OPTIMUM SIZING OF PHOTOVOLTAIC DIESEL-GENERATOR HYBRID POWER SYSTEM

Apoorv Vats*

Pandi Tom*

ABSTRACT

This paper presents the methods to minimize the cost of PV system according to reduction of PV array area and storage battery. A new method has been used to calculate the minimum PV array area and minimum number of storage days of the battery. A program has been developed by using MATLAB software, for sizing of Photovoltaic Diesel-Generator Hybrid Power System. This program is used to size hybrid system which consist of PV system, storage system and diesel generator. Characteristic curves also have been developed for PV system and total battery capacity. Thus, this proposed method can be used to size any system.

Keywords: *Photovoltaic system, Diesel generator.*

*Department of Electrical Engineering, College of Engineering Roorkee, Uttarakhand, India.

I. INTRODUCTION

Photovoltaic (PV) system installation has played an important role in the solar industry because PV systems are clean, environment friendly and secure energy sources. However the drawback of PV systems is their high capital cost compared to that of conventional energy source. Therefore, many research studies have focused on the optimization of PV system, such as Hybrid PV/Diesel generator system. Hybrid Photovoltaic Systems (PV-hybrid) use photovoltaic energy combined with other sources of energy, like wind or Diesel. If these systems are optimally designed, they can be more cost effective and reliable than PV-only systems. Some of the methods for sizing of Hybrid Systems are (i) HOGA (Hybrid Optimization by Genetic Algorithms) based [1] (ii) FORTAN language based [2] (iii) SDM and SAR based [3].

Rodolfo Dufo-López, Josė L. Bernal-Agustĭn, et al in [1] proposed a method to size Hybrid system using HOGA program. P. Arun, Rangan Banerjee, Santanu Bandyopadhyay [4] used Monte Carlo simulation approach to size a hybrid system. Said H. EL-HEFNAWI [2] proposed a method using FORTAN language.

In this paper sizing a method for Photovoltaic Diesel-Generator Hybrid system is given. PV array area and minimum number of storage days of battery has been calculated using efficient formulae. Characteristic curves using MATLAB software has been developed.

II. CONVENTIONAL STAND ALONE SYSTEM SIZING TECHNIQUES

The first step in stand-alone system sizing is to select the battery capacity for battery storage to cover exceptionally long periods without sunshine or at night. The second step is to decide the acceptable depth of discharge (DOD) for the system battery under normal seasonal fluctuations in solar energy input. Current and voltage output are sized separately. The voltage output should be large enough to allow the battery to be charged efficiently throughout the year. In selecting the system voltage, the effect of temperature must be considered. The output current is chosen to ensure that the battery does not charge the selected DOD during the worst case seasonal effects or days without sun. The system sizing characteristic depends on the conditions of the site and there is no exact formula for that purpose, but there are empirical equations for system sizing in different applications. In a solar PV powered rural health center in India, the size of a stand-alone PV system is obtained from the following relationship:

$$P_V = \frac{\{\mathbf{E_L} + (\mathbf{E_L} + \frac{D}{C_R} * \mathrm{BE}) * 100\}}{\boldsymbol{X}}$$

Where P_V : The array size in peak watts

E_L: The daily energy requirement in Wh/day

D: The required number of storage days

C_R: The charge recovery of the battery days

B_E: The watt-hour efficiency of the battery

X: the annual average equivalent peak hours/day (sunshine period)

For the required battery storage of D number of days, the battery capacity is obtained as follow:

$$C_t = \frac{(E_L * D)}{(V_S * D)}$$

Where V_S: The system voltage

C_D: Maximum permissible depth of discharge

In the previous methods for stand-alone system sizing, the number of storage days has not determine a direct relation, since it was dependent on the total number of days without sun during the year, which depend on the nonregular characteristics of weather sites. Also, the maximum permissible DOD does not have a constant value due to variation in weather parameters from one year to another. The previous two problems are solved and governed in a fixed formula in a hybrid system.

III. HYBRID SYSTEM SIZING

A. Diesel Generator Sizing

The main concern for the diesel-generator sizing and optimized operation are: the diesel shall not be lightly loaded; the diesel runs for sufficient period of time to reach operating temperature; and the excessive operation during the final charge period be avoided. The optimum diesel-generator operating range is 70-89% from the rated power. The diesel generator chosen was a KOBOTA, 3kw, single phase generator, with manual and automatic starting and self-regulation using a governor to give the engine an accurate fuel quantity at different load requirements. The governor acts to keep the engine speed (generator frequency) approximately constant at any load level.

B. PV Stand-Alone Sizing in Hybrid System

To size the PV array and the battery capacity, the average load energy E_L and the ampere-hour required per day (Ah_r) should be estimated from the load profile. The ampere-hour required per day is:

$$Ah_r = {E_L}/{V_s}$$

Where V_s is the system voltage

Ah_r is used to calculate the required current from the PV array

C. Battery Capacity Determination

The battery capacity C_t is given in equation (3.2). Using this relationship, the ideal battery capacity can be calculated at 100% charge –discharge efficiency, bit the charge-discharge losses are approximately 25% of the total capacity. The charge losses refer to the PV side, but the discharge losses refer to the battery side. The watt-hour efficiency (WHE) for a lead-acid battery has a value of 75% and is defined as:

$$BCT = \frac{Ah_r * D}{C_D * \sqrt{WHE * M}}$$

The discharge efficient should be calculated to their part of energy only which is Ah_r. By including the discharge efficiency and the maximum permissible state of charge SOC (M), in the battery capacity determination, the total battery capacity (BCT) is:

$$C_D = \frac{(C_t - Ah_r)}{C_t}$$

The minimum number of storage days is:

$$D = C_D * (D+1)$$

By determining the required maximum permissible DOD, the minimum number of storage days can be calculated.

D. Current Determination

The average PV system current is:

$$I_a = \frac{Ah_r}{(number\ of\ sunshine\ hours\ per\ day)}$$

Considering charging efficiency, this current should be:

$$I_{a1} = \frac{I_a}{\sqrt{WHE}}$$

By including the low level insolation and highly dust accumulation periods, the average current should be increased by a 5% ratio. Then the PV output current is:

$$PVC = I_{a1} * 1.05$$

E. Voltage Determination

Voltage determination to charge a 12 V battery is 13.V. The required system voltage should be large enough to charge the batteries, so:

*V_s = (number of batteries in series)*13.6+ voltage drop across blocking diode*

E. PV Module Configuration

The number of modules in series = Integer part of (System voltage/module voltage) + 1

The number of parallel strings = $\frac{\text{Photovoltaic current}}{\text{String current}}$

IV. ALGORITHM FOR SIZING OF HYBRID SYSTEM

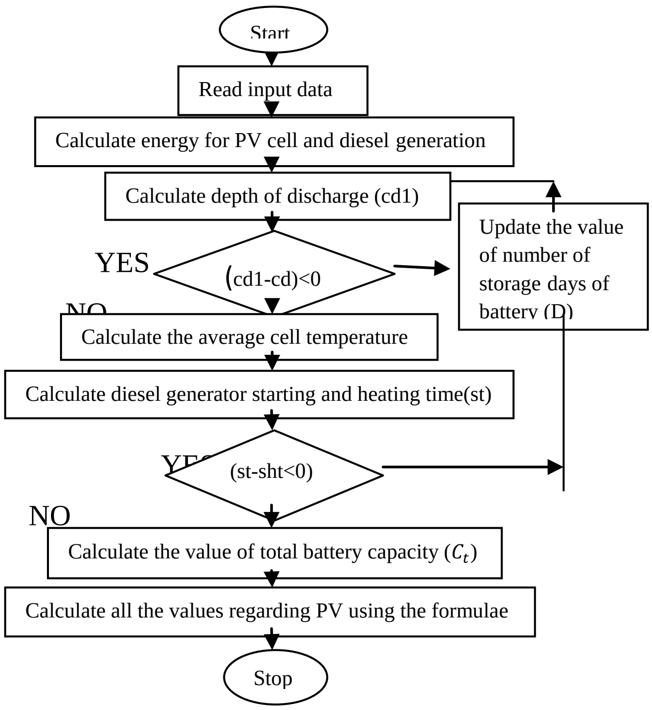

Fig. 1. Flow Chart

V. CASE STUDY

Data are collected at an isolated farm in the Egyptian Eastern Desert, site latitude 27’ and meridian 33 E.G. The average irradiation is 6.88Wh/m^2/d and the sunshine period is 9 h/d for 350 d/year. The system voltage is 24 V. The load profile (Fig 2) can be deduced from the load data by calculating the distribution of load during day as follows:

22-6	L= 99.6 W	(8 h)
6-7	L= 74.6 W	(1 h)
7-10	L= 82.1 W	(3 h)
10-15	L= 2461.8 W	(5 h)
15-18	L= 82.1 W	(3 h)
18-22	L= 282.6 W	(4 h)

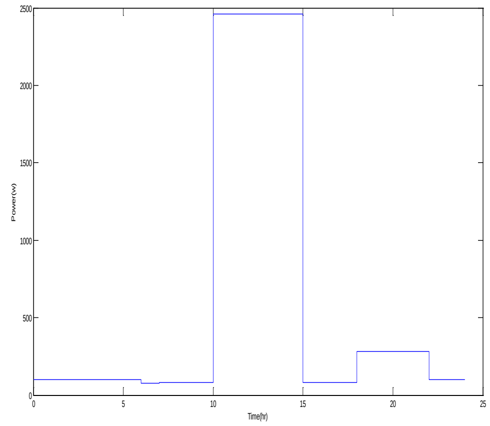

Fig. 2. The load profile

It can be seen from the load profile that the overload period lies between 10-15, therefore, the diesel generator should be used in this period. To optimize the hybrid system design, the load profile should be divided into two sections during the overload period: (1) PV stand-alone load which has a value of 74.6 W; and (2) the diesel-generator load which has a value of 2387.2 W. Then, the daily energy required from the stand-alone PV system section (PV array and battery) is:

E_L= 99.6*8 + 74.6*6 + 82.1*6 + 282.6*4 = 2867.4 W

VI. MODULE PARAMETER CORRECTION DUE TO SITE PARAMETERS

The available modules for our system have the following data: U_n =9.6 V, P_n=23.3 W, dimension 46*56 cm^2, number of cells = 20 in series, but have internal blocking diodes. Generally, the module data is given at standard test condition (STC): Irradiance 1000 Wh/m^2, with the references solar spectral irradiance distribution, cell temperature 25^0C and the tests are carried in laboratory. The previous parameters will be changed according to site parameters. The average irradiance is 6.88/9 kw/m^2 =760 w/m^2. The expected theoretical modules characteristics for site parameters are:

$P_n = V_n * I_n$

$I_n = \frac{23.3}{9.6} = 2.4167$ A

$I_M = I_n$ * (average on site irradiance/STC irradiance)

$= 2.4167 * \frac{760}{100} = 1.8367$ A

$V_M = V_n$ – (Δt*3mV* no. of module cells)

$= -9.6-[(35-25) * (3*10^{-3})*10] = 9$ V

$P_M = V_M * I_M = 16.53$ W

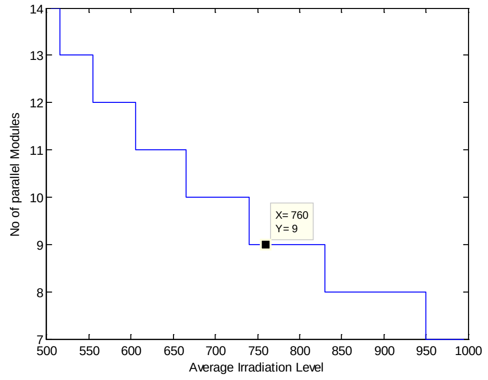

FIG 2: Variation of parallel modules with change in average irradiation level.

By using the previous initial values, the results obtained from the system sizing program are:

CD1 = 0.7509 D = 3.0150

BCT = 553.9008 ST = 6.2354 min

NOSM = 4 module NOPS = 9 string

PVC = 16.0951 RSV = 27.9000

VM = 9V PM = 16.6013

OMC = 1.8446 NOSB = 2

SC = 4.9781 SP = 597.6450

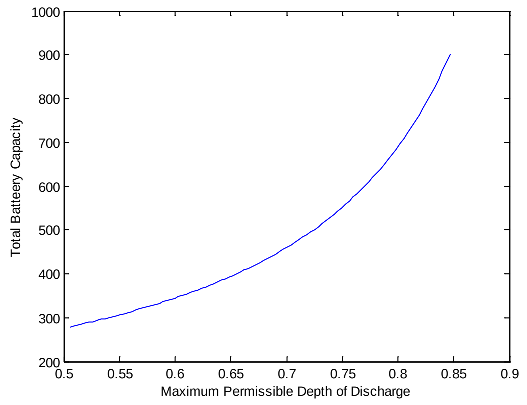

Fig. 3. Variation of total battery capacity with change in depth of discharge

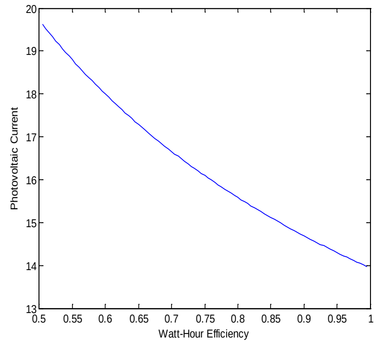

Fig. 4. Variation of Photovoltaic current with change in Watt-Hour Efficiency.

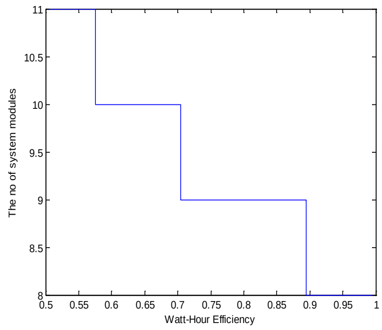

Fig. 5. Variation of the no. of system modules with Watt-Hour Efficiency

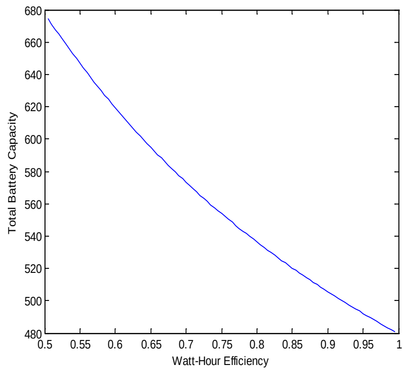

Fig. 6. Variation of total battery capacity with change in Watt-Hour Efficiency

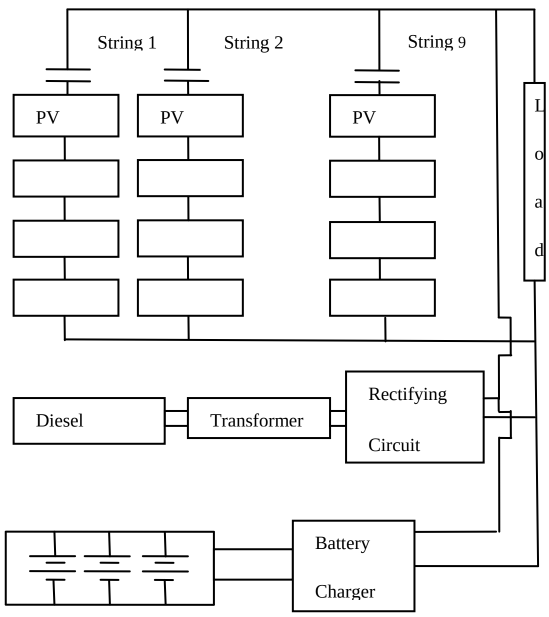

Fig. 7. The System Profile

VII. CONCLUSION

The importance of renewable energy and why we use renewable energy is discussed. The development of solar energy utilization for power generation is also discussed.

The maximum number of storage days has been determined and the maximum permissible depth of discharge is limited. The sizing program developed can be used to size any PV diesel-generator hybrid power system. The available pre-operating period for a diesel-generator is determined according to the engine type selected. The sized hybrid system is reliable and can absorb any load disturbances. The hybrid system is more economic than the stand-alone system, because of the minimization of array size and battery capacity required.

A case study has been done and results are presented for a given load at an isolated farm in the Egyptian desert, site latitude 27^0 and meridian 33 E.G.

REFERENCES

[1] Rodolfo Dufo-López, Josė L. Bernal-Agustĭn, Design and control strategies of PV-Diesel system using genetic algorithms

[2] Said H. EL-HEFNAWI, "Photovoltaic Diesel-Generator Hybrid Power Systemsizing", *Renewable Energy,* Vol. 13,No.1, pp. 33-40,1998

[3] M. Muselli*, G. Notton, P Poggi, A Louche," PV-hybrid power systems sizing using incorporating battery storage: an analysis via simulation", *Renewable Energy,* 20(2000), pp. 1-7.

[4] P.Arun, Rangan Banerjee, Santanu Bandyopadhyay, "Optimum sizing of photovoltaic battery systems incorporating uncertinity through design space approach", *SCIENCE DIRECT,* Solar Energy 83 (2009), pp. 1013-1025.

[5] Bogdan S. Borowy and Ziyad M. Salameh, "Optimum Photovoltaic Array Size for a Hybrid Wind/PV System," *IEEE Trans. on Energy Convers.*, vol. 9, no. 3, pp. 482-488, September 1994.

[6] Bogdan S. Borowy and Ziyad M. Salameh, "Methodology for Optimally Sizing the combination of a Battery Bank and PV Array in a Wind/PV Hybrid System," *IEEE Trans. on Energy Convers.*, vol. 11, no. 2, pp. 367-375, June 1996.

[7] S. Arul Daniel and N. Ammasai Gounden, "A Novel Hybrid Isolated Generating Syste Based on PV Fed Inverter-Assisted Wind-Driven Induction Generators,"*IEEE Trans. On Energy Convers.*, vol. 19, no. 2, pp. 416-422. June 2004

[8] S. Yanagawa, T. Kato, K. Wu, A. Tabata, and Y. Suzuoki, "Evaluation of LFC capacity for output fluctuation of photovoltaic generation systems based on multi-

point observation of insolation," in *Proc. IEEE Power Eng. Soc. Summer Meeting*, 2001, pp. 1652–1657

[9] Woyte, V. V. Thong, R. Belmans, and J. Nijs, "Voltage fluctuations on distribution level introduced by photovoltaic systems," *IEEE Trans. Energy Convers.*, vol. 21, no. 1, pp. 202–209, Mar. 2006.

[10] H. Asano, K. Yajima, and Y. Kaya, "Influence of photovoltaic power generation of required capacity for load frequency control," *IEEE Trans. Energy Convers.*, vol. 11, no. 1, pp. 188-193, Mar. 1996.