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International Journal of
Electrical and Electronics Research (IJEER)
Research Article | Volume 11, Issue 4 | Pages 988-992 | e-ISSN: 2347-470X

Optimal Location and Size of Solar photovoltaic Generator to Improve the Stability of Iraqi National Super Grid Power System

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ABSTRACT- The Iraqi National Super Grid Power System is facing significant challenges in terms of stability and reliability, leading to power outages and disruptions. One potential solution to this problem is the integration of solar photovoltaic generator (SPVG) into the grid system. This article explores the optimal location and size of solar PV generators in order to improve the stability and reliability of the Iraqi National Super Grid Power System (INSGPS). The simulation results showed that the bus (20) is the optimal location for connecting the solar PV generator, and also through the simulation a 1000 MW is the optimal capacity (optimal size) of the SPVG determined using the capacitance technique, that gives the least losses in the power system network, which led to an improvement in the voltage margin and an increase in the load factor, which enhanced the stability of the system. The program software, which was utilized in this work were done by MATLAB (R2020a) package based on power system network load flow analysis tool-box (PSAT - version 2.1.11) using Newton-Raphson (N-R) algorithm.

Keywords: Solar PV generator, INSGPS, load flow, Voltage stability, Optimal Location, Optimal Size, PSAT software.

ARTICLE INFORMATION

Author(s): Mohammed A. Khalaf, Abdulstar H. Jasim and Bilal A. Nasir;

Received: 28/07/23; **Accepted**: 20/10/23; **Published**: 07/11/23;
E- ISSN: 2347-470X;
Paper Id: IJEER230717;
Citation: 10.37391/IJEER.110416
Webpage-link:
https://ijeer.forexjournal.co.in/archive/volume-11/ijeer-110416.html

1. INTRODUCTION

Stability of the power system voltage is the main key-point to obtain acceptable system voltages at all bus-bars of the system considering normal operation and contingencies. Therefore, when an over-load or disturbance cause an increasing and uncontrollable voltage drop, the power system becomes in a state of instable voltage [1].

From the analysis of voltage stability, the relationship between the system voltage and load becomes the point of interest. In this analysis the power-voltage (P-V) curve, also known as "nose" curve is widely used for this type of analysis. As shown in *figure 1*, the nose point indicates the critical condition of operation, which is represented as the maximum limit of an acceptable operation [2].

For a demand of higher load, the power part of the curve has points with inverse P-V sensitivity, as the voltage increased with increasing the load power. The distance between the critical point and the operating point (P_0), in MW, is defined as the margin of the voltage stability. P-V curve is usually obtained using fixed approaches, including the analysis of load flow and continuation of power flow [2,3].

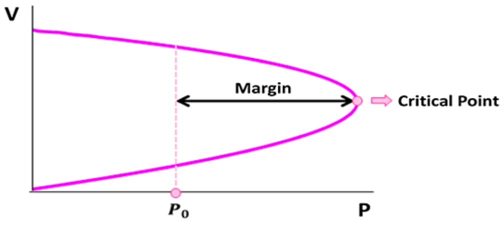

Figure 1: P-V characteristics

The analysis of voltage stability is used by static methods due to their simplicity and acceptable accuracy. The modeling and performance analysis of the SPVG on power system voltage stability were executed to improve the system stability by increasing the ability boundary [4-5].

In this work, a comprehensive deliberating is carried out to articulate the SPVG influence in improving and enhancing of power system voltage stability by using three techniques (minimum power loss, reactive power-voltage curve and continuation power flow). The utilized techniques are examined on the Iraqi National Super Grid power system.

The remainder of the paper is arranged as follows: *Section 2* deals with the methods of voltage stability. *Section 3* deals with optimal location of solar PV generator in the network of the power system, while *Section 4* deals with optimal size (Capacity) of the SPVG connected to the power system network. *Section 5* deals with simulation results and discussion. Finally, *Section 6* deals with the conclusion of this work.

2. VOLTAGE STABILITY METHODS

In this research, a study was conducted to enhance the voltage stability by finding the optimal location for connecting the solar PV generator to the electric grid, as well as finding the optimal size for it. The solar photovoltaic generation in figure 2 shows the structure of a power system network joined to a photovoltaic generator.

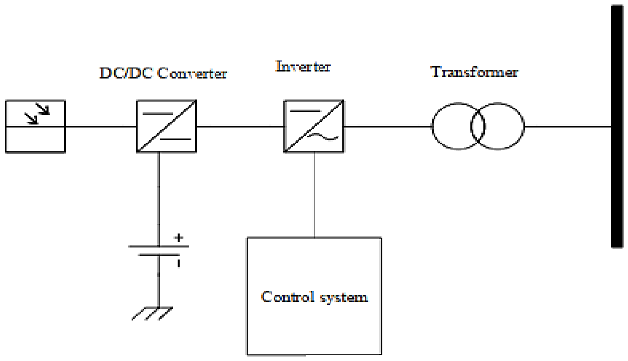

Figure 2: Structure of a grid-connected SPVG

The solar PV generator consists of photovoltaic arrays, a DC-DC chopper and an inverter. The outputs of the inverter are [5,6]:

$$i_d = \frac{1}{1+sT_p} i_{ds} \tag{1}$$

$$i_q = \frac{1}{1+sT_q} i_{qs} \tag{2}$$

where: id, iq the d-q axes currents of the inverter output; Tp, Tq the d-q axes steady-state gains and ids, iqs are the d-q currents set-point. The set-point currents are determined depending on the chosen active power and reactive powers as [6]:

$$\begin{bmatrix} i_{ds} \\ i_{qs} \end{bmatrix} = \begin{bmatrix} v_d & v_q \\ v_q & -v_d \end{bmatrix}^{-1} \begin{bmatrix} P \\ Q \end{bmatrix} \tag{3}$$

The magnitude of the reactive power reference is determined depending on the magnitude of the actual and set-point voltage through the PI controller as [5,6]:

$$Q = (k_v + k_i s)\left(v_{dc} - v_{dc\,ref}\right) \tag{4}$$

The power flow was implemented through the power systems analysis program (PSAT), using the Newton-Raphson algorithm. For large-scale power system, the Newton-Raphson method of analysis is found to be the most active and practical. The iterations needed to obtain a solution is independent of the system capacity, but more functional evaluations are needed at each iteration. The polar form of the load power flow Newton-Raphson forging is [7]:

$$\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = \begin{bmatrix} J_1 & J_2 \\ J_3 & J_4 \end{bmatrix} \begin{bmatrix} \Delta\delta \\ \Delta|V| \end{bmatrix} \tag{5}$$

In this paper, the needed data for N-R program are bus-bar and transmission line data, which are required to perform repeated power load flow solution in order to obtain bus-bar voltage, phase angle, active and reactive power of the network load bus-bars. The flowchart for solving the load flow problem by N-R iteration method is shown in *figure 3*.

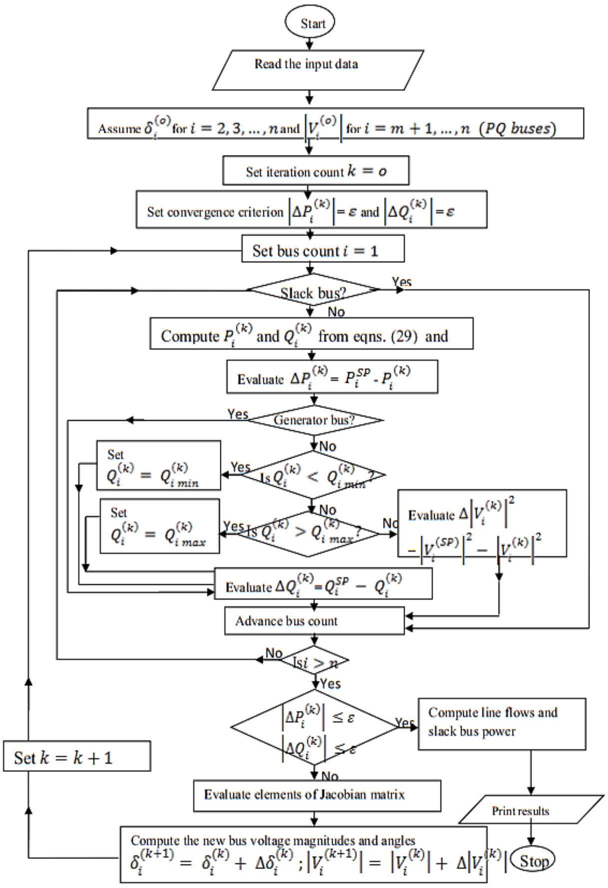

Figure 3: Flow chart of N-R method in load flow problem

3. OPTIMAL LOCATION OF SOLAR PV GENERATOR

In order to spread a SPVG plant on a utility-scale, a number of standards and factors must be taken into account with goal of optimizing the location, which will lead to a most effective system and make it most economical to supply the required customers. Figure 4 shows that some standards taken in the criteria for correct selection of SPVG system site suitability etudes. In SPVG plant site suitability studies, the magnitude of solar irradiation was identified as the most influential reported decision factor. Convergence to power system lines, which minimizes power loss, ranked second in importance [8].

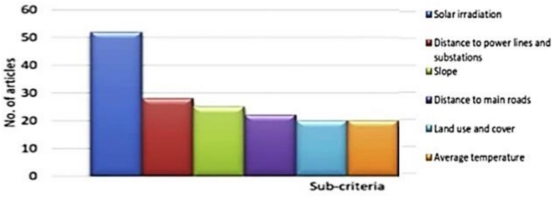

Figure 4: Criteria in utility-size PV system studies

The suitability of SPVG system technology for electricity generation across Iraq is attributed to the uniform distribution of solar radiation; therefore, solar irradiation criteria are not taken into account when selecting SPVG sites. In order to determine the optimal location for the SPVG, the study therefore employs the second criterion calculation of power loss for grid-connected SPVG systems via load flow analysis. Assuring adequate grid accessibility and minimizing power loss in transmission lines, proximity to power lines and substations guarantees optimal grid accessibility while minimizing overall power system losses and potential effects [9],[10].

The optimal location was determined through the use of three strategies, the first is to identify the weakest bus through the use of the technique of continuous power flow (CPF) through the curve (P-V) method, and the second method of eigenvectors and eigenvalues, and the three strategy is to determine the bus that when connecting the SPVG at which the load power losses of the system are as low as possible [11],[3].

4. OPTIMAL SIZE OF SOLAR PV GENERATOR

Solar PV electricity penetration, expressed as a percentage, is the proportion of a solar PV electricity production to its total electricity generation or demand [12]:

$$V\ Penetration\ (\%) = \frac{Total\ PV\ generation\ (MW)}{Total\ demand\ generation\ (MW)} \qquad (6)$$

Numerous studies have been examined in order to estimate the maximum allowable solar PV system penetration (hosting capacity), which will ensure the correct operation of the grid. The grid remains largely unaffected when SPVG penetration falls below 15% of total generation or maximum capacity, as agreed upon by the majority of researchers [13-18].

Figure (5) was depicted in addition to the voltage level indication of a potential hosting capacity. This diagram depicts the power loss experienced by the network at various levels of penetration. As shown in *figure 5*, network power loss decreases as the level of penetration rises to a certain threshold. As the level of network penetration increases, power loss begins to escalate at this juncture. Assigning the optimal size of the SPVG the penetration level that results in the least amount of power loss is ideal.

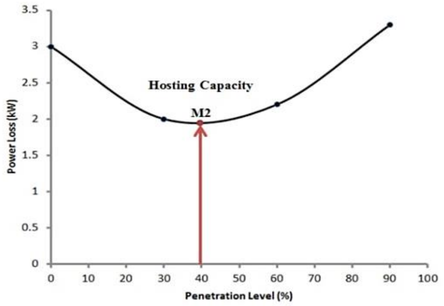

Figure 5: The grid Power Loss with penetration level

5. RESULTS AND DISCUSSION

Our The transmission network of voltage level on the Iraqi super grid power system consists of 400 KV and 132 KV network has connected with it. In this work, the study has specified to the 400 KV network with its bus-bars and transmission lines. The network under consideration consists of twenty-four bus-bars and thirty-nine transmission lines for overall length of 3750 Km. Figure 6 shows one- line schematic diagram of the INSGPS (400 kV), the data of bus, line, generator, are given in tables (A-1) and (A-2), in references [14-15]. The line has performed by nominative sections and the power load by a constant admittance. All data of the network have utilized in per-unit (P.V) with 100 MVA base power and 400 kV base voltage. The network has twenty-four bus-bars, nineteen load power bus-bars and eleven generation bus-bars. In the analysis of power flow, bus-bar no. 1 (MUSP) has specified as a slack bus-bar.

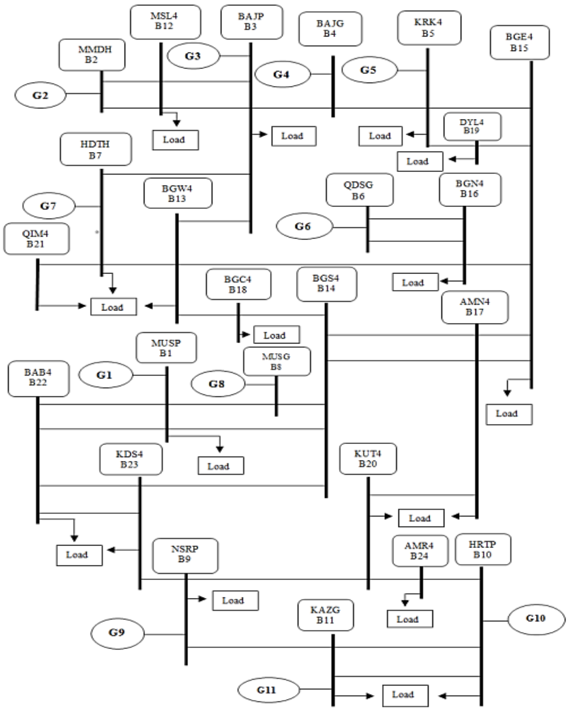

Figure 6: One line diagram of the INSGPS (400 kV)

5.1 The Optimum Location for Solar PV Generation

The simulation results of the continuation power flow are shown in figure 7. From these results, bus-bars 18, 20 and 24 are the weak buses. Among these load power bus-bars, bus-bar no. 20 has the lowest voltage profile. The voltage value at maximum power loading of bus-bar no. 20 as the weakest load bus-bar is 0.54436 P.U.

The power-voltage curves (P-V Curves) for the weakest three load power bus-bars have shown in figure 8, in which the Jacobian matrix of the power system has become singular at $\lambda = 3.6584\ P.U.$ Therefore , depending on the analysis, bus-bar no. 20 has delimited as the best location for the solar PV generator.

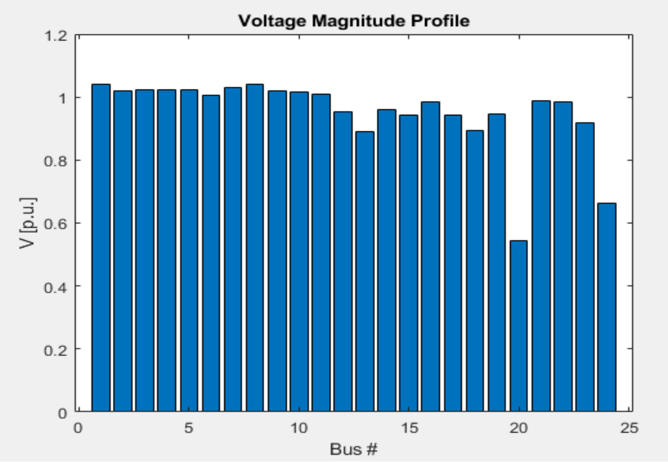

Figure 7: Voltage profile for 24 buses

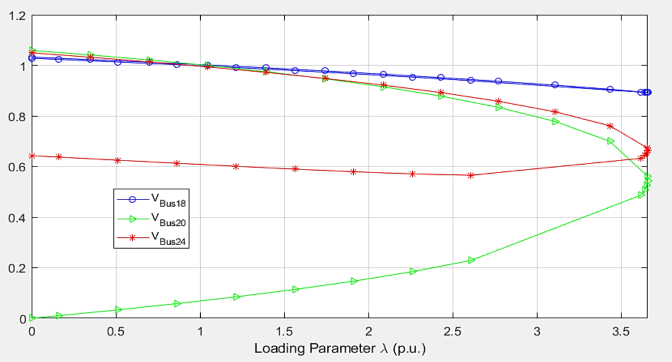

Figure 8: PV curves for the weakest three buses of Iraqi electrical grid

The eigenvectors and eigenvalues at critical loading condition are shown in *table 1*. At this critical loading factor ($\lambda = 3.6584\ P.U$) an eigenvalue equal to – 0.57947, which approximately approaches to Zero and the bifurcation point is reached. By tracing the value of the eigenvector components corresponding to the minimum eigenvalue, it is found that the maximum value is 0.7826 which happen at bus-bar no.20. Hence, bus-bar no. 20 is the weakest bus-bar. Therefore, the SPVG is to be located at this bus-bar.

Table 1. Eigenvalues of 24 system bus-bars

Eigen value		-0.57947			-0.57947
Eigen value	Bus01	0		Bus13	4.0E-05
	Bus02	0		Bus14	5.0E-05
	Bus03	0		Bus15	7.0E-05
	Bus04	0		Bus16	0
	Bus05	0		Bus17	0.00015
	Bus06	0		Bus18	5.0E-05
	Bus07	0		Bus19	8.0E-05
	Bus08	0		Bus20	0.78262
	Bus09	0		Bus21	0
	Bus10	0		Bus22	8.0E-05
	Bus11	0		Bus23	0.00079
	Bus12	0		Bus24	0.21608

Also, the optimal location can be specified by the total power loss calculation, as shown in *table (2).*

The PV model SPVG is connected to the load buses (3,5,7,9,10,11,12, 13,15,16, 17,18,19,20,21,22,23,24) on a per-bus basis. It monitors the ratio of total active power losses to total active power generation and designates the location with the smallest value of losses as the optimal one. As shown in *table 2*, bus-bar no. 20 is the optimal location for connecting the solar PV generator due to its minimal losses.

Table 2. Percentage power loss at buses of Iraqi electrical grid

bus number	Percentage P loss		bus number	Percentage P loss
3	3.855%		16	3.845%
5	3.968%		17	3.789%
7	4.090%		18	3.904%
9	5.711%		19	3.909%
10	5.990%		20	3.645%
11	5.163%		21	3.953%
12	3.964%		22	3.851%
13	3.916%		23	3.761%
15	3.785%		24	4.814%

5.2 Optimal size of solar PV generator

The SPVG is connected to bus 20, and its capacity is modified in fixed increments while monitoring the active power losses in relation to the active power generation. As the optimal size of the SPVG, the penetration rate at which minimum percentage power loss occurs is regarded.

As shown in *table 3*, the optimal penetration ratio for a solar photovoltaic generator with a 1000 MW capacity and the lowest active power loss is 17.425.

Table 3. Solar PV generator penetration

capacity of solar PV generator MW	100	200	400	600	800
Percentage P loss	1.542%	1.473%	1.361%	1.281 %	1.231%
PV penetration %	1.742%	3.485%	6.970%	10.45 5%	13.940%

capacity of solar PV generator MW	1000	1200	1400	1500
Percentage P loss	1.208%	1.211%	1.238%	1.260%
PV penetration %	17.425%	20.910%	24.395%	26.138%

5.3 INSGPS 24-Bus Test System With SPVG

Installing the solar PV generator had an impact on improving the voltage profile and raised of loading factor value of λmax=3.6584 to λmax=4.3838, and decreased the proportion of total energy losses from 3.947% to 1.208%. The inclusion of solar PV generators resulted in enhanced system stability, as depicted in *figure 9*, which illustrates the voltage profile.

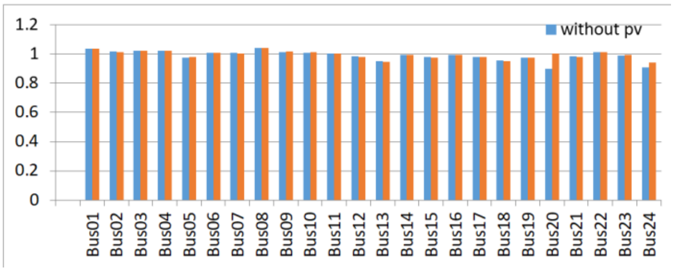

Figure 9: voltage profile without and with PV solar

6. CONCLUSION

This research presents an evaluation of the impact of SPVG on power system voltage stability through the implementation of three static assessments. The test system employed for the study was a 24-bus Iraqi National Super Grid system. The ideal position was determined through the application of a static approach that considers the bus voltage magnitude, eigenvalue, and minimizes losses for each bus. Based on the findings of the simulation, it was determined that bus 20 represents the most optimal placement. The optimal size of the solar photovoltaic generator (SPVG) was determined using the capacitance technique, which minimizes losses. The findings indicate that a capacity of 1000 MW is the optimal size for the SPVG. Furthermore, connecting the SPVG to the system improves system stability by enhancing the voltage profile and increasing the loading factor value. In future research, it is possible to employ intelligent algorithms, such as Particle Swarm Optimization, to determine the ideal placement and dimensions of Solar Photovoltaic Generators (SPVGs) within power systems, with the aim of improving system stability.

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