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INFLUENCE OF PHOTOVOLTAIC SYSTEM ON VOLTAGE STABILITY OF PRACTICAL NETWORK

Sabah Mansour Al-Jubouri
AMA International University-Bahrain
Kingdom of Bahrain

Abstract

Photovoltaic systems are an important part of renewable energy systems. They graw ver quickly nowadays because of advanced technology. This paper focuses on the influence of photovoltaic generations set on voltage stability of power systems. Singular value Decomposition of Jacobean matrix is adopted for voltage stability assessment. Active Participation Factor(APF) of the minimum eigen value mode is used for the placement of photovoltaic generation set. The adopted network is a part of GCC interconnected network.

The results show very good improvement of the capability of the adopted power system.

Keywords: Voltage stability, Photovoltaic system, Electric power systems, Reactive power, Singular value decomposition,

Introduction

The Conventional methods of electrical energy production mainly depend on fossil fuel such as coal, oil, and natural gas. The recent development in the world needs more energy. Then more fossil fuel will be consumed resulting serious greenhouse effect. Such effect pollutes the atmosphere and has great effect on the world. All these things forced the scientists and engineers to find another sources of energy. Renewable energy is the best choice to overcome these kinds of effects. Solar energy is one of the important kinds of renewable energy. There are two main types of solar systems used in electricity generation; the first type converts the light to electricity which is called photo voltaic system, and the second uses sun's heat to make steam which can be used to rotate steam turbines. Photo voltaic system (PV) technology has been developed quickly. The cost of production and installation could be decreased quickly as well. PV system can be used in standalone, hybrid and grid-tie configurations.

Voltage stability of the power system is the vital factor for the security of electrical power industry. That's because there is no physical indicator could be monitored before voltage collapse take place. Voltage stability could be defined as the "the ability of the system to provide adequate reactive power support under all operating conditions so as to maintain stable load voltage magnitude within specified operating limits in the steady state". [1]. If PV system is connected to the electrical grid, the security of the system should be studied and assessed. This work will study the influence of PV system on the practical network and the effect of penetration and distribution of PV systems on the voltage stability.

Statement of the problem

Real practical electrical power system is really complex. Security of such system is very important to keep electrical power, always, available for the consumers. The voltage profile of all the buses should be kept in acceptable slandered level. The voltage collapse point should be known when the PV generation system is added to the network of the system.

In GCC region the solar energy is a good choice of renewable energy because there is sun's light in most days in the year. The main goal of this work is to study the impact of different sizes and places of PV generation sets on voltage stability of the power system and to find the best places and penetration of PV generation.

Significance of the study

This work will study the real power system. Such system is a part of the GCC interconnected power system. Practical power systems need a new analysis and assessment when any extension is made to the system. So, When PV systems are added to the practical system it should be analyzed and assessed specially from security point of view.

Scope and limitation

The main limitation of this work may be the actual plans for PV system penetration in the existed network.

Conceptual Frameworks

In this research work, the practical power system should be modeled and analyzed to assess the voltage stability of the system. Practical data of the equipment of the system will be used. PV system will be modeled too and integrated with the original power system to be able for analysis and assessment within the whole power system.

Literature review

The effect of energy production using fossil fuel on the environment of the planet is very vital and important. There is more concern about the climate changes due to CO_2 emissions as a result of fossil fuel consumption. Renewable energy is the best choice. Solar energy participation in electrical generation is increased rapidly in the recent years. photovoltaic grid connected is growing faster than stand alone photo voltaic systems as reported by[EPIA] European PV industries Association. The grid connected photo voltaic system may make several conditions in the power system like fluctuation of voltage in the distribution side, high losses in the transmission and distribution networks, overloading and harmonics. There is influence of photo voltaic generation on voltage stability of the system. [2].

Mayilvaganan, A. B, et al presented a PV system use as synchronous static compensators (STATCOM) in order to regulate the voltage of common coupling point to the grid.[3]. Amaresh, K. and Sankar, V., proposed a model of photovoltaic system interconnected with radial distribution system using MATLAB/SIMULINK. The influence of such system was tested on IEEE 15 bus radial system. The analysis target of the proposed system was to quantify the impact of the distributed generators on the voltage profile, total power losses and reliability.[4]. Adibah, Z. et al had studied the dynamic voltage stability of the power system with grid connected photovoltaic generators. They used line instability as well as fast voltage stability margin were used as indicators of identifying the proximity of voltage collapse. The effect of transient cloud and sweep cloud on dynamic voltage stability was studied. They found that both kinds of clouds should be considered in dynamic voltage stability because of the dynamic load and the high ratios of X/R. [5]. Suampuna, W., has studied the analysis of voltage stability of grid connected PV system using CPFLOW software. He found P-V curve for the analysis of voltage stability. The effect of PV system on voltage stability was found for different levels of penetration. CPFLOW was found as fast and reliable in this kind of studies and analysis.[6]. Kumar, M. S. and Rajakumar, P., have implemented photovoltaic system using MATLAB/ Simulink. Voltage stability index has been evaluated continuously for 33 bus distribution system. [7].

Methodology

This work will focus on the static voltage stability of the power system. There are many methods which were used to predict the proximity of the voltage collapse of the power system. The main target of these methods is get an indicator could be used to assess the voltage stability of the system.

Singular Value Decomposition Method

Singular value decomposition is one of these methods. It is method of orthogonal decomposition used for the computation of matrix [1]. The singular value decomposition of an (n×n) matrix (A) is give by:

$$A = U \sum V^T = \sum_{i=1}^{n} \sigma_i u_i v_i^T \qquad (1)$$

Where U and V are ortho normal matrices of size (n×n). The singular vectors u_i and v_i are the columns of the matrices U and V respectively. ∑ is a diagonal matrix such as:

$$\sum(A) = \mathrm{diag}\{\sigma_i(A)\} \qquad i = 1, 2, n \qquad (2)$$

$\sigma_i \geq 0$ for all i. The diagonal elements of the matrix ∑ are ordered so that $\sigma_1 \geq \sigma_2 \geq \ldots\ldots. \geq \sigma_n \geq 0$.

If the rank of the matrix A is $r(r \leq n)$, the singular values of such matrix ($\sigma_1, \sigma_2, \sigma_3, \ldots \sigma_r$) are the only nonzero entries in the n×n diagonal matrix∑.

When singular value decomposition is used in the analysis of static voltage stability, it focuses on the smallest singular values until it becomes zero.

This approach can be used in the power systems by adopting the active power and reactive power at the nodes of the power network versus the voltage magnitudes and voltage angles of the same nodes of the network. The load flow Jacobean [J] matrix of Newton-Raphson method could be used for this approach [8].

$$\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = [J] \begin{bmatrix} \Delta\delta \\ \Delta V \end{bmatrix} \qquad (3)$$

ΔP and ΔQ are the incremental changes in active power and reactive power respectively, while ΔV and Δδ are the incremental changes in voltage magnitude and voltage angle respectively.

$$J = \begin{bmatrix} J_{P\delta} & J_{PV} \\ J_{Q\delta} & J_{QV} \end{bmatrix} \qquad (4)$$

By applying singular value decomposition on the above matrix,

$$J = U \sum V^T = \sum_{i=1}^{n} \sigma_i u_i v_i^T \qquad (5)$$

The measure of the closeness of the Jacobean matrix [J] to singularity will be the minimum singular value $\sigma_n(J)$. If there is a small disturbance, let

$$\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = u_n \qquad (6)$$

u_n is the last column of the matrix U.

$$\begin{bmatrix} \Delta\delta \\ \Delta V \end{bmatrix} = \sigma_n^{-1}\, v_n \qquad (7)$$

v_n is the last column of the matrix V.

The interpretation of the above equations can be made as follows [9]:

1. The minimum singular value, σ_n, represents the indicator of the closeness to the steady state stability.
2. The right singular vector, v_n, which is corresponding to σ_n represents the indicator of sensitive voltage magnitudes and angles.
3. The left singular vector, u_n, which is corresponding to σ_n represents the indicator of the most sensitive direction of the injections of the active power and reactive power.

Active Power Participation Factor

Let $\Delta Q=0$, then equation (3) will be:

$$[\Delta\delta] = [J_{RP\delta}]^{-1}\, [\Delta P] \qquad (8)$$

Where

$$[J_{RP\delta}] = J_{P\delta} - J_{PV}\, J_{QV}^{-1}\, J_{Q\delta} \qquad (9)$$

is the Jacobean matrix after reduction (reduced Jacobean) which contains the components of active power (P) and the angle of bus voltage (δ) only. Equation (3) will be solved as:

$$\begin{bmatrix} \Delta\delta \\ \Delta V \end{bmatrix} = \begin{bmatrix} J_{RP\delta}^{-1} & -J_{RP\delta}^{-1}\, J_{PV}\, J_{QV}^{-1} \\ -J_{RQV}^{-1}\, J_{Q\delta}\ \ J_{P\delta} & J_{RQV}^{-1} \end{bmatrix} \begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} \qquad (10)$$

$$= [J]^{-1} \begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} \qquad (11)$$

By using Schur's formula,

$$\begin{aligned} \det(J) &= \det(J_{P\delta})\, \det(J_{RQV}) \\ \det(J) &= \det(J_{QV})\, \det(J_{RP\delta}) \end{aligned} \qquad (12)$$

In practical power systems J_{QV} and $J_{P\delta}$ are not singular. So the J matrix will be singular only when the sub-matrices J_{RQV} and $J_{RP\delta}$ are singular. Equation (12) shows that both J_{RQV} and $J_{RP\delta}$sub-matrices are of the same importance.

There is another important relationship between the eigenvectors of the matrices J, $J_{RP\delta}$and J_{RQV}. It will be shown in the following that at the singularity point the eigenvectors of the matrices $J_{RP\delta}$and J_{RQV} represent that of the matrix J. For this target, two auxiliary matrices M and N are defined as:

$$M = \begin{bmatrix} I & 0 \\ -J_{Q\delta}\, J_{P\delta}^{-1} & I \end{bmatrix};\ N = \begin{bmatrix} I & -J_{PV}\, J_{QV}^{-1} \\ 0 & I \end{bmatrix} \qquad (13)$$

Assume x is the eigenvector of the matrix J corresponding to the zero eigenvalue (λ=0). Le t x be divided into (x_1 and x_2), x1 shows the reflection of the components which are related to the active power part of the matrix J, and x_2 shows those related to reactive power part. So

$$(J-\lambda I)\, x = Jx = \begin{bmatrix} J_{P\delta} & J_{PV} \\ J_{Q\delta} & J_{QV} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} = 0 \qquad (14)$$

Multiplying equation (14) by M on the left,

$$[M]\begin{bmatrix} J_{P\delta} & J_{PV} \\ J_{Q\delta} & J_{QV} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} = \begin{bmatrix} J_{P\delta} & J_{PV} \\ 0 & J_{RQV} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} = 0 \qquad (15)$$

It gives

$$J_{RQV}\ x_2 = 0 \qquad (16)$$

Such equation shows that x_2 is the eigenvector of J_{RQV} corresponding to a zero eigenvalue. Now, multiplying equation (14) by N on the left also:

$$[N]\begin{bmatrix} J_{P\delta} & J_{PV} \\ J_{Q\delta} & J_{QV} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} = \begin{bmatrix} J_{RP\delta} & O \\ J_{Q\delta} & J_{QV} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} = 0 \qquad (17)$$

It can be noticed that:

$$J_{RP\delta}\ x_1 = 0 \qquad (18)$$

Therefore x_1 is the eigenvector of $J_{RP\delta}$ which corresponds to a zero eigenvalue. Equations (16) and (18) can prove that the same information of modal analysis which is obtained from the matrix J and singularity point of such matrix can be obtained also from the matrices $J_{RP\delta}$ and J_{RQV}. Modal analysis of the matrix J_{RQV} can show the influence of reactive power on voltage stability. In the same way modal analysis of matrix $J_{RP\delta}$ can show the influence of active power on voltage stability.

The participation factor of the active power can be defined by:

$$APF_{ki} = U_{ik}\ V_{ki} \qquad (19)$$

For the same change in physical power at a given bus, there would be more significant change in modal power with the bus of higher eigenvector entry. Because the voltage collapse of the power system is taken place due to such critical modal power, the APF which measures the relative magnitude of the eigenvector elements can show the buses where the changes of active power have more impact on voltage stability of power system. The buses which have larger APF values are the critical buses limiting system margin from the active power point of view. The last conclusion leads us to use such approach to select the most influenced bus where the grid-tie PV system should be installed.

Results and Discussion

The practical network which is used in this work is a part of GCC interconnected electrical grid. It is 20 bus network of two levels of voltages (13.8Kv and 115Kv), and 44 branches. Seven buses are power stations, eight branches are transformers and thirty six branches are transmission lines [11]. Fig. 1 shows the adopted power system.

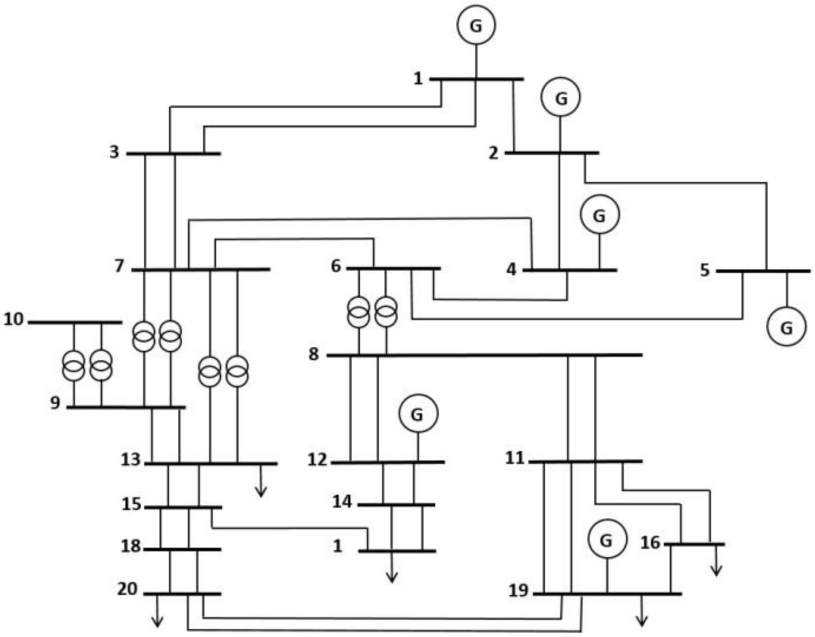
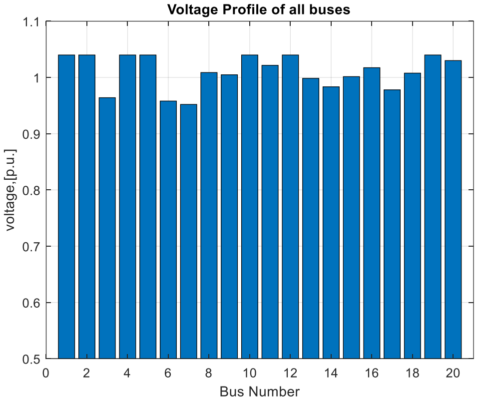


Fig. 1 SingleLine Diagram of the Practical Network

Computer program was developed to find singular value of the Jacobean matrix of Power flow program based on Newton-Rap son method. Active Participation Factor could be found by the same program. Mat lab code was used to develop such program.

Practical data was used for the base case. The buses which contain tie lines with the other parts of the system are taken as load buses because they deliver power to those parts.

Fig. 2 shows the base case voltage profile of the adopted network, and Fig. 3 shows the participation factors for minimum Eigen value at bus 14 for all load buses.



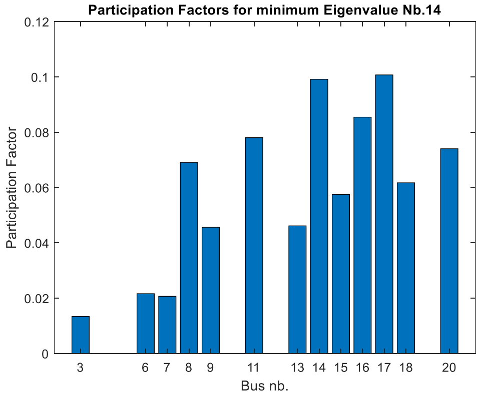


Fig. 2 Voltage Profile of Base Case

Fig. 3 Participation Factors (APF) of Base Case

Table 1 shows the main results which describe such base case.

Table-1

Voltage profile range (p.u)	Total Active power (p.u)	Total reactive power (P.u)	Singular value

0.952-1.040	28.49	7.72	1.3070

The load was increased in all buses of the system in the same rate keeping the power factor of each bus constant.

Table-2 shows the main results of the system just before voltage collapse.

Table-2

Voltage profile range (p.u)	Total Active power (p.u)	Total reactive power (P.u)	Singular value
0.711-1.040	38.2065	12.1311	0.0267

Fig 4 and Fig 5 show the voltage profile and active participation factor of the system respectively.

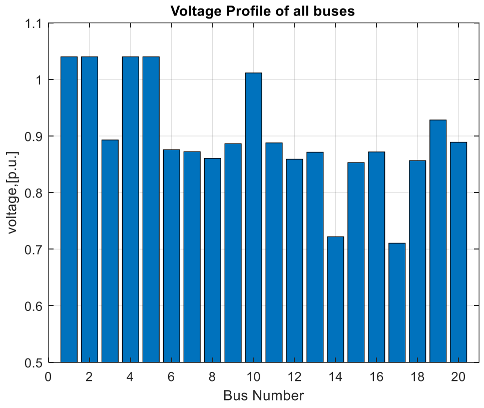


Fig. 4

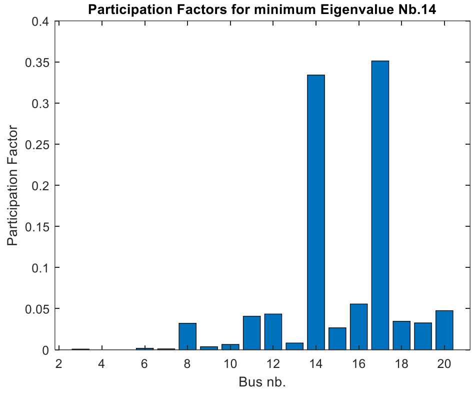


Fig. 5

The target of this work is to study the influence of PV system on the voltage stability of transmission and sub transmission network.

The most important issue is the selection of the place of the PV station which is more effective in improvement of voltage stability of the system. Since the larger active participation factor of the mode of the minimum eigenvale indicates the place of load shedding [10], so it can be used for active power source like PV station. Bus 14 will be the most vulnerable bus in the power network adopted in this work.

PV system could be modeled as load bus with active power generator of unity constant power factor [12]. A grid connected PV system of a size 5% of the maximum total active load of the system was connected on bus 14. Voltage stability of the system was clearly improved and the voltage collapse didn't take place. The voltage profile of the system was really improved and became with standard levels in spite of there is no any additional reactive power as show in Fig-6 and table-3.

Table-3

Voltage profile range	Total Active power	Total reactive	Singular	PV

(p.u)	(p.u)	power (P.u)	value	(p.u)
0.953-1.040	38.2065	12.1311	1.0981	1.9=5%

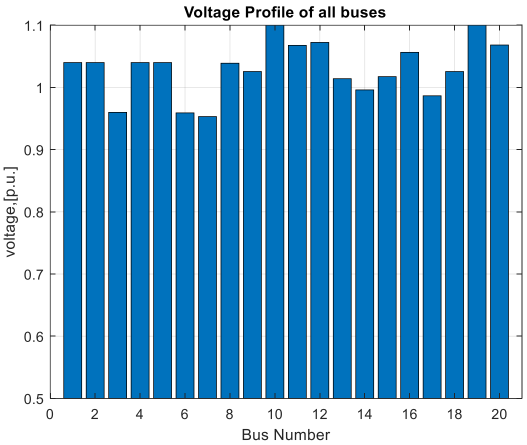


Fig- 6

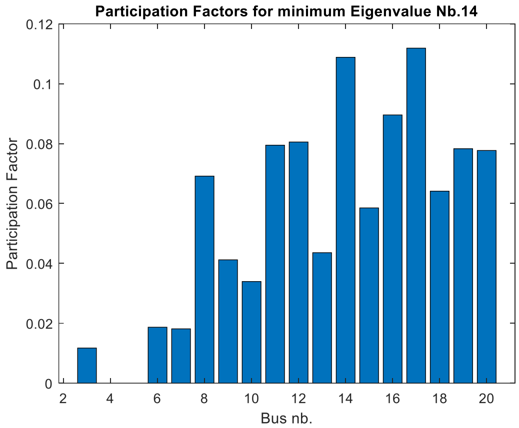


Fig-7

Fig-7 shows that bus 14 was still the vulnerable bus which means that more active power could generation could be added in such bus. The load of the system was increased in the same manner, i.e. the active and reactive load were increased gradually in the same rate but keeping the power factor constant until voltage collapse takes place.

Table-4

Voltage profile range (p.u)	Total Active power (p.u)	Total reactive power (P.u)	Singular value	PV (p.u)
0.821-1.040	40.7926	13.4115	0.4825	1.9=5%

Table-4 shows that the addition of 5% PV generation could improve the capability of the system by 7%.

Another bus with small APF was chosen to connect PV generation set to find the influence on voltage stability. Bus 8 was chosen, but the improvement was less than 1%, which very low influence on voltage stability of the system compared to that achieved when the high APF was chosen.

Conclusion

The presented work focused on the influence of interconnected photovoltaic generation set on the voltage stability of the power system. Singular value decomposition method was used for the assessment of the voltage stability. The PV generation set was modeled in power flow study as active power source with unity power factor. Active Participation Factor is very good and effective tool to identify the place where the PV generation set should be connected. Based on such criteria the system capability was improved by 140% of the PV power which was added to the system, even there is no any additional reactive power.

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