Winter and Summer seasons at Hurghada site.

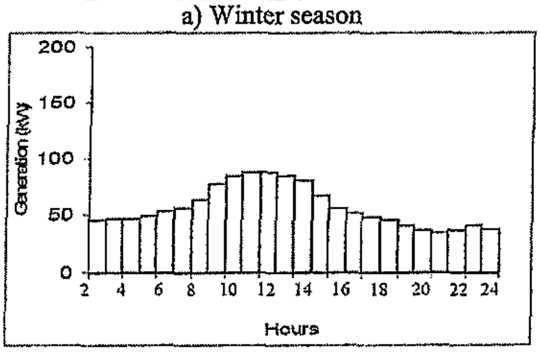
3.1. Assessement of Alternative I; WG/BS Generation System:

Using the MLP, The results of Figure (4) are compared with load demand, Figure (3), and resultant in the number of different WGMs and BS capacity required for Alternative I (WG/BS generation system) to supply the study load and given in Table (1). Also, the economy of these hybride generation systems are obtained in terms of unit energy cost at using the following economical assumption. [5,10]

- The capital cost of WG and BS are $700/kW$_r$ and $40/ kWh of CB respectively.
- The operation cost of WG is 1.0 ¢/kWh of E_{WG}. This cost is 5% of BS capital cost.
- The life time of WG and BS are 15 and 5 years respectively, while the interest rate for both is 10 %.Thus, UEC_1 is obtained and given in Table (1). The result of this table concluded that the WGM of 600 kW rate is the most economical one of these hybrid generation systems for isolated load study.

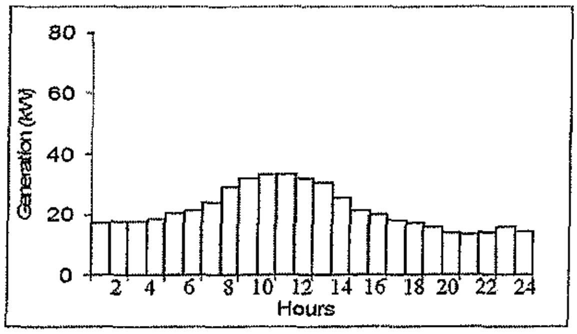


a) Winter season

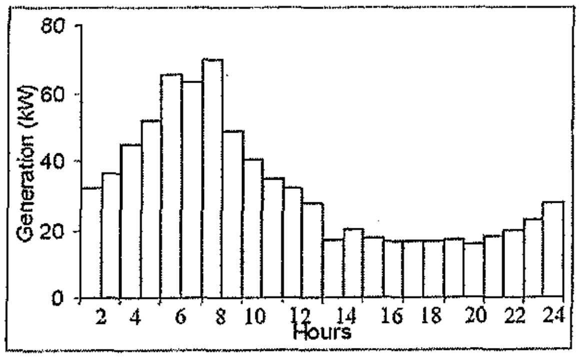


b) Summer season

Fig (3) The daily load demand for the tourist village study through a day of different year seasons

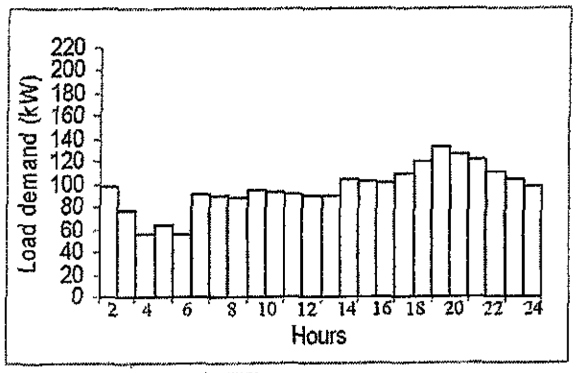


a- Winter season

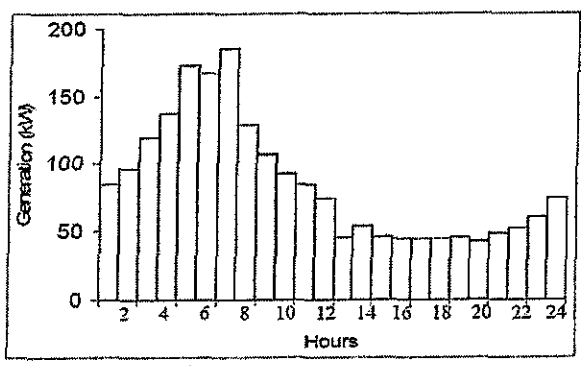


b- Summer season.

a) 100 kW

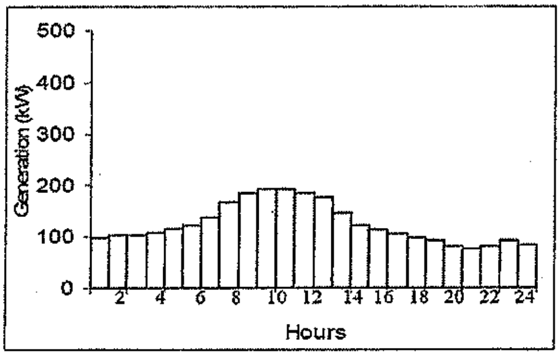


a) Winter season

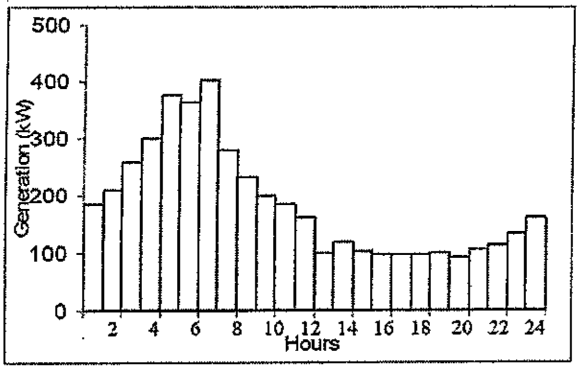


b- Summer season.

b)300 KW



a- Winter season



b- Summer season.

Fig (4) The average daily generation of different WGMs at Hurghada through the year seasons.

Table (1). The number of different WGMs and the corresponding BS capacity for Alternative I (WG/BS) generation system to supply the isolated load study

WGM	Number of WG	BS capacity (MWh)	Unit energy cost (¢/kWh)
100 kW	7	178	167.5
300 kW	3	144	136.7
600 kW	2	34	37.5

3.2 Assessment of Alternative II; WG/PV/BS Generation System:

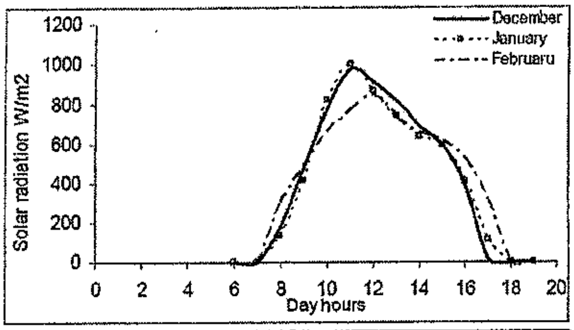
The MLP is applied here using the proposed model of alternative II, section 2, with the results of Figures (3) and (4) to optimize the number of each WGM study in terms of the deficit generation through the sunshine periods of different year months. These deficits are used with the monthly solar radiation at Hurghada site [11] and the design model of Ref [12] to estimate the monthly and global PV array sizes to meet the deficit generation of WGMs through the sunshine periods. Solar radiation received on PV array is developed using the proposed model in Ref [13] and shown in Figure (5).Also, the global PV array size is used with monthly solar radiation at the study site to determine the monthly generation of PVPS to meet the deficit generation of WGMs or /and charge the BS, Figure (2). The results of this application are summarized in Table (2). This table illustrates the optimal number of the WGMs study, the corresponding PV size and BS capacity. Also, the unit energy cost of different hybride generations of Alternative II is determined and shown in Table (2). Taking the following assumptions into consideration [5,10]:

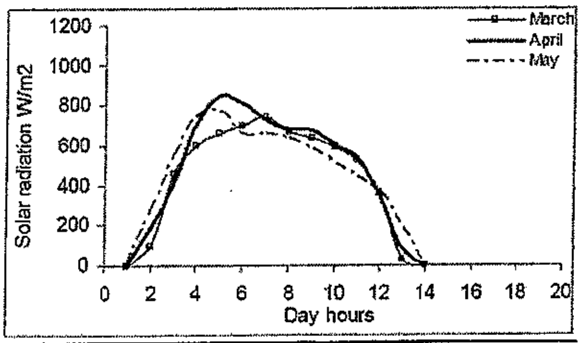
- The capital cost of PVPS is 5$ /W_p and operation cost is 0.2 ¢/kWh of E_{PV}.
- The life time of PVPS is 20 years and interest rate is 10%

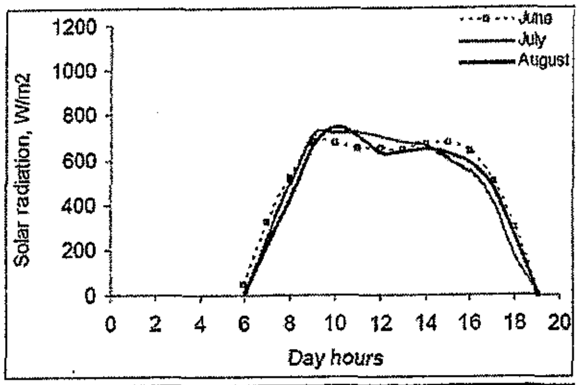
The results of this application are obtained in terms of UEC_2 and given in Table (2). The results of this table concluded that 300 kW-WGM is the most economical ones for Alternative II (WG/BS/PVPS generation system).

Table (2). The number of different WGMs and the corresponding PVPS size and BS capacity for Alternative II (WG/BS/PVPS generation system). to supply the isolated load study.

WGM, kW	Number of WG	PVPS size		BS capacity (MWh)	UEC (¢/kWh)
		S_v, m^2	P_v, kW$_P$. kWh		
100	7	79	17.942	76	74.5
300	3	190	39.514	0.0338	36.8
600	2	-	-	34	37.5







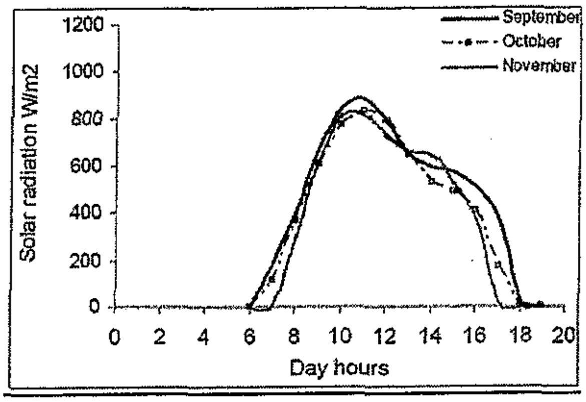


Fig (5) The hourly solar radiation received on unit area of PVPS through a day of the year months at Hurghada site.

4. CONCLUSIONS:

A hybrid generation and economical models are presented for operating alternative of renewable energy sources as a back-up- power supply with wind generator to supply isolated loads. These models are applied to assess and optimize the generation of hybrid generation systems of WG/ BS and WG/ PVPS/ BS have alternative of WGMs to supply the load of a tourist village on the Egyptian coast of Red Sea. The remarkable results of this application are:

1- For WG/ BS generation system; two wind generators of 600 kW rate with 34 MWh BS capacity is the optimal hybrid generation system in this case (UEC=37.5 ¢/ kWh) at Hurghada site.

2- For WG/ PVPS/ BS generation system, three wind generators of 300 kW rate , PVPS have an array of 190 m^2 and 33.8 kWh BS capacity is the optimal hybrid generation system in this case (UEC=36.8 ¢ / kWh)

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