STUDY DESIGN AND PERFORMANCE OF PHOTOVOLTAIC / DIESEL / BS POWER GENERATION SYSTEM WITH APPLICATION IN EGYPT

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SUMMARY

This paper studies the design and performance of PV/DG/BS HGS to feed the load demand in remote Egyptian site such as Oweinat site. This site is located at the western south of Egypt and lies between latitudes 22^o 10^- - 22^o 50^- N.
The PV/DG/BS HGS has been designed as a mini-grid to feed the agriculture load demand in the Oweinat site under study. This design includes the determination of the system component size to satisfy the optimal operation and the most techno-economical performance.
Depending on the proposed computerized energy balance technique, the optimum solar cells size is calculated. The battery banks are used to charge through the high insolation hours (PV-excess energy) during the day time and discharge through the deficit energy. Thus, the required BS size is calculated.
System configuration is determined and the diesel generators are used as supplementary power supply to feed the load during deficit periods. The units are operated near the full output as long as possible to get high efficiency and reduce the fuel consumption.
Solar cells arrays with BS have been designed to feed different ratio of the load demand. This ratio is called as penetration level, PLV. The price of kWh produced from the proposed PV/DG/BS HGS for each PLV has been determined by using special computer program. The reliability of HGS for each PLV has been estimated in details under different conditions of the failure of their components.
Comparative study has been carried out to determine the best techno-economical PLV of HGS. The best techno-economical PLV means that, the PLV who gives a low price of kWh produced and has the highest reliability.
The computerized energy balance technique, which proposed here, can be used to study the design and performance of PV/DG/BS HGS for any site in the world.

1- INTRODUCTION

Many isolated areas in Egypt or any other countries are supplied electrical power mainly by diesel generators. However, diesel generation has some problems, e.g. bad maintainability, unreliable fuel supply and high generation cost [1]. Many alternative energy sources have been considered for the solution of that problem. One of them is Photovoltaic / Diesel / BS Hybrid Generation System. (PV/DG/BS HGS), which mainly consists of PV solar cells (SC,s), Battery Storage (BS), Regulators, Inverters and Diesel Generators (DG,s).

2- METHODOLOGY

1- Monthly best tilt angle of the PV array is estimated as follows

$$S = \phi - \delta \qquad (1)$$

Where :

ϕ is the latitude of the site, degree

δ is the sun's declination angle, degree ranges between +/- 23.45^o.

2- The hourly solar radiation on the tilted surfaces is calculated using the method in Refs. [3,4].

3- The optimum solar cells area ,OSCA, needed for certain load is determined using the following equations:

(Eins) Assuming the size of PV array is SA m2, then, the hourly output of PV power system, PVO (t) can be determined as follows :

$$PVO(t) = SA * H_T(t) * \eta_{cell}(t) * \eta_{Pc} * \eta_{Tr} * \eta_{TL} * VF/Fs \qquad (2)$$

Where :

$$\eta_{cell}(t) = \eta_{cr}\ [1 - 0.0062\ (T_{cell}(t) - T_{cr})] \qquad (3)$$

$$T_{cell}(t) = T_a(t) + q \times H_T(t) \qquad (4)$$

Where:

$H_T(t)$	: Hourly solar radiation on tilted surface, kW/m^2
$T_{cell}(t)$	: Hourly cell temperature in the field, ^{o}C
$T_a(t)$	: Hourly average ambient temperature, ^{o}C
T_{cr}	: Cell temperature at standard test condition, STC
η_{cell}	: Cell efficiency in the field
η_{cr}	: Cell efficiency at , STC
q	: Solar-cell temperature coefficient , 3 ^{o}C / kW.m^2
η_{Pc}	: Efficiency of power conditioner, (Inverter, Controller)
η_{Tr}	: Transformer efficiency
η_{TL}	: Efficiency of the interconnection
FS	: Factor of safety ≈ 1.1
VF	: Variation factor takes into account influence of the variation in the solar radiation from year to year ≈ 0.95

(Zwei) The monthly output energy of PV power system can be estimated as follows:

$$TPV(M) = [\sum_{t1}^{t2} PVO(t)] * 30.4 \quad kWh \qquad (5)$$

Where the average days per month is 365/12 ≈ 30.4 , t_1 and t_2 is the sunrise and sunset respectively

(Drei) The yearly output energy of PV power system can be estimated as follows:

$$TPV1 = \sum_{M=1}^{12} TPV(M) \quad kWh \qquad (6)$$

(Vier) The total load energy required per month considering the penetration level PLPV as follows:

$$TP(M) = [\sum_{T=1}^{24hr} PL(t)]*10\^{}3*PLV*30.4 \quad kWh \qquad (7)$$

Where:

PL(t) : Hourly load demand , MW

PLV : The ratio of the load which supplied by PV power systems (from 20% to 100%)

(Fünf) The yearly load energy required:

$$TP1 = \sum_{M=1}^{12} TPL(M) \qquad kWh \qquad (8)$$

Then , the yearly output of PV power system TPV1 has been compared with the yearly load energy TP1 as follows:

$$EN = TPV1 - TP1 \qquad (9)$$

If EN > 0 then SA must be decreased with an incremental value Δ , and repeat the above steps.

If EN < 0 then SA must be increased with an incremental value Δ , and repeat the above steps.

If EN = 0 then SA recorded as the optimum of solar cells area, OSCA.

Photovoltaic modules are bought, sold and labeled according to their peak power rating (at 1000 W/m^2 , cell temperature 25 or 28 ^oC). It is therefore necessary to convert an array area figure into a peak power value. This conversion is accomplished using the following Equations .

$$\text{PV array peak power kWp} = \text{OSCA } (m^2) \text{ x one sun x ME x MPF} \qquad (10)$$

$$\text{Total number of modules in the array} = \frac{\text{PV array peak power}}{\text{Peak power of selected module}} \qquad (11)$$

Where :

OSCA : Optimum solar cells-area, m^2

One Sun : Reference radiation 1 kW/m^2

ME : module efficiency at STC

MPF : Module paking factor (active module area / total module area)

4- The capacity of battery banks ,BS, is estimated using the following formula;

$$\text{BS Size} = \frac{\text{Max surplus energy through the year months (kWh)}}{\text{Battery efficiency}} \qquad (12)$$

The battery storage is used to charge during the surplus periods and then discharged through the deficit periods to feed the peak load as load-shaving.

The voltage regulator rating ,VR, is estimated as;

$$VR = \frac{BS\ Size}{BS\ Operation\ hours\ per\ day * ç_{VR}} \quad (13)$$

Where:

$ç_{VR}$ is the efficiency of voltage regulator

$$\text{No. of inverter units} = \frac{1.25\ x\ Max.\ Load}{Inverter\ Rating} \quad (14)$$

5- The No. of diesel units needed for each PLV is estimated hourly according to the load as follows;

- Plot the PV array output versus time of the day on the same graph drawn for the daily load demand.
- Discharge the battery system as peak load shaving to minimize the No. of DG units then, assess the hourly deficit load which must be fed from diesel units.
- The rating in MVA of diesel generator(s) can be estimated as follows;

$$\text{Diesel capacity , MVA} = \frac{Load\ demand\ , MW}{P.F\ \ x\ Loading\ of\ max.\ eff.} \quad (15)$$

6- Reliability is determined for Hybrid System of PV/DG/BS, $R_{PV/DG/BS}$ at different penetration level , PLV (20% - 100%).

7- Energy cost figure is calculated for hybrid system according to each PLV using the life-cycle-costing ,LCC, which is presented as follows [5];

$$LCC = \text{Initial cost} + \text{Pval of} \sum O\&M + \sum \text{Replacement} + \sum \text{Fuel cost} \quad (16)$$

Amortized annual payment ,P,

$$P = LCC\ x\ RF \quad (17)$$

$$RF = \left[\frac{(1+dr)^{N}\ x\ dr}{(1+dr)^{N} - 1} \right] \quad (18)$$

$$\text{Unit cost} = \frac{P}{\text{Annual energy production}} \quad (19)$$

Where:

dr : Real discount rate

N : Project life time

3- APPLICATION AND RESULTS

The above methodology has been applied by using new proposed computer programs for the Owienat Site, which its daily load profile is estimated as depicted in Fig. (1). The calculated daily hourly tilted radiation used to estimated the size of PV array is depicted in Fig. (2)

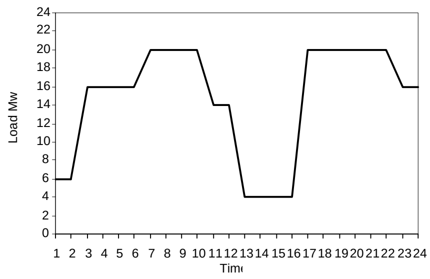

Fig1 : daily load cu

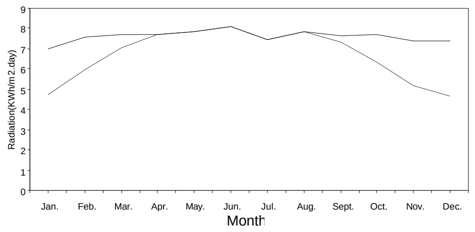

Fig2 Tilted Solar Radiation used to calcu of PV Array

Table (1) shows the characteristics of the selected PV solar module, inverter and diesel unit.

Table (1) Characteristics of the selected components

PV Solar module:	
Type	: Polycrystalline silicon
Maximum output power P_m	: $80W_p$
Output voltage at max. power V_m	: 16.9 Volts d.c
Output current at max. power I_m.	: 4.73 Amp. d.c
Efficiency	: 14%
Active PV module area	: 0.636 m^2
Module Packing factor	: 0.898
Inverter:	
Capacity	: 1000kVA
Rated input voltage	: 400 Volts d.c.
Range of input voltage	: 240 – 400 volts. d.c.
Output voltage	: 400 volt a.c., 3-phase, 50 Hz
Type	Self commutated
Efficiency	95%
Diesel Unite:	
Capacity	: 1000kVA / 800 kW
Output voltage	: 380 - 440 volt, 50 Hz

Table (2) displays the solar cells size, No. of diesel units, Bs size , ECF and reliability for each PLV.

Table (2) The economic and reliability of PV/DG/BS hybrid system under different values of PLV

Penteration level		SCA, m^2	BS size MWh	DG units	ECF ¢ / KWh	reliability
PV	DG					
0.0%	100%	-	-	40	14.1	0.969676896
20%	80%	128531.5	31.7	29	13.62	0.979261632
40%	60%	257062.5	100	24	13.79	0.982192517
60%	40%	385593.5	178	19	13.99	0.982603255
80%	20%	514125	264	11	14.18	0.982662729
100%	-	642656	3265	-	20.45	0.976529939
	-	-	-	-	11.65	0.969794132

Fig. (3) shows the effect of PLV on the ECF of PV/DG/BS hybrid system and Fig. (4) display the influence of PLV on the reliability of the PV/DG/BS

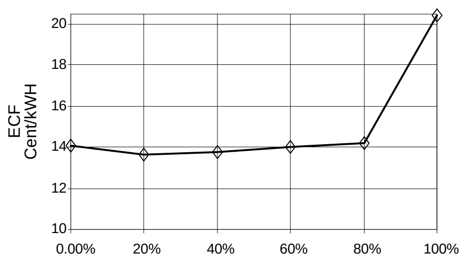

Fig.3 Ihe Effect of PLV on the Energy Cı

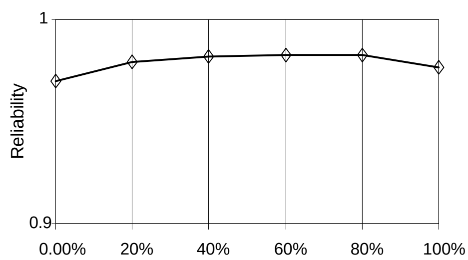

Fig4 The Influnce of PLV on the Reliability of PV/BS

4- CONCLUTION

From Figs. 3,4 and Table (2) , it can be concluated that :

1- The most economic hybrid EPS is PV/BS/DG at PLV = 20%
2- The most reliable hybrid EPS is PV/BS/DG at PLV = 80%
3- If the reliability of PV/BS/DG EPS increased with 0.35%, the ECF will be increased with 4.11% w.r.t the case of PLV = 20%
4- The reliability of DG EPS (PLV = 0%) is 0.969676896 but the reliability of PV EPS (PLV = 100%) is 0.969794132. This means that the reliability of PV EPS increases with 0.012% but the ECF of PV is decreased with 21 % w.r.t. the case of PV EPS.
5- The reliability of PV/BS EPS is increased with 0.7% than that of DG EPS w.r.t. the case of PV/BS EPS, but the ECF will be increased with 31 % than that of DG EPS w.r.t. the case of PV/BS EPS.
6- The BS increases the reliability of PV EPS with 0.695% and increases the ECF with 43 % w.r.t. the case of PV EPS.

From the above discussion, the most economic and reliable EPS is PV/BS/DG hybrid system at PLV equal to 20%

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