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POWER SYSTEM STABILITY ENHANCEMENT BY PV DISTRIBUTED GENERATION

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ABSTRACT

the present paper investigates the effect of penetration of photovoltaic generation (PVGs) systems on the transient and small signal stability. Recently interest in photovoltaic (PV) power generation systems is increasing rapidly and the installation of large PV systems or large groups of PV systems that are interconnected with the power system grid is accelerating despite their high cost and low efficiency due to environmental issues and depletions of fossil fuels. Photovoltaic generators (PVGs) have significant impacts on the existing power systems, these impacts may be either positively or negatively depending on many factors such as PVGs location, size and inverter characteristics. The eigenvalue analysis and the transient analysis of the system are done without any PVGs penetration and with PVGs penetration and then the results are compared. The investigation is applied on IEEE-39 bus test system. The stability analysis is carried out using simulation program of power system analysis tool box (PSAT).

Keywords : Photovoltaic generators (PVGs), Small signal stability, PSAT, Eigen values, Transient stability

الملخص العربي

في هذا البحث تم دراسة تأثير اضافة أنظمة توليد الطاقة الكهروضوئية (PVGs) على استقرار الإشارة المؤقت والصغير. تزايد الاهتمام مؤخرًا بنظم توليد الطاقة الكهروضوئية (PV) بسرعة ، وتسارع تركيب أنظمة كهروضوئية كبيرة أو مجموعات كبيرة من الأنظمة الكهرو ضوئية المترابطة مع شبكة نظام الطاقة على الرغم من كلفتها العالية وانخفاض كفاءتها بسبب المشكلات البيئية واستنزاف الطاقة و الوقود الحفري. المولدات الكهروضوئية لها تأثيرات كبيرة على أنظمة الطاقة الحالية ، وقد تكون هذه التأثيرات إما إيجابية أو سلبية اعتمادًا ع لى العديد من العوامل مثل موقع PVGs وحجمها وخصائصها العاكسة. يتم تحليل القيمة الذاتية والتحليل العابر للنظام دون اضافة اي خلايا كهروضوئية وكذلك مع اضافة خلايا كهروضوئية ثم تتم مقارنة النتائج. تم تطبيق الاختبارات علي شبكة IEEE-39. وتم تنفيذ تحليل الاستقرار باستخدام برنامج محاكاة (PSAT).

1. INTRODUCTION

With increasing the demand of using electricity so the conventional power plant for generating electricity can’t be provide this huge amount of demanded electricity specially that depended on the fossil fuel which be a finite reserve [1].

So the world trend to produce the electricity from renewable energy resources such as solar power to overcome the disadvantages of the conventional power plants such as limited reserve and environmental effects as the greenhouse effect caused by the increase of the CO_2 concentration in the earth’s atmosphere problem [2].

The integration of Photovoltaic Generators (PVGs) in power system networks has a large effect not only on the distribution networks but also on the national transmission and generation system [3].

High PV penetration levels can significantly affect the steady state as well as the transient stability of the systems due to their distinct characteristics that differ from conventional generation resources. With high PV generation, a significant amount of conventional generation may be replaced with distributed PV resources. While a portion of this replaced generation is supplied by utility scale PVs, a majority of PV generation addition is expected to be provided by residential rooftop PVs that are located closer to the loads on the distribution system [4].

This paper is organized as follows. Section 2 describes the concept of the small signal stability analysis. Section 3 gives the description of the test system and the modeling of the PVGs system. Section 4 describes analysis of the small signal and transient analysis of the system. And finally conclusions which are drawn from the analysis are given in the section 5.

2. SMALL SIGNAL STABILITY

The behavior of power system dynamic can be described by a set of n first order nonlinear ordinary differential equations in vector-matrix notation [5]

$$\dot{X} = f(x, u, t) \quad (1)$$

Where $x = (x_1, x_2 \ldots.. x_n)^T$ is the vector of state variables, $u=(u_1, u_2, \ldots. u_r)^T$ is the vector of system input variables.

$$Y = (y_1, y_2, \ldots. y_m)^T \quad (2)$$

Where Y is the vector of system outputs variables, $f = (f_1, f_2, \ldots. f_n)^T$ and $g = (g_1, g_2, \ldots. g_m)^T$ are the vectors of nonlinear functions defining the states and the outputs respectively of the system, time is denoted by t, and the derivative of sate variable X with respect to time is $\dot{X}$ .if the derivative of the state variables are not explicit function of the time, equations (1) and (2) can be simplified as:

$$\dot{X} = f(x, u),\ Y = g(x, u) \quad (3)$$

For small signal stability analysis a small perturbation is considered, the non-linear function f and g can be linearized using Taylor series with the initial points $x=x_0$ and $u=u_0$,

The system can express in the following equation:

$$\Delta\dot{x}=A\Delta x + B\Delta u, \quad \Delta y=C\Delta x + D\Delta u \quad (4)$$

Where Δx is a small deviation in the state vector, Δy is a small deviation in the output vector, A is the state matrix, B is the input matrix, C is the output coefficient matrix and D is the feed forward matrix [6].

According to Lyapunov's first method, the eigenvalues of the state matrix A can be illustrate the behavior of the system according to small signal stability, the eigenvalues of the state matrix A may be:

1-A real eigenvalue corresponds to a non- oscillatory mode where a negative real Eigen value represents a decaying mode, a positive real represents aperiodic instability.

2-Complex eigenvalues occur in conjugate pairs, and each pair corresponds to an oscillatory mode.

- When the Complex eigenvalues have negative real parts, the original system is stable.
- When at least one of the Complex eigenvalues has a positive real part, the original system is unstable.
- When at least one of the eigenvalues has zero value, the original system is critical stable [7].

For any eigenvalue λ_i, the n-column vector Φ_i is called the right eigenvector which gives the mode shape and the n-row vector Ψ_i is called the left eigenvector identifies which combination of the original state variables displays only the i^{th} mode , are satisfies Equations:

$$A\Phi_i=\lambda\Phi_i \quad (5)$$

$$\Psi_i A=\lambda_i\Psi_i \quad (6)$$

Where $\Psi_i\ \Phi_i = 1$

A measure of the association between the state variables and the modes is the participation factors, p= [$p_1\ p_2 \ldots\ldots p_n$], with

$$Pi = \begin{bmatrix} P1i \\ p2i \\ \vdots \\ pni \end{bmatrix} = \begin{bmatrix} \Phi 1i\ \Psi i1 \\ \Phi 2i\ \Psi i2 \\ \vdots \\ \Phi ni\ \Psi in \end{bmatrix}$$

3. DESCRIPTION OF THE TESTED SYSTEM

A. IEEE-39 Bus System.

IEEE-39 bus system is used for the analysis of the PVGs penetration. The total load of the system is 6586 MW. There are ten generators in the system connected at buses from 30 to 39 as shown in the following fig. (1). the ten generators are 6^{th} order and equipped with IEEE type II governors and IEEE type II exciters.

In this paper, the utility scale PV plant will be added into the system to see the impact of the PV system on the small signal and transient stability in addition to conventional synchronous generators.

The PV penetration level in the system is defined as,

PV Penetration (%) = (Total PV generation (MW) ÷ Total generation (MW)

B. Modeling of PVGs Systems

The single-line diagrams of the developed PVGs models according to the control modes and their capabilities are depicted in Figs.2 and .3 , for Model 1 (constant PQ) and Model 2 (constant PV) ,respectively.

There are various possibilities for inverter transfer functions; however, the following two are probably the most appropriate [8]:

(a) First order functions with unity steady state gain.

(b) The closed loop controller transfer functions.

Both yield very similar results and hence the first one is adopted here. Figs.2 and 3 show the block-diagrams of the two developed models.

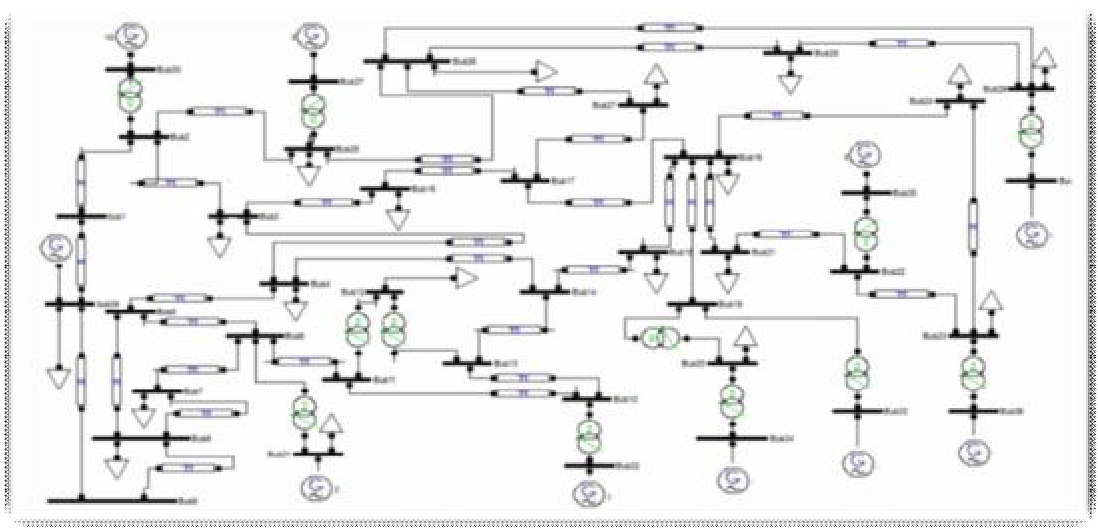
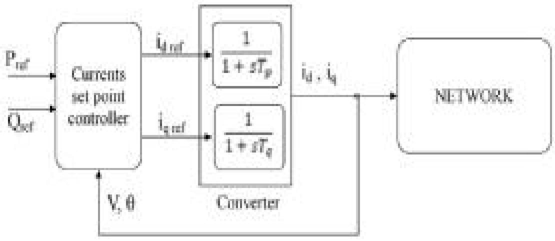


Fig.1. IEEE-39 bus test system



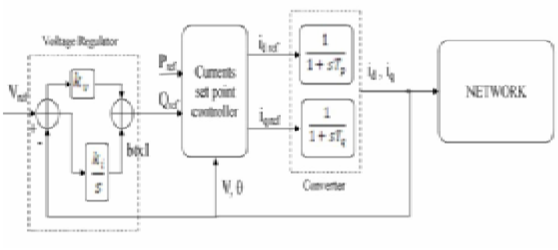


fig.2. PVGs Model 1 block diagram

fig. 3. PVGs Model 2 block diagram

In these models, the current set points can be obtained based on the desired active and reactive powers and current measurements of terminal voltage in the dq reference frame.
In Fig. 3, the reference value for reactive power is obtained based on the set-point and actual voltage values through a PI controller [9].

4. SIMULATION AND RESULTS

A. Eigenvalue Analysis

The objective of the paper is to analyze the small signal stability of the system with and without adding PVGs into the system. For this using PSAT program, depending on the Eigenvalues of the system the following scenario is implemented.

CASE(1) Represents the base case where all generators in the system are synchronous generator and there is no PVGs in the system.

a) Normal case.

In this case, the system operates at its rated load. Small signal stability of the tested system is computed and Eigenvalues of the system with its dominant states as shown in table.1 and Fig.4.

TABLE 1. Computed Eigenvalues of base case

Zero Eigen		Positive Eigen	
number	Dominant states	number	Dominant states
91	delta_Syn_9	--	--

As seen, IEEE-39 bus test system has 110 Eigen number all Eigen numbers are negative except the Eigen number λ 91 is zero value, so the system is critically stable. The participation factors associate the delta of synchronous generator connected at bus 39 with this critically stable of the system.

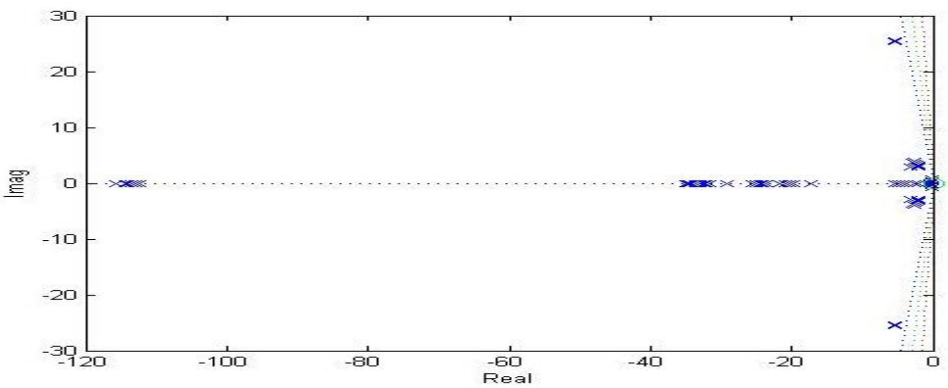


fig. 4. Computed Eigen values of base case

b) Contingency case

In this case the system loads are increased into 120% of its rated values and compute the small signal stability of the system; Eigenvalues of the system with its dominant states are shown in table.2 and Fig.5.

TABLE 2. Computed Eigenvalues of contingency base case

system	Zero Eigen		Positive Eign	
	number	Dominant states	number	Dominant states
Increasing system load into 120%	94	delta_Syn_2	61 91	delta_Syn_1 vr2_Exc_1

As shown, all Eigen numbers are negative except the Eigen number λ94 is zero value and Eigen numbers λ61 and λ91 are positive real parts. So the system is unstable.

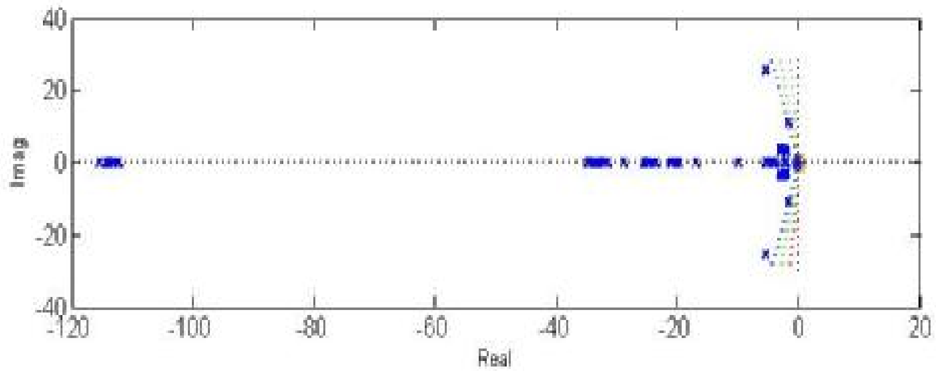


fig. 5. Computed Eigen values of Contingency case

CASE(2) Adding PVGs into the system. According to [10], the optimal location to construct PVGs with ratio 10% of the total load is at bus 8.

a) Normal case

Small signal stability test is done; Eigenvalues of the system with its dominant states are shown in table.3.

TABLE 3. Computed Eigenvalues of system with 10% PVGs.

Zero Eigen		Positive Eigen	
number	Dominant states	number	Dominant states
95	delta_Syn_10	--	--

The results show that the system has 113 Eigen number all Eigen numbers are negative except the Eigen number λ95 is zero value so the system is critically stable. The participation factors associate the delta of synchronous generator connected at bus 30 with this critically stable of the system.

b) Contingency case

In this case the system loads are increased into 120% of its rated values and compute the small signal stability of the system; Eigenvalues of the system with its dominant states are shown in table.4.

TABLE 4. Computed Eigenvalues of Contingency system with 10% PVGs.

system	Zero Eigen		Positive Eigen	
	number	Dominant states	number	Dominant states
Increasing system load into 120%	97	delta_Syn_10	--	--

As shown, all Eigen numbers are negative except the Eigen number λ97 is zero value. So the system is critically stable. The participation factors associate the delta of synchronous generator connected at bus 30 with this critically stable of the system.

B. Transient analysis

For IEEE 39 bus system a fault is making at bus 12. This fault is three phase fault occurs at t = 1sec and its duration is 0.25 s then the fault is clearing. The effect of this fault on voltages of nearing buses, speeds and power angles of generators and active and reactive powers of generation buses when there's PVGs with rating 658.8 MW at bus 8 and there's no PVGs as shown in the following figures.

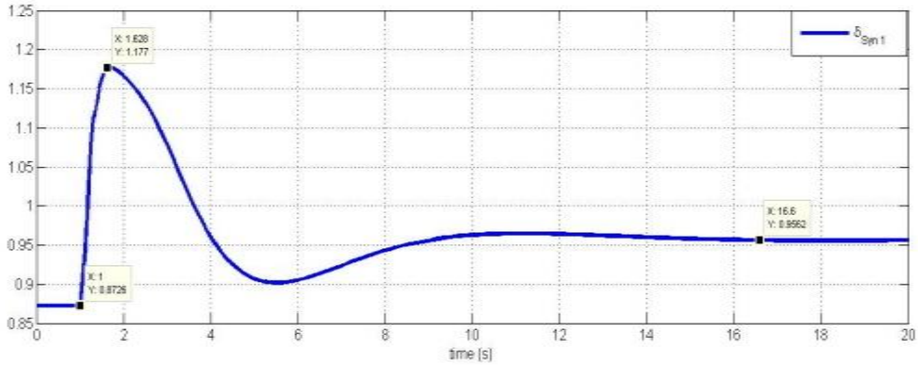


fig. 6. Rotor angles of the slack generator without PV penetration

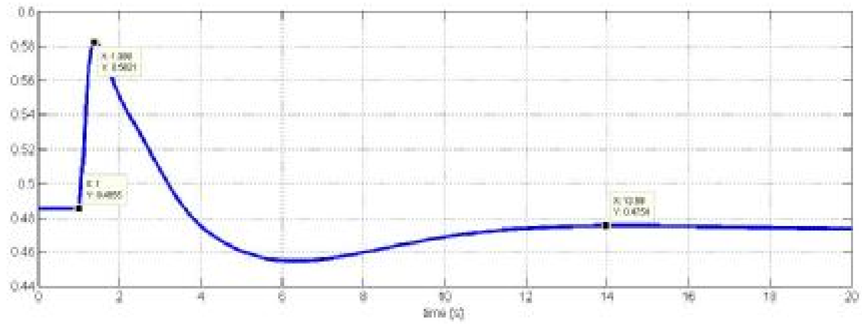


fig. 7. Rotor angles of the slack generator with 10% PV penetration

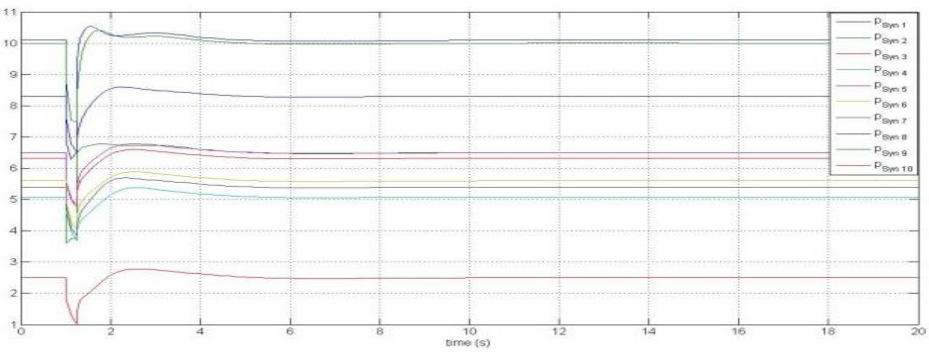


fig.8. Active power of generators without PV penetration

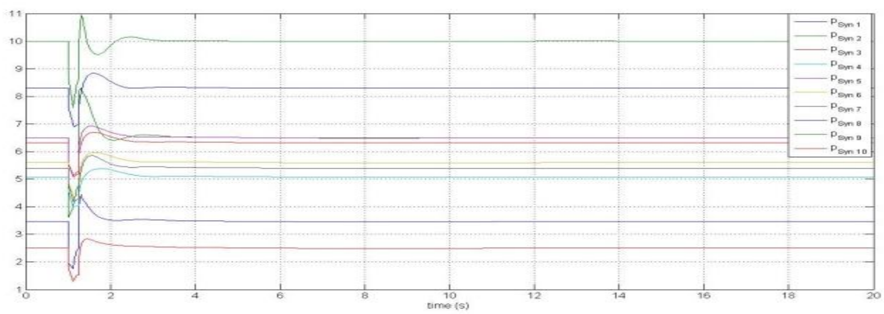


fig. 9. Active power of generators with 10% PV penetration

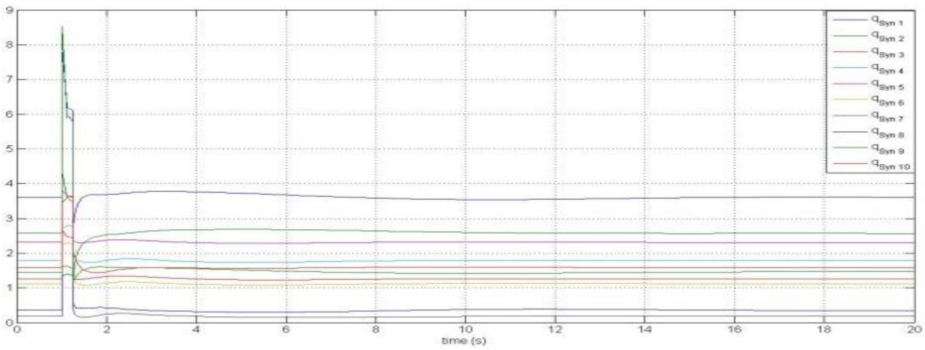


fig.10. Reactive power of generators without PV penetration

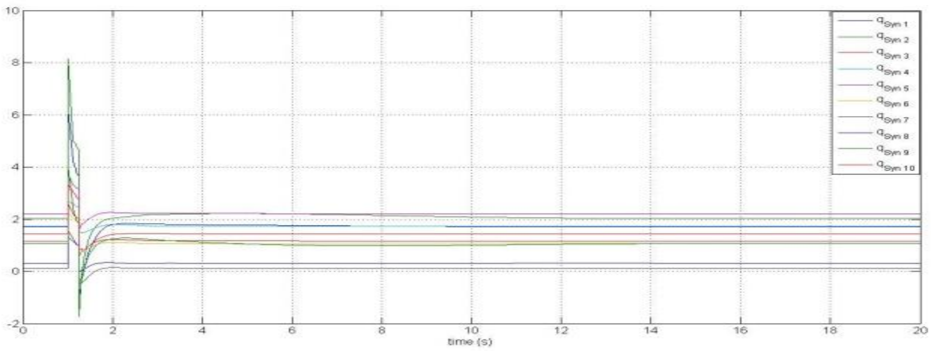


fig. 11. Reactive power of generators with 10% PV penetration

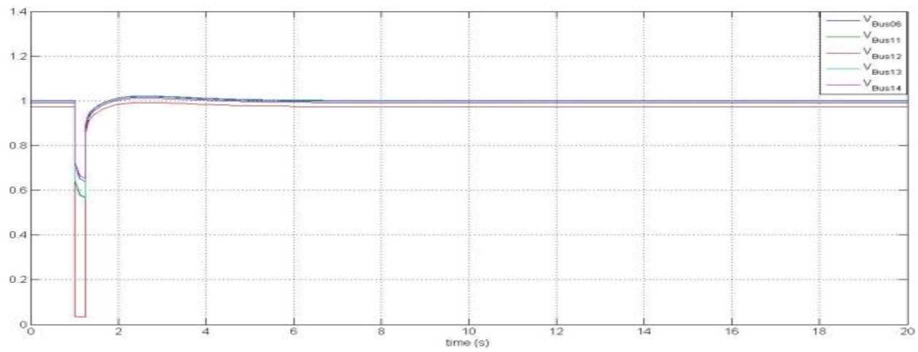


fig. 12. Voltages at nearing buses to bus 12 without PV penetration

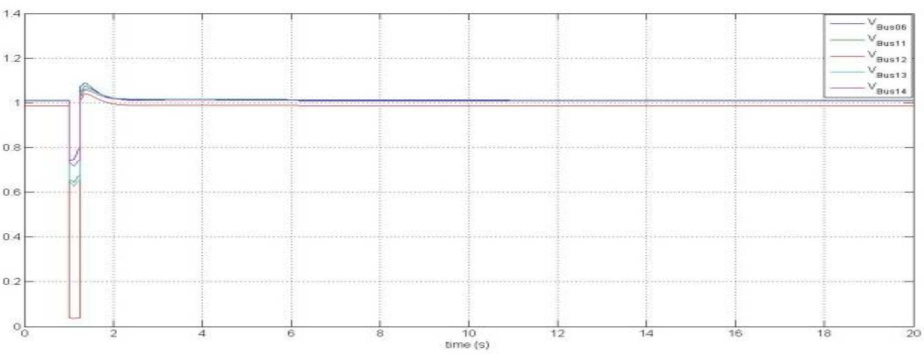


fig. 13. Voltages at nearing buses to bus 7 with 10% PV penetration

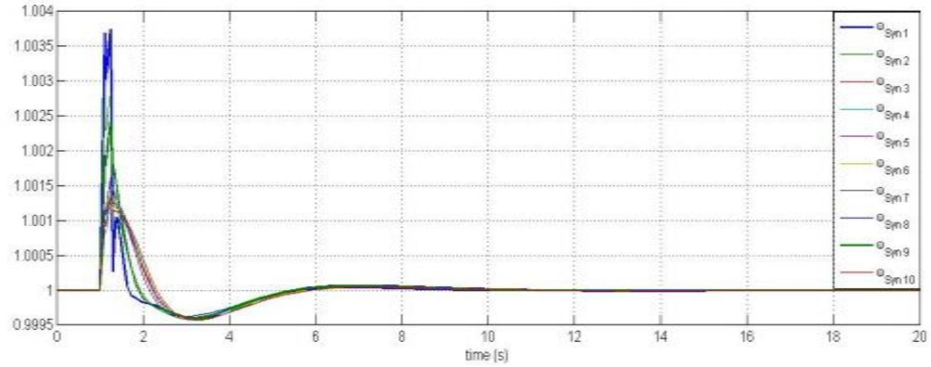


fig.14. Speeds of generators without PV penetration

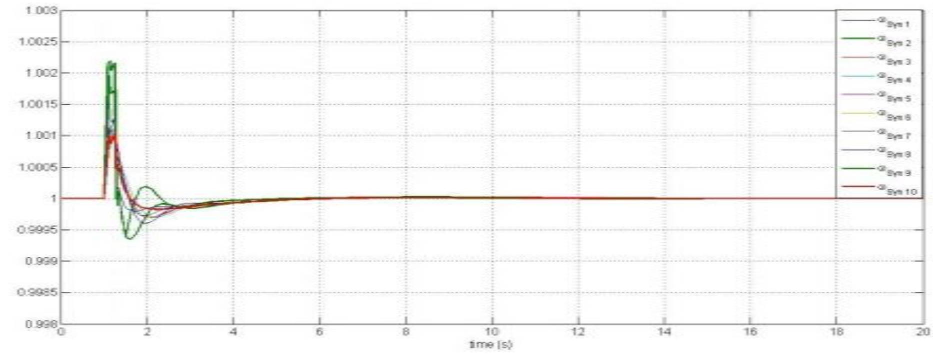


fig. 15. Speeds of generators with 10% PV penetration

As seen in figures 6 to 15, power angle of the slack synchronous generator witch connected at bus 31, active and reactive power of generators, voltages at nearing buses to bus 12 and the speeds of generators are plotted during transient disturbance. When PVGs are connected to the system, the curves are stabilized faster than the case which no PVGs are connected to the system.
From all the previous studied cases, adding of the PV generation leads to more stable system in addition to the other advantages of solar energy.

5. CONCLUSION

Is this paper, for IEEE 39-bus power system the investigation of the small signal stability analysis and Transient stability analysis has been done with and without injection of Photovoltaic generation. To observe the effect of Photovoltaic Generation on the small signal stability of the system, the eigenvalue sensitivity has been used considering increase of the load of the system. It showed that adding of PVGs into the system leads to improvement in small signal stability of the system. Transient stability analysis performed through time domain simulations, shown that the system contains PVGs are able to restore rotor angles, voltages, speeds and power after a three phase fault better than conventional generators though a quick response in restoration .

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