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PV Plant Connection and Sizing Design Methodology

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Key words: PV system sizing, PV system design, inverter connection, maximum energy yield, statistical analysis, PV module connection

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Abstract: As energy is a main factor of sustainable development, renewable energy as an alternative to fossil fuels has been increasingly deployed with Photo Voltaic (PV) being the most common. Several design factors and proper sizing of these systems must be considered for maximum energy yield. This includes type of PV modules, number of series connected modules and number of strings. In addition to the number, type and typologies of inverters and the Maximum Power Point Tracking (MPPT) method employed. The system design must utilize the best combination to deliver the highest possible energy yield. In this study, a new methodology to design and size a PV system is proposed. The methodology is based on system modeling, simulation and statistical analysis.

INTRODUCTION

Energy is the driving force of business, industry and transportation of services to serve economies. It is a main factor of sustainable development. Energy, especially, electricity does a major function in developing the quality of life.

Large PV generation plants are organized in combinations of series and parallel PV modules and strings to meet inverter voltage and current requirements. PV systems generally consist of three major parts: PV panels, power converters and controller. The number and method of connection of the series and parallel connected modules varies as per the requirement of the connected inverter and load[1].

A photovoltaic system consists of a number of PV solar cells. For higher output power, PV cells can be connected together in series and parallel. The equivalent circuit of a PV cell is shown in Fig. 1.

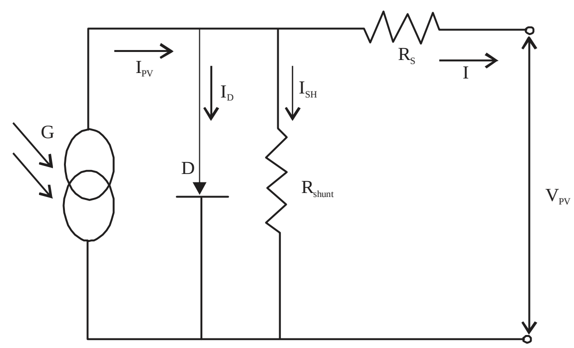

Fig. 1: Equivalent circuit of a PV cell

The output power of the PV panels is a function of its operating voltage. The current-Voltage (I-V) and Power-Voltage (P-V) characteristics curves are shown in Fig. 2.

Inverters are power electronic devices that are used to convert DC power of the PV array into AC power with

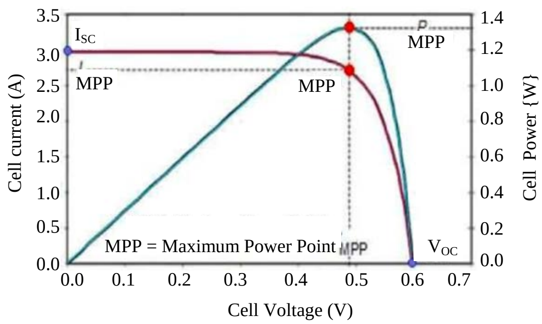

Fig. 2: I-V and P-V characteristics curves for PV panel

proper voltage magnitude, frequency and phase[2]. There are many configurations for power inverter topologies including: central, string, multi string and micro inverters[3].

The proper selection of the suitable inverter for the specific application is a very important step in designing of PV systems. The correct selection depends on various factors such as: maximum DC voltage, inverter's output current, power capabilities of PV modules and PV array configuration[4].

Central inverter are large inverters which may serve large parts of the plant. Typical sizes are in the range of 750 kW to 2 MW. The main drawback is that the maximum power point of each module can be lost due to partial shading and clouding conditions. Other drawbacks include the existence of high-voltage DC cables and the lack of flexibility to increase the system[5]. On the other hand, this type has a simple configuration and it is reliable which makes it the best choice for large-scale PV systems. Furthermore, a multi-central inverter system can be achieved by connecting the output of several central inverters in parallel[5].

String inverters can solve the main drawback of central inverters which is the limitation of reaching the MPP of individual modules. A string contains an appropriate number of PV modules connected to the inverter. Compared to central inverters, string inverters provide a more accurate MPPT and higher efficiency during partial shading and clouding conditions. This type is used in small and medium-scale PV systems[5].

In a micro-inverter configuration, each PV module has its own inverter. The main advantages of this configuration is that it eliminates the gap-losses between the PV modules, raises the MPPT accuracy, reduces the effect of shading. However, using an inverter for each module leads to increase in the cost per watt[5].

The efficiency of photovoltaic modules is extremely low, and the output power continuously changes due to the environmental conditions such as change in radiation intensity and ambient temperature. Different control methods are applied to guarantee that most of the available power is harvested. For any solar module there is always a single Maximum Power Point (MPP) for a certain value of current and voltage[6].

MPPT is basically operating-point matching between the PV modules and power converter. The aim is to ensure that at any given radiation or temperature the maximum available power is extracted from the PV modules through matching its Power-Voltage (P-V) operating-point with the corresponding power converter[7, 8].

There are different classifications of MPPT methods, the most popular are: conventional methods which use real time measured data (such as radiation, temperature, current and voltage) such as incremental conductance and perturb and observe methods. Artificial intelligence based methods use real time data and have better performance characteristics than conventional methods such as fuzzy logic and hybrid methods that combine two of the above methods[9].

Conventional methods have many advantages that include simplicity, ease of implementation, fewer measured parameters and low cost[7, 8]. They vary in many aspects allowing for application-based selection in simplicity, number of sensors, speed of reaching MPP, cost, operating variety, efficiency to discover several local MPP and their uses[10]. They also vary in the precision of expecting exact MPP and sensibility[11].

The Perturb and Observe (P&O) algorithm is one of the most preferable MPPT method because of its simplicity, ease of implementation and its accuracy[8-10, 12]. The aim of this method is to force the PV voltage to its maximum value such that maximum power can be extracted from the system.

The incremental conductance (IncCond) Method is one of the most commonly used MPPT due to its high performance, ease of implementation and rapidity in tracking MPP[13]. It has many advantages compared to P&O method. It works more efficiently when there is a rapid change in weather conditions[14, 15]. Furthermore, it results in no oscillation around the MPP while such oscillation is observed when using the P&O method[13]. On the other hand it is more complex than the P&O method[9, 16].

The principle of operation depends on the power variation and the sign of the slope of the photovoltaic system power curve. The slope is zero at MPP, negative if Pout is higher than MPP and positive if Pout is less than MPP[8].

The literature is rich in knowledge related to inverter design, MPPT methods and control implementation. There is also plenty of discussion on PV system design, but the literature lacks a discussion how these different components and parameters effects the overall PV system energy yield. In this study detailed modeling and simulation in addition on statistical analysis of simulation results are used to better design and size PV systems for high specific energy yield.

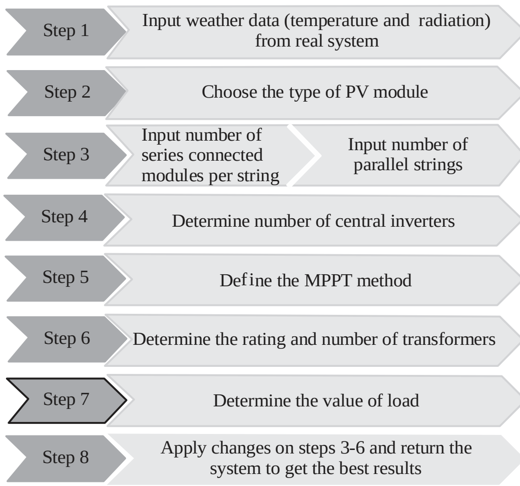

Fig. 3: PV plant sizing procedure

MATERIALS AND METHODS

In this research, a 5 MW PV power plant project at Jordan University of Science and Technology (JUST) is considered as a case study was implemented and simulated in MATLAB/Simulink. The system was simulated to validate the output current, voltage and DC power against real system data. This was done to ensure that the modeled system matched the real system's performance.

The MPP depends on the voltage and current of the PV system that is connected to the inverter. The inverter also has a voltage operating range and a maximum power. This is accomplished by connecting PV modules in series strings to meet the voltage requirement and then placing these strings in parallel to increase the current and meet the power requirement. These inverters are then paralleled to meet the plant power requirements. The overall energy yield depends on choosing the properly sized inverter, then making the right series parallel combination. The following procedure is proposed to properly size the PV plant.

Figure 3 demonstrates the repeated loop (Step 3,4,6) which were implemented in details to determine the most significant factor affecting the AC output power of the system. Among the different parameters: the number of series modules per string, the number of parallel strings for each inverter, the number of inverters (Fig. 4).

The voltage of the system (VPV), current of the system (IPV) and system power (PPV) are measured. The inverter typology is then selected (either central or string), and the number of inverters which will be used in the first iteration is specified. Furthermore, the number of series modules per string and number of parallel strings for each inverter are determined to meet power requirements is calculated.

The model is then simulated in MatLab and new records for the voltage VPV, cal, IPV, cal and PPV, cal are saved. PPV and PPV, cal are then compared, if they are equal then the system is optimal and there is nothing to do to enhance its performance. Contrary if PPV is less than PPV, cal, then the algorithm proceeds to the next step and increase the number of strings and re-calculates the number of series connected module per string and rerun the simulation recording the new value of PPV, cal and updating the previous value. Then the difference between the old value of PPV, cal and the new one is calculated (p). The condition of this value is checked if it is >1% repeat the increase step of parallel string and calculating the number of series connected modules, run the system, record PPV, cal, calculate (p) and check the value of p until p<1%. In this case the system has reached a close to optimum point for the specified number of inverters. The algorithm then repeats the above steps for a different number of inverters. As the computation effort is a large burden, it is important to understand the effect of each design parameter on the energy yield to better apply the design algorithm.

The correct sizing and design of grid connected PV systems is an important issue to insure that the system operates in an optimal way with high performance. The correct sizing depends on many factors, however, the most important two are: the sizing of the main components of the system such as PV array and inverters and connecting in a suitable combination.

There are many techniques to reach to the optimal design of PV systems, one of which is the Design of Experiments (DoE) which is used in this research. Statistical analysis is the science of accumulating, discovering and offering large amounts of data to find out primary forms.

DoE is a statistical analysis used as a practical method to help understand and describe variability between factors[17]. This may then be used to select the best design for each component in order to optimize the energy yield of the overall system. It can also be used to perform detailed analysis of measurements to better understand the results and enhance the overall system performance[18].

The use of experimental design in the engineering design procedure results in products that are: easier to manufacture have better field reliability and performance than another product designed without using DoE and products that can be produced, designed and developed in less time and cost of operation[16].There are many tools for statistical data analysis; the two major tools are Factorial Analysis and Analysis of Variance (ANOVA).

When performing ANOVA, experiments are usually part of the engineering and technical decision-making procedure. Experiment usually consists of performing more than one test sample. Findings from experiment are usually used to make decisions according to design factors. Many experiments required considering more

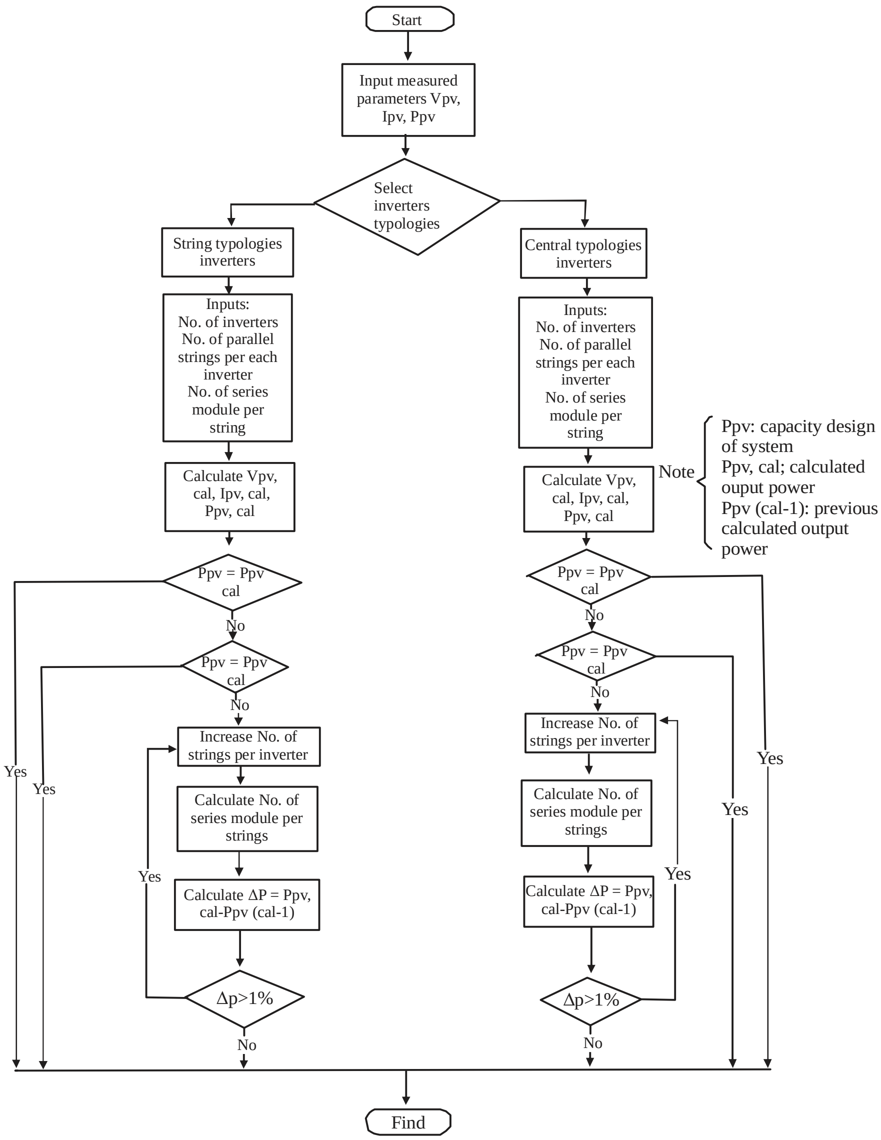

Fig. 4: Proposed algorithm flow chart

than two levels for each factor in this case the Analysis of Variance (ANOVA) should be used. It can be used for one factor (One-Way ANOVA) and two factors (Two-Way ANOVA). For a higher number of factors, it will be complicated to apply ANOVA, so, a different tool of DoE must be used which is factorial analysis.

Factorial Analysis is used when many factors are of interest in an experiment, these factors have low and high levels and the interaction between these factors are taken in consideration. The effect of each factor and the change in their levels are expressed as well as the change in response. This effect is called the main effect[16]. Factorial Analysis was used in this study, since, there are >2 factors with most having >2 levels.

In this study the Design of Experiment (DoE), specifically factorial analysis was carried out using Minitab 17 Software. This is done to determine the most significant factor (inputs) which affecting the energy yield (output) and to get a mathematical relationship between two or more of these factors and the response. There are many evaluation indexes to evaluate the performance of the PV system. Energy yield was chosen to be the response for the factors variation.

RESULTS

In this research, a 5 MW PV power plant project at Jordan University of Science and Technology (JUST) is considered as a case study was implemented and

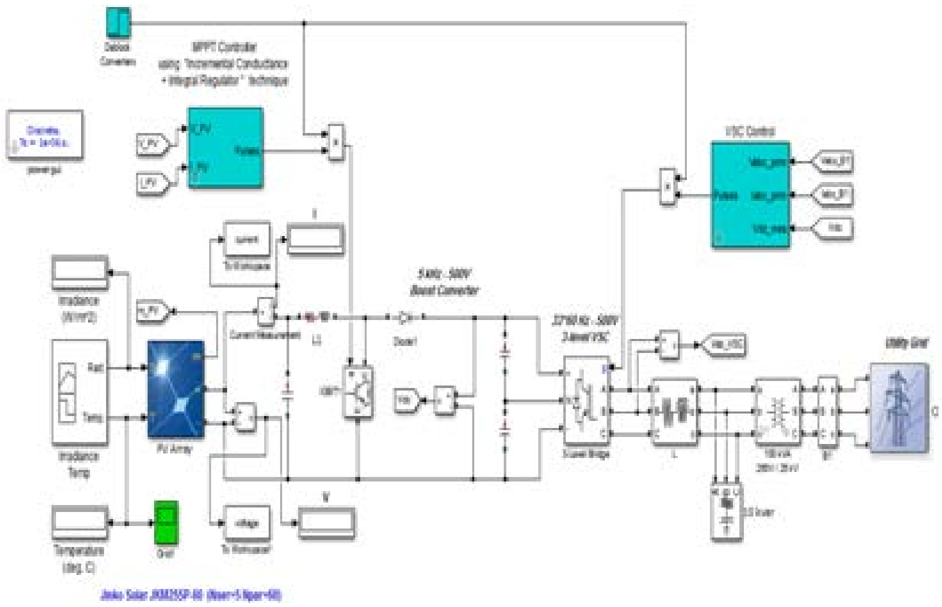

Fig. 5: PV system Simulink Model

Table 1: PV Panel specifications

Specification	Values
Manufacturer	Jenko solar
Maximum power voltage	31.4 V
Open circuit voltage: 38.6V	38.6 V
Maximum power current: 8.44A	8.44 A
Short-Circuit current: 9.03A	9.03 A
Efficiency: 16.19%	16.19%

Table 2: JUST inverter specifications

Specification	Values
Manufacturer	SMA
Operating temperature range	-25 to +60ºC
Related power at nominal voltage	60000 W
Maximum apparent AC power	60000 VA
Maximum reactive power	60000 VAR
Nominal AC voltage	400-480 V, ±10%
Maximum input voltage per string	1000 V
Number of MPPTs	1
MPP voltage range	570-800 V
Maximum input current	110A

simulated in MATLAB/Simulink. Simulation results were compared to actual data measured. The specifications of the PV panels used are shown in Table 1 and of the inverter used in Table 2.

Figure 5 shows a sample of the PV system model. This structure includes the following components and blocks: irradiance and temperature, PV array, boost converter, inverter, MPPT algorithm, VSC control, transmission lines, transformer and the utility grid.

The first six blocks were then repeated 22 times to represent one transformer link of the 5 MW system. These components were then repeated four times to match the actual system configuration. The complete modeled system contains 84 signal builder blocks, PV arrays, boost converters, MPPT algorithm blocks and inverters. Since, string inverter topology is used an additional 84 VSC control blocks, one transformer and one utility grid are connected to model the whole 5 MW system.

The system was simulated to validate the output current, voltage and DC power against real system data. This was done to insure that the modeled system matched the real system's performance.

There are many evaluation indexes to evaluate the performance of the PV system. Energy yield was chosen to be the response for the factors variation. Table 3 shows the input and output results obtained from repeated MATLAB/Simulink simulations.

In general, the function that connects the response y-with the k-factors x and takes the form of 4th° polyline is expressed as:

$$y = f\left(x1 \times x2 \times x3, ..., xk\right) \tag{1}$$

$$y = \sum_{i=0}^{k} ao + aixi + \sum_{\substack{i,j=1 \\ i<j}}^{k} aijxixj + \sum_{\substack{i,l=2 \\ i<l}}^{k} ailxixl +^{k} \tag{2}$$

Where:

y = Response stands for energy yields
x = x factors
k = Number of x factors

ao, ai, aij, coefficients to be calculated and represents the effects and interactions in factorial design. Higher coefficient means higher effect on response for this factor.

Table 3: Input factors and output responses

Energy yield	Series modules	Parallel strings	Power (kWp)	Specific energy (kWh/kWp)	MPPT method (kWh)	Number of inverters
718.96	22	10	561	1.28	PO	10
959.86	22	10	561	1.71	IncCond	10
1364.66	22	10	1122	1.22	PO	20
1698.30	22	10	1122	1.51	IncCond	20
1743.58	22	10	2244	0.77	PO	40
2169.97	22	10	2244	0.97	IncCond	40

Table 4: Series connected modules, parallel strings and MPPT

Energy yield (kWh)	Series modules	Parallel strings	Power (kWp)	Specific energy (kWh/kWp)	MPPT method
718.95	22	10	561	1.28	PO
732.46	27	8	550.8	1.33	PO
684.47	22	12	673.2	1.02	PO

Table 5: MPPT methods vs. series module, parallel strings

Energy yield (kWh)	Series module/parallel strings	Power (kWp)	Specific energy (kWh/kWp)	MPPT method
732.466	8/27	550.8	1.33	PO
718.956	10/22	561	1.28	PO
684.478	12/22	673.2	1.02	PO
985.858	8/27	550.8	1.79	IncCond
959.861	10/22	561	1.71	IncCond
973.608	12/22	673.2	1.45	IncCond

Initially, each two factors were taken together to find the more significant one and then all factors at the same time to rank from the highest effect to the least. The factors were studied in 3 steps, the comparison between two factors was done individually.

Series connected module vs. parallel strings: For the comparison between the series connected modules and the parallel strings within an array, one MPPT method was studied at a time, the number of inverters was 10 (Table 4).

Mppt methods vs. series connected module, parallel strings: The next step is to determine the most significant MPPT method and whether it is more significant than the array configuration. To do so, the two MPPT methods were implemented individually to the three sets of the array configuration while fixing the number of inverters at 10. The energy yield from each set was then compared as shown in Table 5.

Number of inverters vs. MPPT: In this step a comparison between the energy yield obtained from the two MPPT methods with different number of inverters was done. The number of series connected modules and the number of parallel string was studied, 22 series connected modules and 10 strings were used as a test bed for comparison.

DISCUSSION

The simulation results from MATLAB were then used in the statistical analysis done in Minitab.

Series connected module vs. parallel strings: When comparing the effect of series connected modules and parallel strings, the regression equation is (Fig. 6):

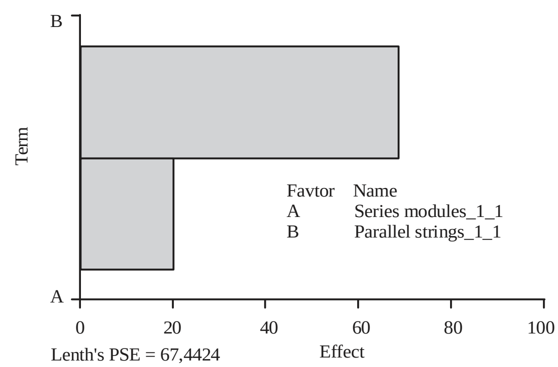

Fig. 6: Pareto chart of series modules vs. parallel strings; Pareto chart of the effect (response is energy yield_1_2; α = 0.05)

$$\text{Energy yield} = 983.6 + 4.194\,\text{series modules} - 17.24\,\text{parallel strings} \quad (3)$$

The Pareto chart shows that the parallel strings have a higher effect on energy yield than series connected modules. The coefficients for each factor in the regression equation also prove this result. Parallel strings have higher coefficient values than series modules.

The contour plot shown in Fig. 7 shows that when using 8 parallel strings with 27 series connected modules per string within the array, the energy yield has the highest value. Three array configuration will be used in the following comparisons:

- Configuration 1 (sp1): 8 parallel strings with 27 series modules
- Configuration 2 (sp2):10 parallel strings with 22 series modules.
- Configuration 3 (sp3): 12 parallel strings with 22 series modules

Table 6: MPPT methods vs. No. of inverters

Energy yield (kWh)	Power (kWp)	Specific energy (kWh/kWp)	MPPT methods	Number of inverters
959.86	5616	1.71	IncCond	10
718.96	5616	1.28	PO	10
1698.30	11226	1. 51	IncCond	20
1364.66	11226	1.22	PO	20
2169.971	22446	0.97	IncCond	40
1743.581	22446	0.77	PO	40

Table 7: Factorial analysis results for MPPT vs. sp

Analysis of variance

Source	df	Adj. SS	Adj. MS	F-values	p-values
Model	3	103405	34468	206.81	0.005
Linear	2	103081	51541	309.24	0.003
sp	1	900	900	5.4000	0.146
MPPTT	1	102181	102181	613.09	0.002
2-way interactions	1	324	324	1.9400	0.298
sp*MPTT	1	324	324	1.9400	0.298
Error	2	167	167		
Total	5	103739			

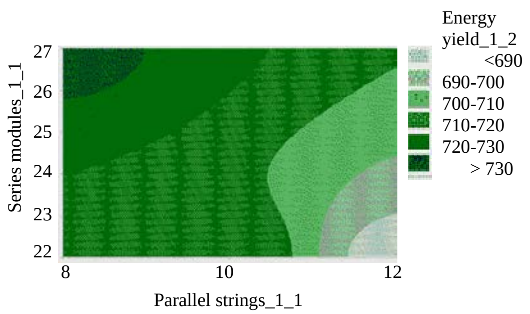

Fig. 7: Contour plot of energy yield vs. series modules and parallel strings; Contour plot of energy yield_1_2 vs. series modules_1_parallel strings

MPPT methods vs. Series connected module, parallel strings: Factorial analysis was applied to the data presented in Table 6 using Minitab to determine which factor was more significant between the MPPT methods and array configuration at 10 inverters. The results are as following. The regression Equation is (Table 7):

$$\text{Energy yield} = 841.8\text{-}3.333\,\text{sp.}+130.5\,\text{MPPTT} \tag{4}$$

It can be concluded according to the DoE analysis results that MPPT is a more significant factor than Array configuration (sp) because it has a higher F-value and a higher coefficient in the regression equation. Figure 8 shows the results of the analysis.

As can be concluded from Fig. 8, MPPT is a more significant factor, followed by the interaction between it and parallel strings, then the interaction with series connected modules, after that comes parallel strings and finally series connected modules per string.

The contour plots shown in Fig. 9 show that when sp1 is used with the IncCond. method, the energy yield is higher than with the PO method.

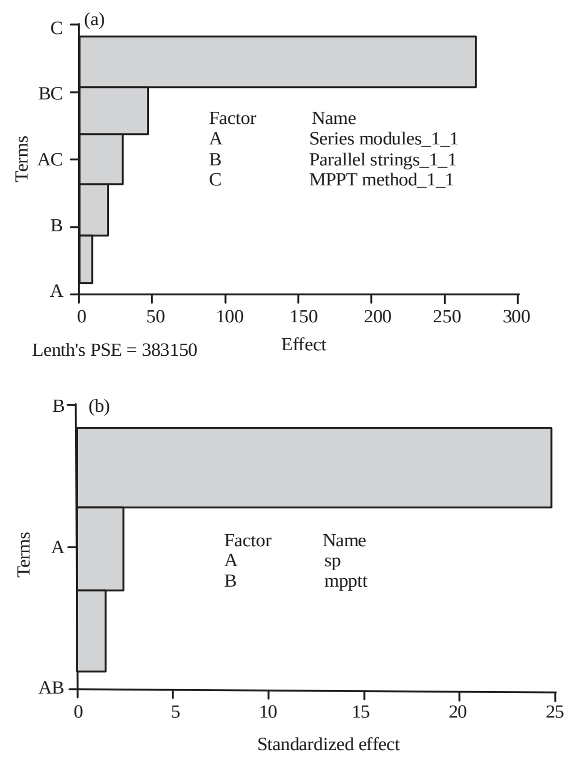

Fig. 8(a, b): (a) Pareto chart of the effect (sp, MPPT) and (b) Pareto chart of the effects (series modules, parallel strings and MPPT); Parto chart of the effect (response is energy yield_1_2, α = 0.05); Parto chart of the standardized effect (response is energy; α = 0.05)

Number of inverters vs. MPPT: Performing statistical analysis on the data from Table 6, results are shown.

Table 8: Factorial analysis results for MPPT vs. no. of inverters

Analysis of variance

Source	df	Adj. SS	Adj. MS	F-values	p-values
Model	3	1318221	439407	6.670	0.133
Linear	2	1316922	658461	10.00	0.091
MPPT	1	174111	174111	2.640	0.246
inv	1	1142811	1142811	17.35	0.053
2-way interactions	1	8279	8279	0.130	0.757
MPPT*inv	1	8279	8279	0.130	0.757
Error	2	131757	65879		
Total	5	1449978			

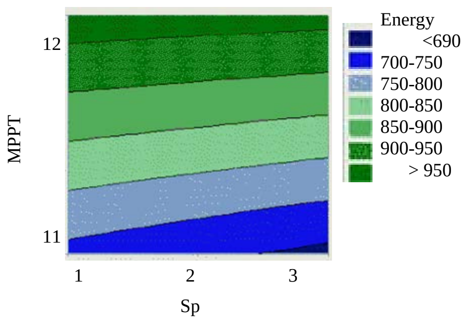

Fig. 9: Contour plot of (energy yield vs. sp, MPPT); Control plot of energy vs. MPT. sp

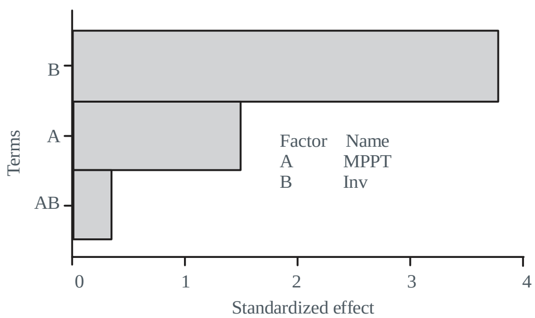

Fig. 10: Pareto chart of the effect (inv, MPPT); Parto chart of the standardized effect (response is energy yield_1_1; α = 0.05)

Regression equation:

$$\text{Energy yield} = 1442+514.7\ \text{inv}+166.9\ \text{MPPT}$$

It can be concluded according to the DoE analysis results that inv (number of inverters) is a more significant factor than MPPT as is shown in Table 8. Because it has a higher F-value and for the interaction between the two factors it has the lowest F-value. In addition, as obtained from the regression equation the number of inverters coefficient was higher than MPPT method coefficient. As Fig. 10 shows, the number of inverters is the most significant factor followed by the type of MPPT then the interaction between these two factors.

The contour plots shown in Fig. 11, point out that when the IncCond. methodis used with 40 inverters, the energy yield has a higher value than for the same MPPT with less number of inverters. It we can be concluded that using higher number of inverters give higher energy yield.

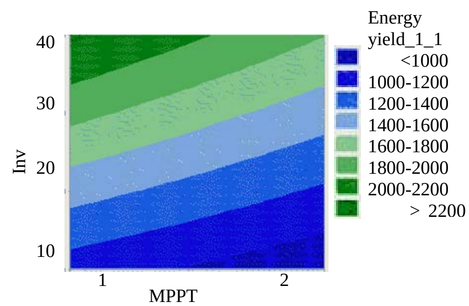

Fig. 11: Contour plots of (energy yield vs. inv, MPPT); Contour plot of energy yield_1_ vs. inv; MPPT

CONCLUSION

A PV power plant was modeled and simulated in MatLab/Simulink. A new approach for sizing PV systems was proposed and a statistical analyze to determine the most significant factors was performed in Minitab. It was found that the number of inverters used in the configuration is the most significant factor effecting energy yield, followed by MPPT methods and parallel strings while series connected module being the lest significant. In addition, the interaction between the studied factors has a slight effect on overall energy yield of the system.

Simple summary: Several design factors and proper sizing of PV systems must be considered for maximum energy yield. In this paper, a new methodology to design and size a PV system is proposed. A PV power plant was modeled and simulated in MATLAB/Simulink. It was found that the number of inverters used in the configuration is the most significant factor effecting energy yield, followed by MPPT method sand number of parallel strings while the number of series connected module being the lest significant.

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REFERENCES

01. Rajesh, R. and M.C. Mabel, 2015. A comprehensive review of photovoltaic systems. Renewable Sustainable Energy Rev., 51: 231-248.
02. Pattanaik, P.A., N.K. Pilli and S. Singh, 2015. Design, simulation & performance evaluation of three phase grid connected PV panel. Proceedings of Power, Communication and Information Technology Conference (PCITC), October 15-17, 2015, IEEE, Bhubaneswar, India, pp: 195-200.
03. Hassaine, L., E. OLias, J. Quintero and V. Salas, 2014. Overview of power inverter topologies and control structures for grid connected photovoltaic systems. Renewable Sustainable Energy Rev., 30: 796-807.
04. SBaez-Fernandez, H., N.D. Ramirez-Beltran and M.I. Mendez-Pinero, 2016. Selection and configuration of inverters and modules for a photovoltaic system to minimize costs. Renewable Sustainable Energy Rev., 58: 16-22.
05. Hasan, R., S. Mekhilef, M. Seyedmahmoudian and B. Horan, 2017. Grid-connected isolated PV microinverters: A review. Renewable Sustainable Energy Rev., 67: 1065-1080.
06. Jaiswal, P., S.K. Srivastava and K.B. Sahay, 2016. Modeling & simulation of proposed 100 kW solar PV array power plant for MMMUT Gorakhpur. Proceedings of the 2016 International Conference on Emerging Trends in Electrical Electronics & Sustainable Energy Systems (ICETEESES), March 11-12, 2016, IEEE, Sultanpur, India, pp: 261-266.
07. Shukla, R.D. and R.K. Tripathi, 2012. Maximum power extraction schemes and power control in wind energy conversion system. Int. J. Scient. Eng. Res., 3: 1-7.
08. Liu, L., X. Meng and C. Liu, 2016. A review of maximum power point tracking methods of PV power system at uniform and partial shading. Renewable Sustainable Energy Rev., 53: 1500-1507.
09. Gupta, A., Y.K. Chauhan and R.K. Pachauri, 2016. A comparative investigation of maximum power point tracking methods for solar PV system. Solar Energy, 136: 236-253.
10. Safari, A. and S. Mekhilef, 2011. Simulation and hardware implementation of incremental conductance MPPT with direct control method using cuk converter. IEEE. Trans. Ind. Electron., 58: 1154-1161.
11. Viswambaran, V.K., A. Ghani and E. Zhou, 2016. Modelling and simulation of maximum power point tracking algorithms & review of MPPT techniques for PV applications. Proceedings of the 2016 5th International Conference on Electronic Devices, Systems and Applications (ICEDSA), December 6-8, 2016, IEEE, Ras Al Khaimah, pp: 1-4.
12. Reisi, A.R., M.H. Moradi and S. Jamasb, 2013. Classification and comparison of maximum power point tracking techniques for photovoltaic system: A review. Renew. Sustainable Energy Rev., 19: 433-443.
13. Loukriz, A., M. Haddadi and S. Messalti, 2016. Simulation and experimental design of a new advanced variable step size incremental conductance MPPT algorithm for PV systems. ISA. Trans., 62: 30-38.
14. Chauhan, J., P. Chauhan, T. Maniar and A. Joshi, 2013. Comparison of MPPT algorithms for DC-DC converters based photovoltaic systems. Proceedings of the 2013 International Conference on Energy Efficient Technologies for Sustainability, April 10-12, 2013, IEEE, Nagercoil, India, pp: 476-481.
15. Bendib, B., H. Belmili and F. Krim, 2015. A survey of the most used MPPT methods: Conventional and advanced algorithms applied for photovoltaic systems. Renewable Sustainable Energy Rev., 45: 637-648.
16. El-Khozondar, H.J., R.J. El-Khozondar, K. Matter and T. Suntio, 2016. A review study of photovoltaic array maximum power tracking algorithms. Renewables Wind Water and Solar, Vol. 3, No. 1. 10.1186/s40807-016-0022-8
17. Montgomery, D.C. and G.C. Runger, 2010. Applied Statistics and Probability for Engineers. John Wiley & Sons, New York, USA.,.
18. Hannane, F., H. Elmossaoui, T.V. Nguyen, P. Petit, M. Aillerie and J.P. Charles, 2013. Forecasting the PV panel operating conditions using the design of experiments method. Energy Procedia, 36: 479-487.