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Development of Regression Models For Appropriate Battery Banking Determination In Solar Power System

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Abstract: *Photovoltaic power system converts solar irradiance directly into electricity. It can be used as electrical power source for home to meet daily energy requirement. Individuals and small scale firms rarely invest in this power system due to their inability to determine the actual battery banking specification and cost. Acquiring photovoltaic power system, involves selecting, developing, and determining specifications of different components used in the system that comform to the desired load. Accomplishment of this specifications depend on a variety of factors such as geographical location, weather condition, solar irradiance, and load consumption. This work outlines in detail the procedure for specifying each component of the battery banking for photovoltaic power system, that is, using formula to ascertain the capacity of the components needed and designing a regression model capable of determinning the specifications of the components in order to achieve the desired output from the system. The work verifies and validates the fact that regression models can be used in determining the capacity of components used in actual application of a Photovoltaic solar power system. The minimum correlation coefficient is 0.995 which shows that the relationship between the theoretical and pridicted model is highly dependable.*

Keyword: *Inductive load, Photovoltaic power, Resistive load, Semiconductor, Solar irradiance*

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I. Introduction

Energy plays fundamental role in our daily activities. The degree of development and civilization of a country is determined by the amount of energy utilized by its human beings. Energy demand is increasing day by day due to increase in population and urbanization. The world's fossil fuel, which has been the main source of energy supply via Coal, petroleum and natural gas until now; will thus be exhausted in a few hundred years (Abhik, 2015). The rate of energy consumption is increasing while the availability of fuel and other fossil products are depleting. This will lead to energy crisis one day. It will also results in inflation, poverty and global warming. Hence alternative or clean renewable energy sources have to be explored and developed to meet future energy requirement. Renewable energy technology is one of the solutions, which generates energy by transforming natural phenomena (or natural resources) into useful energy forms (Dincer, 2011).

Solar and wind energy are clean, inexhaustible and environmental friendly among the renewable energy options. Solar energy is one of the most promising renewable energy sources, characterized by a huge potential of conversion into electrical power. Solar energy can be converted directly into electrical energy using solar cells via photovoltaic process (Roth, 2004). The conversion of solar radiation into electrical energy by photovoltaic (PV) effect is a very promising technology. It is clean, silent and reliable with very small maintenance costs and small ecological impact (Tiberiu, 2012). Among all renewable systems, photovoltaic system is the one which has a great chance to replace the conventional energy resources. Solar panel directly converts solar radiation into electrical energy. Solar panel is mainly made from semiconductor materials. Silicon (Si) is used as the major component of solar panels with its maximum efficiency of 24.5% (Ryan, 2001). The photovoltaic (PV) process generates electricity directly and it is completely self-contained; as there are no moving parts (Luque and Hegedesl, 2003). Findings has shown that majority are afraid of entering into energy production from solar radiation because installation cost are overestimated by technicians involved and that the battery banking specification are under designed such that the devices recommended for a particular power output are rarely met by the technician hence, there is a need to develop a multiple regression model for appropriate battery banking in solar power system.

II. Research Methodology

Battery banking system design is a process of determining capacity (in terms of power, voltage and current) of each component of a stand-alone photovoltaic power system with the view to meeting the load requirement for which the design is made. This is done based on the following steps; which are site inspection, calculation of building load, choice of system components, determination of inverter capacity, determination of Battery capacity and charge controller specification.

Site Inspection

The first step and the most important part of the design is the site inspection. It will determine whether a Photovoltaic system is viable or not. It involves the placement of PV panel to get the maximum sun rays required for the needed charge time of the battery and the determination of the time per day of maximum solar intensity for battery recharge process. Amount of electrical energy that can be generated depends on the time of radiation intensity on PV panel throughout the day. Shadow analysis will help to find out the time duration for which solar radiation falls on solar panel.

Calculation of Building Load

The electrical load of a specific house will dictate the capacity of a PV system to be installed. The residence load profile is determined by listing all the residential appliances with their power ratings and hours of operation at different seasons to obtain the average total energy demand in watt-hours. Inductive load and resistive load should be separately calculated to specify *inverter* rating. Raju, (2015) in his equation gives an idea of how to estimate load. AP_n represents the name of electrical appliance in a building, for example light, fan, TV etc. whereas N_n is its total quantity (n=1, 2, 3, ---∞). Here, n is the representing serial number of appliance. According to Raju, (2015) total power rating (T_p) is the summation of the rated power of individual load multiply by the number of product as shown in equation 1.

$$\Sigma_n W T_n \qquad (1)$$

where,

$\Sigma_n W$ = summation of the rated power

T_n = total number of product

n = serial number of appliance

Selection of System Components

Once the building load is determined, DC Voltage of the PV system has to be fixed. Generally, it should be taken as high as possible so that less current will be required to meet the high energy requirement. Lower current through cables will reduce electrical energy loss, because cable has resistivity and high current will cause joule heating of cable. Otherwise, much thicker wires are required which will increase cost of the system. In addition to PV panels in a typical standalone system, battery, inverter, charge controller, cables and mounting structure are other subsidiary components required.

Determination of Inverter capacity

Solar PV system delivers DC voltage and power. So an inverter, which converts DC power to AC power, is needed as most of the appliances used in a house require AC power. Although, there are still some appliances using DC power in some areas, we have not considered such in this paper in order to keep it simple. An inverter is rated by its output power (P_{KVA}) and DC input voltage (V_{dc}). Power rating of the inverter should not be less than the total power consumed in different loads. On the other hand, it should have the same nominal voltage of battery bank that is charged by solar PV module (Wiles, 2006). In a household, consumption of power in appliances can be classified into two categories: resistive power (P_{res}), such as in light, heater, iron etc. and inductive power (P_{ind}), such as in fan, motor, etc. typically, capacity of the inverter is taken to the sum of all the loads running simultaneously and 3.5 times the total power of the inductive loads to take care of surge protection (Markvart and Castaner, 2003). Further, the value obtained is to be multiplied by 1.25 to get the requirement, if an option of 25% extra is kept for a reasonable future load expansion. The power (P_{invI}) delivered by inverter will be estimated using equation 2 as given by Raju, (2015).

$$P_{invl} = (T_p + 3.5P_{ind}) \qquad (2)$$

where,

P_{inv} = power delivered by inverter

P_{ind} = inductive power

T_p = total power of loads

Here, total power rating of all loads $T_p = P_{res} + P_{ind}$

However, this is an ideal situation. This power calculation has to be corrected for power factor of inverter. Power rating of inverter ($P_{out\ put}$) is related to the real power that is delivered by inverter as output and it is given by Subhra , (2015) as expressed in equation 3.

$$P_f = \frac{Deliverable\_real\_power}{Power\_rating\_of\_inverter} \qquad (3)$$

where P_f = power factor

Real power is the power that is consumed for work on the load (P_{invl}) in this case and it is as calculated from equation (1). Value of P_f is generally taken as 0.8 for most of the inverter. So,

$$P_{kva} = \frac{P_{inv}}{P_f} \qquad (4)$$

where:

P_f = power factor

P_{inv} = power deliver by the inverter

P_{kva} = output power.

Inverter converts DC power to AC power. But this conversion is not 100% efficient. So, efficiency (invl) inverter is an important parameter which has to be taken care of. Continuous AC power load, which is the total power (T_p as obtained above) needed when all the appliances are running at steady state condition, has come from a DC power sources, such as battery. Therefore, the continuous power load to the inverter (T_{pi}) is given by Abhik, (2015) in equation 5.

$$T_{pi} = \frac{T_p}{\eta_{inv}} \qquad (5)$$

where,

T_{pi} = total power to the inverter

T_p = total power

The continuous (DC) input current (I_{dc}) to an inverter from PV modules can be determined, if the system DC voltage (V_{dc}) is specified, according to the following equation,

$$I_{dc} = \frac{T_{pi}}{V_{dc}} \qquad (6)$$

where,

I_{dc}=direct current

V_{dc}=direct voltage

This parameter is needed for battery selection and design. In terms of energy, daily input energy to the inverter (E_{inv}) is daily maximum energy requirement which is E_{daily} as stated by Abhik, (2015) divided by the inverter efficiency, that is;

$$E_{inv} = \frac{E_{daily}}{\eta_{inv}} \qquad (7)$$

where,

E_{invl} = energy of the inverter

E_{daily} = daily maximum energy

This huge amount of energy must come from battery daily to fulfill the load requirement of the inverter.

Determination of battery capacity

The battery type generally suggested for use in solar PV power system application is deep cycle battery, specifically designed such that even when it is discharged to low energy level it can still be rapidly recharged over and over again for years (Dunlop, 2011). The battery should be large enough to store sufficient energy to operate all loads at night, cloudy or raining days. Battery storage is conventionally measured in Ah (ampere hour) unit.

The charge capacity of the battery bank (B_{Ah}) is determined by the daily energy requirement and number of days for backup power (N_{backup}) using the following equation.

$$B_{Ah} = \frac{E_{inv} \times N_{backup}}{V_{dc} \times D.O.D.} \qquad (8)$$

where,

B_{Ah} = energy storage capacity of the battery banking

N_{backup} = number of days for backup power
E_{inv} = energy to the inverter
D = depth of discharge

The percentage of total charge, that is, energy of battery that can be allowed for running the load is referred to as Depth of discharge (D.O.D.) of the battery. C-rating is also an important part of choosing a battery (Pacca, 2007). It tells us what will be the optimum charging and discharging rate of a battery. Typically C-10 rated batteries are available in the market. Optimum battery bank (BO_{Ah}) should be chosen at that rate according to the following formula,

$$BO_{Ah} = \frac{T_p \times C - rating}{V_{dc} \times \eta_{inv}} \quad (9)$$

where,
BO_{Ah} = Optimum energy of the battery bank
V_{dc} = direct voltage
T_p = total power

To meet the requirement of the application load, a number of batteries have to be connected in series for the system voltage specification and in parallel for the current specification. The number of batteries connected in series (B_s) is obtained by system Dc voltage of individual battery using the following equation,

$$Bs = \frac{V_{dc}}{V_{sb}} \quad (10)$$

where,
V_{sb} = voltage of single battery
B_s = battery connected in series
V_{dc} = direct voltage

The number of batteries which will be connected in parallel (B_p) can be obtained by the following equation,

$$B_p = \frac{B_{Ah}}{B_{sc}} \quad (11)$$

where,
B_{sc} = capacity of a single battery
B_p = battery connected in parallel
B_{Ah} = battery bank

The total number of batteries (N_b) can then be obtained by the following equation,

$$N_b = B_s \times B_p \quad (12)$$

where,
N_b = total number of battery
B_s = battery connected in series

If we take battery efficiency (η_{bat}) to be 85% typically for lead acid battery, then energy required (E_{bat}) from the solar PV array to charge the battery bank as given by Abhik, (2015) in equation 13.

$$E_{bat} = \frac{V_{dc} - B_{Ah}}{\eta_{bat}} \quad (13)$$

where,
E_{bat} = total energy required to charge the battery
V_{dc} = direct voltage
B_{Ah} = energy storage capacity of the battery bank
η_{Bat} = battery efficiency

Charge controller specification

The solar charge controller is generally sized in a way that will enable it perform its function of current control. A good charge controller must be able to withstand the array current as well as the total load current and must be designed to match the voltage of the PV array as well as that of the battery bank. Multiple power point trackers (MPPT) charge controller is specified based on PV array voltage handling capacity. Now-a-days, MPPT charge controllers usually come with inverter. There is a recommended voltage range, within which PV array DC voltage must be chosen. Let's take the PV array voltage to be Cc_{volt} which should be greater than system DC voltage.

III. Development of Models

The table below was generated from the theoretical models base on specific load with an interval of 10 watt increment. This is achieved by using a mathematical formula to determine the specification of the component of a battery banking system. It is such that, when the parameters needed for each formula are available, the capacity of each solar banking component can be determined using their respective equation as presented in Table 1.

Calculations by Formula

In determining the battery capacity C_p, equation 14 was utilized as given by Abhik, (2015), which results were presented in Table 2.

$$C_p = R\left[\frac{C}{R}\right]^n \qquad (14)$$

where,
C = capacity of battery at specified hour rating
n = Peukert constant (1.3)
R = the hour rating (10 hrs)
The panels capacities (PV_c) were determined using equation 15 as presented in Table 3.

$$PV_c = \text{load} \times \text{peak sun hour} \times \text{shading} \times \text{Panel ratings} \qquad (15)$$

where,
Peak sun = 4hrs
Shading = 0.8
ratings = 0.75
The Charge controller capacities (C_c) were determined using equation 16 as presented in Table 4.

$$C_c = \text{Total short circuit current of PV array} \times 1.3 \qquad (16)$$

The Inverter's capacity (E_{inv}) was determined using equation 17 as presented in Table 5.

$$E_{inv} = \frac{\text{voltage } X \text{ battery X capacity } X \text{ efficiency of inverter}}{\text{load}} \qquad (17)$$

where
Voltage = 12v
Efficiency of inverter = 0.75

IV. Regression Analysis

The regression was done with the use of microsoft excel; the table was prepared as shown in the Figure below with the Load as the X- input and other components, which are: charge controller, inverter, battery and price as the Y- input. In order to get the regression output, the following steps were taken; enter the data into the spreadsheet that you are evaluating, input Y represents the dependent variable that is the inverter, battery, charge controller or pv panel while Input X is the indepent variable, that is, load, Open the Regression Analysis tool. If the version of Excel displays the ribbon, go to Data, find the Analysis section, hit Data Analysis and choose Regression from the list of two. If your version of Excel displays the traditional toolbar, go to Tool > Data Analysis box, click inside the input Y range box. Then, click and drag your cursor in the Input Y range field to select all the numbers you want to analyze. You will see a formula that has been entered into the input Y range spot. Repeat the previous step for the input X range. Modify your settings as desired: Choose whether or not to display labels, residuals, residual plots, e.t.c. by checking the desired boxes. Click OK. The summary of the regression output will appear where designated. These results are similar to each other and also the equation of each parameter with respect to the load is linear. In order to construct a regression model, both the information which is to be used to make the prediction and the information which is to be predicted must be obtained from a sample of objects. The relationship between the two pieces of information is then modeled with a linear transformation. Then in the future only the first information is necessary, and the regression model is used to transform this information into the predicted. In other word, it is necessary to have information on both variables before the model can be constructed. A notational scheme is now necessary to describe the procedure; X_i is the variable used to predict, and is sometimes called the independent variable. In this case, it would be the load; Y_i is the observed value of the predicted variable, and is sometimes called the dependent variable. In this case, it would be the desired specification of component; Y'_i is the predicted value of the dependent variable. In this, it would be the predicted specifications of components. The situation using the regression model is by performing a linear transformation of the predictor variable. The prediction takes the form

$$Y^l = a + bX$$

where,
a and b are parameters in the regression model.

The goal in the regression procedure is to create a model where the predicted and observed values of the variables to be predicted are as similar as possible. The more similar these two values are, the better the model.

V. Result And Discussion

The regression model was developed by using formula to determine the relationship between the load and the components of the banking system. The amount of load desired is used as the independent entity in varying the rating of the banking system's components.

The equations of the developed model were given by equation 18, 19, 20, 21, and 22.

which are:

$B = 2.37L - 39.1666667$ (18)

$I = 0.06688571L + 11.3585714$ (19)

$C_C = 3.12L$ (20)

$PV = 2.4L$ (21)

where,

B = Battery specification

I = Inverter specification

C_C = Charge controller specification

PV = Photovoltaic panel specification

L = Load

The models were tested with load of 50watts, 60watts, 70watts, 80watts, 90watts, 100watts and the following results were obtained as shown in Table 6. The results in Table 6 was compared with the theoretical value as shown in Table 7 , these values were analyzed for both predicted and theoretical using regression analysis for each component in order to determine the R square value. The correlation coefficient for each component was determined by finding the square root value for each component. Table 8 shows the comprehensive results of their correlation coefficient. In Table 9, the minimum coefficient is 0.995141 this shows that the relationship between the theoretical and predicted model is highly dependable, which means that the mathematical model can be used in place of theoretical model.

VI. Conlusion

Regression models were developed in this study, which serves as a powerful tool for predicting a value based on some other values. They involve a linear transformation of dependent variables for predicting the expected value. The parameters of the linear transformation are selected such that the least squares criterion was met, resulting in an "optimal" model. The model can then be used in the future to predict either exact value or intervals of values for battery banking components specification.

Recommendation

The regression model developed is essential to determine for every house, firm or companies who are interested in solar power system installation, the battery banking components specification in order to take advantage of the enormous solar energy that is available in the country.

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Table 1: Theoretical Models Result

S/N	LOAD (w)	BATTERY (A/hr)	INVERTER (w)	CHARGE CON. (w)	PV (w)
1	50	81	14.58	156	120
2	60	103	15.45	187.2	144
3	70	125	16.10	218.4	168
4	80	149	16.76	249.6	192

5	90	174	17.40	280.8	216
6	100	199.5	17.96	312	240

Table 2: Load against Battery Rating

Load	50	60	70	80	90	100
Battery (Ahr)	81	103	125	149	174	199.5

Table 3: Load against PV panel

Load	50	60	70	80	90	100
PV panel (W)	120	144	168	192	216	240

Table 4: Load against charge controller

Load	50	60	70	80	90	100
Charge Con(A)	156	187.2	218.4	249.6	280.8	312

Table 5: Load against inverter

Load	50	60	70	80	90	100
Inverter (w)	14.58	15.45	16.1	16.76	17.4	17.79

Table 6: The Anova Table For Regression Model

S/N	LOAD (W)	BATTERY (A/hr)	INVERTER (w)	CHARGE CON. (w)	PV (w)
1	50	81	156	14.58	120
2	60	103	187.2	15.15	144
3	70	125	218.4	16.10	168
4	80	149	249.6	16.76	192
5	90	174	280.8	17.40	216
6	100	197.83	312	18.05	240

Table 7: Comparisons Between Theoretical (Th) Results And Predicted (P) Result

S/N	LOAD (w)	BATTERY (A/hr)		INVERTER (w)		CHARGE CONT. (A)		PV (W)	
		B_P	B_{TH}	I_P	I_{TH}	CC_P	CC_{TH}	PV_P	PV_{TH}
1	50	79.33	`81	156.0	156	14.7	14.58	120	120
2	60	103.03	103	187.2	187.2	15.37	15.45	144.0	144
3	70	126.73	125	218.4	218.4	16.04	16.10	168.0	168
4	80	150.43	149	249.6	249.6	16.71	16.76	192.0	192
5	90	174.13	174	280.8	280.8	17.38	17.40	216.0	216
6	100	197.83	199.5	312	312	18.05	17.79	240.0	240

Table 8: REGRESSION STATISTICS

REGRESSION STATISTICS	BATTERY	INVERTER	CHARGE CONT.	PV PANEL
Multiple R	0.99946	1	0.99514	1
R Square	0.998919	1	0.990307	1
Adjusted R Square	0.998649	1	0.987883	1
Standard Error	1.63044	0	0.137976	7.72E-15
Observations	6	6	6	6

Table 9: CORRELATION COEFFICIENT (R)

COMPONENT	R^2 square	(R)
Battery (R_b)	0.998919	0.999459
Inverter (R_{inv})	1	1
charge controller (R_{cc})	0.990307	0.995141
Pv Panel (R_{pv})	1	1

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