Size optimization of solar array and battery in a standalone photovoltaic (SPV)

M.Belhadj[1], T.Benouaz[2], A.Cheknane[3] and F.hadjaj[4]

***Abstract:-*Size optimization of solar array and battery in a standalone photovoltaic (SPV) system is investigated. Based on the energy efficiency model, the loss of power supply probability (LPSP) of the SPV system is calculated for different size combinations of solar array and battery. For the desired LPSP at the given load demand, the optimal size combination is obtained at the minimum system cost. One A case study is given to show the application of the method in the weather Bechar Applying this method to an assumed PV/Batt hybrid system to be installed at Bechar (Algeria), the simulation results show that the optimal configuration, which meet the desired system reliability requirements (LPSP = 0) with the lowest LCE, is obtained for a system comprising a 80W photovoltaic module, and storage batteries (using 200 Ah). On the other hand, the device system choice plays an important role in cost reduction as well as in energy production.**

***Keywords:* Optimum system sizing; Loss of power load probability; Levelized cost of energy**

I. Introduction

Standalone photovoltaic (SPV) systems are becoming increasingly viable and cost-effective candidates for providing electricity to remote areas, especially to some areas of Sabah and Sarawak in East Malaysia, where higher solar radiation is received [1–2]. This SPV system typically consists of a solar array, a controller with maximum power point tracker (MPPT), a battery, an inverter and loads. The configuration of an SPV system is shown in Fig. 1. In the system, the solar array converts solar radiation falling on its surface into DC electricity. The controller with the MPPT helps to extract maximum power from the solar array regardless of the variation of solar radiation and temperature as well as protect the battery from overcharging and under-discharging.

The battery stores energy when solar array generates more power than load demand or supplies power to load when the solar array generates less power than the load demand during cloudy or rainy days or at nights.

The inverter converts DC into AC at a similar voltage level and frequency of the power grid for the convenient usage of normal AC loads (electric appliances). Since output power of a solar array varies with weather conditions, the successful operation of the SPV system is to find out the optimal size of a solar array and battery to meet load demand.

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In this system solar energy complete each other; thus the size of the battery is relatively small and the role of the battery is less important than that in the SPV system. the influence of tilt angle on sizes of the SPV system was investigated for the given load demand, the optimal size of solar array and battery was obtained when the tilt angle was adjusted in accordance with seasons, which complicates the installation of the solar array. Based on the spirit of Borowy's method [3], this paper investigates the optimum sizes of solar array and battery in the SPV system under the conditions of a fixed tilt angle and continuous size variations of solar array and battery. The loss of power supply probability (LPSP) is calculated for different size combinations of solar array and battery. For the desired LPSP at the given load demand, the optimal size combination is obtained at the minimum system cost. One case study shows the procedure of the size optimization of the SPV system in Bechar weather conditions.

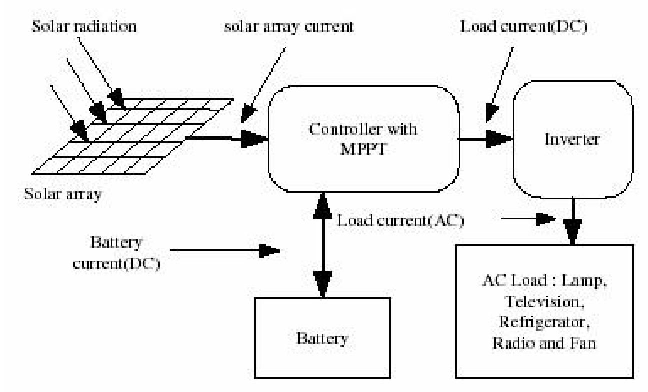


Fig.1.Standalone photovoltaic system.

I.1. Modelling of a PV generator

As the operation and the performance of a PV generator is interested in its maximum power, the models describing the PV module's maximum power output behaviours are more practical for PV system assessment. In this paper, a mathematical model for estimating the power output of PV modules is used. The estimation is carried out using a computer program, which uses a subroutine for determining the power output of a PV module. Using the solar radiation available on the tilted surface, the ambient temperature and the manufacturer's data for the PV modules as model inputs, the power output of the PV generator, P_{PV}, can be calculated according to the following equations [4]

$$P_{pv} = \eta_{ref}\eta_{pt}(1-\beta(T_c - T_{ref}).A.G \quad (1)$$

Where η_{ref} is the PV generator reference efficiency, η_{pt} the efficiency of power tracking equipment, which is equal to 1 if a perfect maximum power point tracker is used, Tc the temperature of PV cell (1°C), T_{ref} the PV cell reference temperature, A the area of a single module used in a system (m2), G the global irradiance incident on the titled plane (W/m^2) and β is the temperature coefficient of efficiency, ranging from 0.004 to 0.006 per 1°C for silicon cells. Based on the energy balance proposed by Dufie and Beckman (1991), the PV cell temperature can be expressed as follows [5]

$$Tc = Ta + G.(\frac{NOCT - 20}{800}) \quad (2)$$

Where Ta is the ambient temperature (1C), UL is the overall heat loss coefficient (W/m^2 per 1C), NOCT the nominal operating cell temperature, η_{ref}, β and A are parameters that depend on the type of module, and given by the manufacturer of the modules.

I.2. Modelling of battery storage

At any hour the state of battery is related to the previous state of charge and to the energy production and consumption situation of the system during the time from t-1 to t. During the charging process, when the total output of PV is greater than the load demand, the available battery bank capacity at hour t can be described by [4]

$$C_{Bat}(t) = C_{Bat}(t-1).(1-\sigma) + (P_{pv}(t) - P_L(t)/\eta_{inv}).\eta_{Bat} \quad (3)$$

On the other hand, when the load demand is greater than the available energy generated, the battery bank is in discharging state. Therefore, the available battery bank capacity at hour t can be expressed as [6-8]

$$C_{Bat}(t) = C_{Bat}(t-1).(1-\sigma) + (P_L(t)/\eta_{inv} - P_{pv}) \quad (4)$$

Where $C_{bat}(t)$ and $C_{bat}(t-1)$ are the available battery bank capacity (Wh) at hour t and t-1, respectively; n_{bat} is the battery efficiency (during discharging process, the battery discharging efficiency was set equal to 1 and during charging, the efficiency is 0.65–0.85 depending on the charging current) [8].

σ is the self-discharge rate of the battery bank. The manufacturer documentation gives a self-discharge of 25% over 6 months for a storage temperature of 20 1°C, that is to say 0.14% per day [7]. $P_{pv}(t)$ is the energy generated by PV and wind generators, respectively; P_L is the load demand at hour t and n_{inv} is the inverter efficiency (in this study it is considered as constant, 92%).

Then, the inverter input power, $P_{inv}(t)$ is calculated using the corresponding load power requirements, as follows:

$$P_{inv}(t) = \frac{P_L(t)}{\eta_{inv}} \quad (5)$$

At any hour, the storage capacity is subject to the following constraints

$$C_{Bat\,min} \le C_{Bat}(t) \le C_{Batmax}$$

Where C_{Batmax} and C_{Batmin} are the maximum and minimum allowable storage capacity, respectively.Using for C_{Batmax} the storage nominal capacity C_{batn}, then

$$C_{Batmin} = DOD.C_{Bat.n} \quad (6)$$

Where DOD (%) represents the maximum permissible depth of battery discharge.

If the battery capacity decreases to their minimum level, C_{Batmin}, the control system disconnects the load and the energy deficit, loss of power supply for hour t can be expressed as follows [6]:

$$LPS(t) = P_L(t)\Delta T - (P_{pv}(t)\Delta t + C_{Bat}(t) + C_{Bat}(t-1) - C_{Batmin}).\eta_{inv} \quad (7)$$

Where ΔT is the step of time used for the calculations (in this study $\Delta T = 1$ Day). During that time, the power produced by the PV is assumed constant. So, the power is numerically equal to the energy within this time step.

The loss of power supply probability, LPSP, for a considered period T, can be defined as the ratio of all the (LPS (t)) values over the total load required during that period. The LPSP technique is considered as technical implemented criteria for sizing a hybrid PV/wind system employing a battery bank. The technical model for hybrid system sizing is developed according to the LPSP technique. This can be defined as [6-7].

$$LPSP = \frac{\sum_t^T LPS(t)}{\sum_t^T E_L(t)\,\Delta T} \quad (8)$$

Where T is the operation time.

To determine the optimal size combination, the cost function of the SPV system is defined as

$$C_{LCE} = a.N_{pv} + b.N_{bat} + C_{T0} \quad (9)$$

the where C_T is the total costs of the systems; Cpv is the capacity of the solar array; C_{batt} is the capacity of the battery; C_{T0} is the other total costs except the solar array and the battery, which is considered to be constant, including the costs of the controller with MPPT, inverter, etc. a is the unit cost of the battery and b is the unit cost of the solar array.

The optimal solution of the equation (9) following is a sealed envelope the relationship:

$$\frac{\partial N_{Bat}}{\partial N_{pv}} = -\frac{b}{a} \quad (10)$$

II. RESULTS AND DISCUSSION

The above-presented analysis is applied to given load distribution assumed to be installed at located in Bechar. Geographic data Longitude, Latitude end Altitude are respectively 2.15w, 31.38'N and 806m.

The technical and economical parameters of the component system are given in Tables 1 and 2

TABLE.1: PHOTOVOLTAIC MODULES PARAMETERS

Type	Pmp(W)	Vmp(V)	Imp(A)	Voc(V)	Isc(A)	NOCT(°C)	A(m2)	Price(EUR)	Bos(eauro)
QX-P-50	50	17,5	2,9	21,5	3,23	42	0.45	299.00	50% of cost
QX-P-80	80	17,2	4,66	21,2	5,1	42	0.716	439.00	50% of cost

TABLE. 2: BATTERY PARAMETERS

Type	Nominal capacity (Ah)	Voltage (V)	Minimum charge (%)	Price(EUR)
ULT-AGM-80-12	80	12	20	194.00
ULT-AGM-100-12	100	12	20	243.00

The consummation profile adopted in this study is shown in Figure 2. This energy distribution schedule is considered identical for all days of the year.

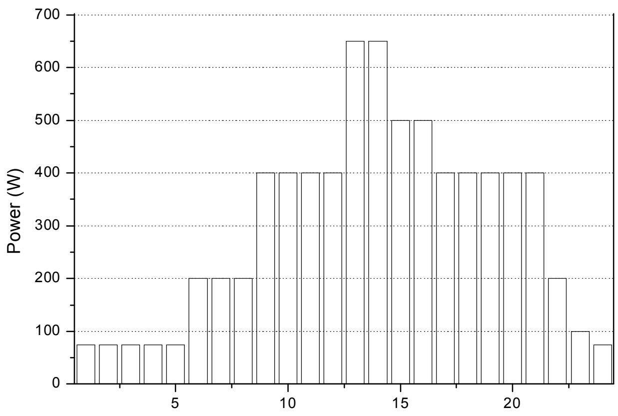
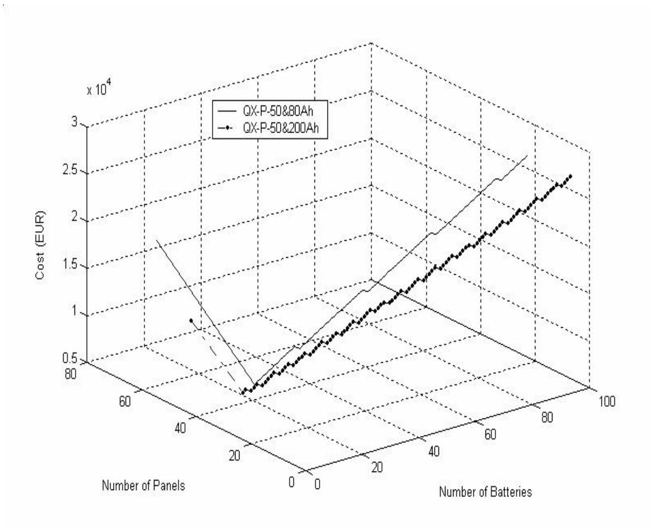
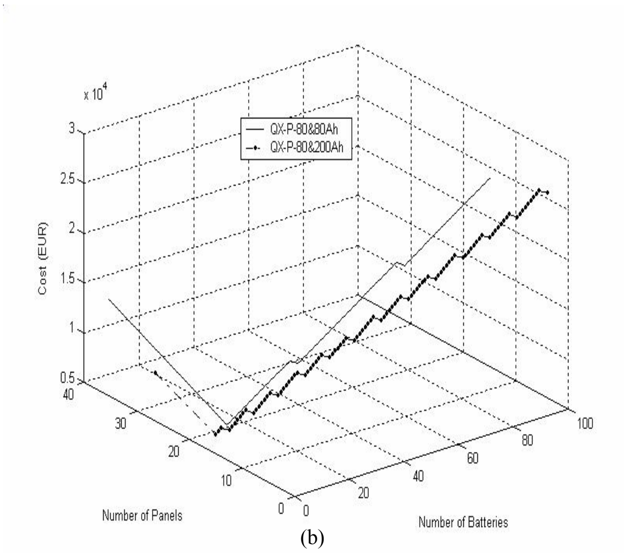


Fig.2. Hourly load profile



(a)



(b)

Fig. 3. Comparison of levelized costs of energy for different configurations (LPSP= 0).

For this purpose, several simulations have been made by considering different combinations taking into account, the power of PV and the capacity storage.

For an LPSP of 0 and a load profile defined in this study, the simulation results, based on the LPSP concept, are presented in Fig. 3.

After the excursions program, we note that the results of simulation system with 50W and a capacity of 80Ah (Fig.3.a). This configuration gives a couple of 48 panel and 30 batteries. This couple requires a cost of 20172 EUR. For a configuration of 50W and 200A h fig (3.a) a torque of 45 panels and 20 batteries with cost 18315 EUR.

Figure 3.b illustrates the simulation results of a configuration of 80W and 80A/h. We see that there is an optimum torque of 22 panels and 15 batteries and cost 12568 EUR. We can also observe in the configuration of 50W and 200A h (fig.5.b) an optimum torque of 18 panels and 8 batteries. This couple requires a minimum cost of 9846 EUR.

We can see from the results of different configurations that the couple who gave a minimum cost is 18 panels (80W) and 8 batteries (200A/h).

III. CONCLUSION

In this paper, we presented a design method for PV system PV / Batt. This method called LPSP (Loss of Power Supply Probability) is used to calculate the optimum number of batteries and PV modules under the criterion of a minimum price. For the dimensions we used the daily values for the winter season (ambient temperature and solar irradiance) profile with the same load for every day of the year a house on the site of Bechar.

After on the results from the simulation program developed for different configuration of components (panel, battery) and for LPSP=0 we deduce that the pair (18,8) gives a minimum cost

REFERENCES

[1] Noh Dalimin Mohd. Renewable energy update: Malaysia. Renewable Energy 1994;6:435–9.

[2] Ajan Christopher W, Shahnawaz Ahmed S, Ahmad Hussien B, Taha Faridah, Mohd Zin Abdullah Asuhaimi B. On the policy of photovoltaic and diesel generation mixes for an off-grid sit: East Malaysian perspectives. Solar Energy 2003;74:453–7.

[3] Ajan Christopher W, Shahnawaz Ahmed S, Ahmad Hussien B, Taha Faridah, Mohd Zin Abdullah Asuhaimi B. On the policy of photovoltaic and diesel generation mix for an off-grid sit: East alaysian perspectives. Solar Energy 2003;74:453–7.

[4] Markvard, T., 2000. Solar Electricity, second ed. Willey, USA.

[5] S. Diaf, D. Diaf, M. Belhamel, M. Haddadi, A. Louche,2007. A methodology for optimal sizing of autonomous hybrid PV/wind system. Elsevier, UK.

[6] Bogdan, S.B., Salameh, Z.M., 1996. Methodology for optimally sizing the combination of a battery bank and PV array in a wind/PV hybrid system. IEEE Transactions on Energy Conversion 11 (2), 367–375.

[7] Markvart, T., Castaner, L. (Eds.), 2003. Practical Handbook of Photovoltaic Fundamentals and Applications. Elsevier, UK.

[8] Bin, A., Hongxing, Y., Shen, H., Xianbo, L., 2003. Computer aided design for PV/Wind hybrid system. Renewable Energy 28, 1491–1512.