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Stability Improvement in a Distributed Generators using Virtual Synchronous Generator

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***Abstract* —** Now a days distributed generators (DG's) utilizations were increased due to increased power demand effect over conventional generations. To maintain synchronism with grid generally phased locked loops are used in DG's. If the power demand was more than requirement then the stability is the majorly effected problem in the DG's. To eliminate this problem by using Virtual Synchronous Generators (VSG's) concept in DG's. It controls DG's to maintaining balance between generation and load and also it is a modern trending technology to this DG's. In VSG's there is no Power system stabilizers to eliminate oscillations generated in the system during abnormal conditions. For this a new control strategy is implemented by using linearizing swing equation to suppressing these unwanted oscillations in the system. This paper is analyzed effectively by considering one more control technique that is Fuzzy logic control system and its observations have been seen in MATLB-SIMULINK software.

Keywords - *Distributed generation (DG's), Fuzzy Logic Controller (FLC), Swing equation, Virtual Synchronous Generator (VSG's), PLL*

I. Introduction

Now a days the need of electrical power consumption applications was increases in each and every environment field. Generally per capita energy consumption of every nation is mainly depending on power sector growth rate. So, to meeting the demand simultaneous counter balancing electrical generation definitely needed. But most of the counties electrical power generating by using fossil fuels such as coal, petroleum, gas, diesel etc. These fuels generally producing harmful gases like Carbon Monoxide (CO), Corban Dioxide (CO2) etc., causes a severe pollution to the environment and also health problems to humans. The fossil fuels are also exhaustive in nature and they are may be not available after few years later. So, we have to depend on other sources like non-conventional source category sources such as wind energy, Hydel energy, Geothermal energy, Tidal energy, ocean energy, Solar energy and Biomass energy etc., are better than conventional energy sources (CES's). The Non-Conventional Energy sources (NCES's) are also called Green Energy sources. The NCES's have many advantages over CES's, and its main advantage is a pollution free sources.

The total installed capacity of India as of June 2020 is 371 GW power generation but out of which only NCES's generation is 17.3 % only. To handling these NCES's suitable type of system is needed for generations such type of equipment is called DG's. Now a day the important of DG's utilization was increasing day by day because of excellent advantages of these devices.

DG's capacity generally in small scale power generation typically are 1 – 10 KW range. Generally, Grid connected DG's are synchronized by PLL [1]. VSG's Concept is new strategy control technology and which forces DG's to be acting like a actual synchronous generators. For this analysis Synchronous generator swing equation has been used and then linearized control methods are applied and analyzed to getting required output. The concept of linearized methodologies and VSG's system were discussed in [2] and [3].

Generally, any sudden change in load causes a severe oscillations were produced in the power system network due to which stability problem usually had been occurring in the system. Generally, in any synchronous machines power system stabilizers (PSS's) are used to eliminating these oscillations. But in case of VSG's such type of oscillations elimination not possible due to their characteristics [4]-[5]. So in order to eliminating such type of unwanted oscillations in the system an additional control technique is used that is a Fuzzy Logic Controller (FLC's). The proposed FLC technique to the existing system results in a effective linearizing model of swing equation has been obtained and also damped the oscillations much effectively. Mathematical formulation of system has been discussing in section II. Simulation results were discussing in section III. Final conclusion will be discussing in the section IV.

II. MATHEMATICAL FORMULATION OF A MODEL

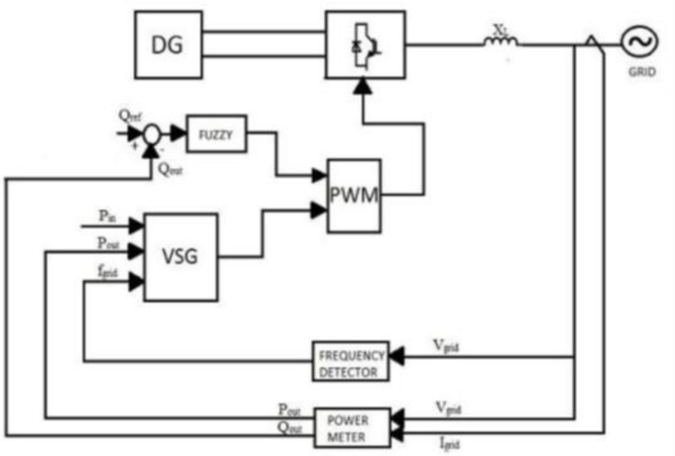

Figure 1. Structure of VSG

Synchronous machine swing equation linearization is also called VSG's implementation. To linearizing swing so many methodologies are there that were discussed in [6]-[7]. But in [3] a new methodology of a novel technology was proposed. This technique is considered and analyzed in the proposed system. The synchronous machine rotor stored K.E is given by

$$\mathbf{W = \frac{1}{2} J\, \omega_m^2} \tag{1}$$

Where **J** is the rotor moment of inertia and $\boldsymbol{\omega_m}$ is the speed of the rotor.
Differentiated the equation (1) with respect to 't' and we will get equation (2) after some system equations substitutions. The obtained equation is called a swing equation interms of change in deviation of system parameters.

$$\mathbf{P_{in} - P_{out} = J\, \omega_m \frac{d}{dt}(\omega_m) - D.\Delta\, \omega_m} \tag{2}$$

Where $\mathbf{P_{in}}$ is the input power, $\mathbf{P_{out}}$ is the output power, $\mathbf{D.\ \Delta\ \omega_m}$ is the damping term, **D** is the damping factor, $\mathbf{\Delta\ \omega_m}$ is $\mathbf{\omega_g - \omega_m}$, ωg is a rotating speed reference of grid voltage.

Generically rotor of a synchronous machine has damper windings and its main role is to be during hunting conditions the damper windings produces a counter balancing power in the machines and stabilize the machines from hunting. The structure of the used VSG is shown in Figure. 1.
From [3], the equation (3) is derived. Where m is the gradient vector.

$$P_{in} - P_{out} + m\,(Q^{*} - Q_{out}) = J\,\omega_m \frac{d}{dt}(\omega_m) - D.(\omega_g - \omega_m) \tag{3}$$

In this paper four cases are considered and discussed.

A. *Case I :*

By using equation (2), the conventional VSG system is deduced

B. *Case II :*

By using equation (3) a linearized model of swing equation has been deriving and the calculation of m is obtaining by using an algorithm and then damping factor D is calculated using equation (4). Where is D' is the D in the next step.

$$D' = D\sqrt{(m^2 + 1)} \tag{4}$$

The gradient vector m an iterative algorithm as follows [3].

1. Choose initial value of m (here, 0.1 initially assumed) and then, move on to next step.

2. Then take temporal differentiation of P, Q, δ and Vt, parameters i.e., dP/dt, dQ/dt, dδ/dt and dVt/dt and then calculate all these differentials in every iteration. Then, move on to next step 3.

3. Compare the current state temporal differential values with the previous state value. If the sign of dδ/dt is changed and dVt/dt is not changed, then go to step 4. If the sign of dδ/dt is not changed and dVt/dt is changed and then also go to step 4. Otherwise, move on to step 5.

4. When dP/dt or dQ/dt =0 (Under steady state), m is inestimable. Then, consider previous state m value. Otherwise, move on to step 5.

5. Renew m. If the sign of dδ/dt changed, m=-(dP/dt)/(dQ/dt). If the sign of dVt/dt is changed, m=(dQ/dt)/(dP/dt). If m is plus, stop renewing m. Then, go back to Step 2.

P, Q, δ and *Vt* parameters were measured in each step of all sampling times. We can calculate D two cases distinctly. Another way of calculating equation is shown in (5)

C. *Case III :*

By using equation (3) that is linearized model of swing equation, the damping term is determined by using linear control theory that is shown in equation (5).

$$D' = 2\,\zeta\sqrt{AJ_m(m^2 + 1)} \tag{5}$$

Where D' is the D in the next step, ζ is damping ratio and J_m is the constant used in place of $J\omega_m$.

To calculating coefficient A value, the following algorithm is to be used.

1. To getting D value as 0.045, choose an appropriate initial value of A and then move on to Step 2.

2. Then take temporal differentiation of P, Q, δ and Vt, parameters i.e., dP/dt, dQ/dt, dδ/dt and dVt/dt and then calculate all these differentials in every iteration. Then, move on to next step 3.

3. Compare the Current state of temporal differential value with the previous state value. When the sign of dVt/dt is changed and dδ/dt is not changed, move on to Step 4). Otherwise go back to Step 2.

4. If dδ/dt =0 is inestimable. Then, go back to Step2). Otherwise, A is determined by (dP/dt)/(ω_m-ω_g) equation. Then, move on to Step 5.

5. Determine the D using equation (5). When D<0.045, reset the D at 0.045. Then, go back to Step 2.

D. *Case IV :*

Synchronous Generator operated with VSG's is to be analyzed. The Case I conventional VSG is compared with remaining all cases for this we are using a Fuzzy logic controller (FLC). The fundamental model structure of FLC is shown in Figure 2. The rule base structure of FLC is tabulated in Table-1. A Mamdani model of a FLC is used in this design. Centroid methodology is used for defuzzification. Generally, FLC's Triangular membership functions are used for this kind of mamdani models.

Fuzzy variables or linguistic variables are used in the model is NB(Negative Big), NM(Negative Medium), NS(Negative Small), Z(Zero), PS(Positive small), PM(positive Medium), PB(positive Big) are defined in the distinct ranges for error, change in error and output variables that were analyzed from the reference [8] as shown in the figure 3 to 5. The rule base structure is created with these linguistic variables are shown in the Table-1. Here the error indicated the difference in reactive power set value and actual value. Change in error denotes rate of change of error. The output from fuzzy logic controller is given to Pulse width modulation generator as reference input.

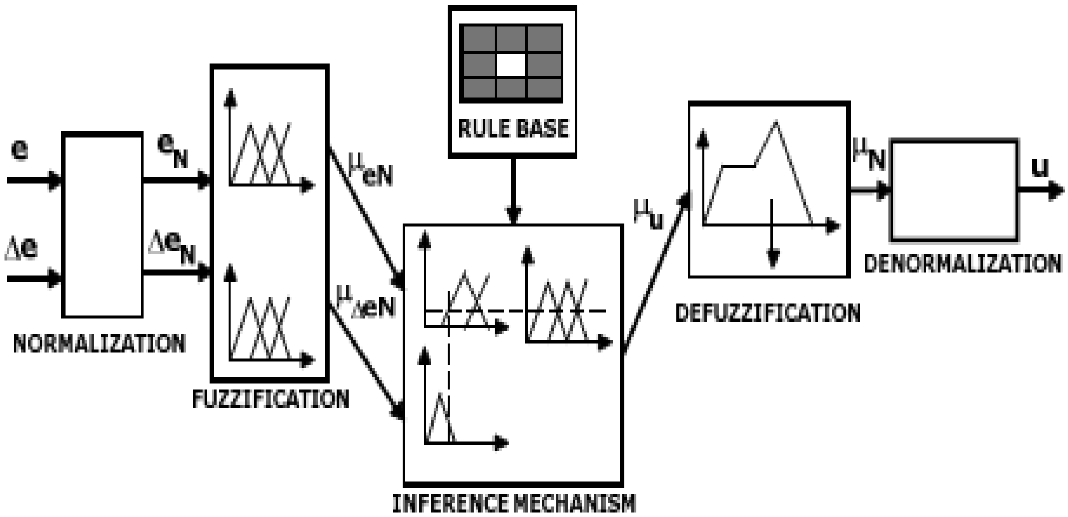

Figure 2. structure of FLC

Table 1. Rule base for FLC

e \ Δe	NB	NM	NS	Z	PS	PM	PB
NB	NB	NB	NB	NM	NM	NS	Z
NM	NB	NB	NM	NM	NS	Z	PS
NS	NB	NM	NM	NS	Z	PS	PM
Z	NM	NM	NS	Z	PS	PM	PM
PS	NM	NS	Z	PS	PM	PM	PB
PM	NS	Z	PS	PM	PM	PB	PB
PB	Z	PS	PM	PM	PB	PB	PB

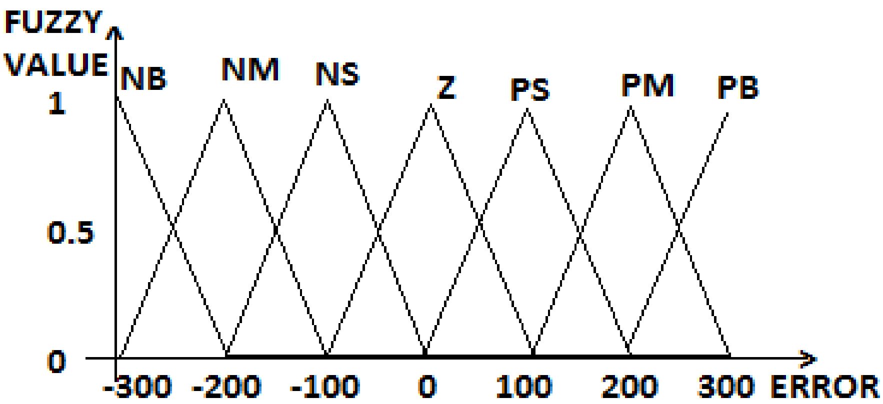

Figure 3. Triangular input membership value for error

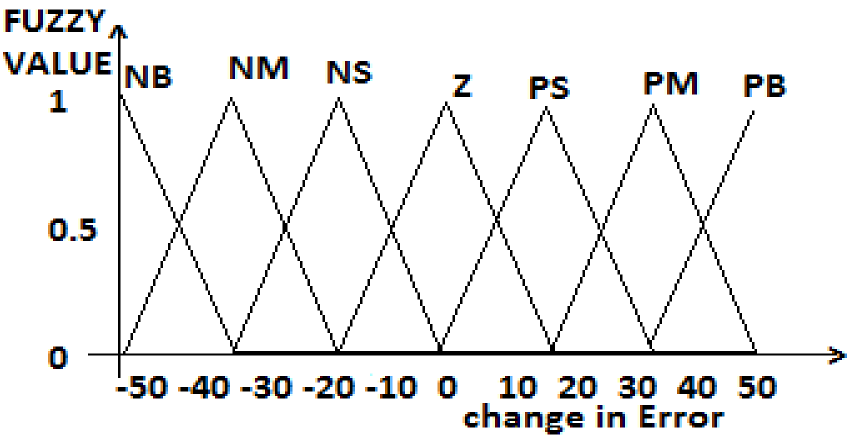

Figure 4. Triangular input membership value for change in error

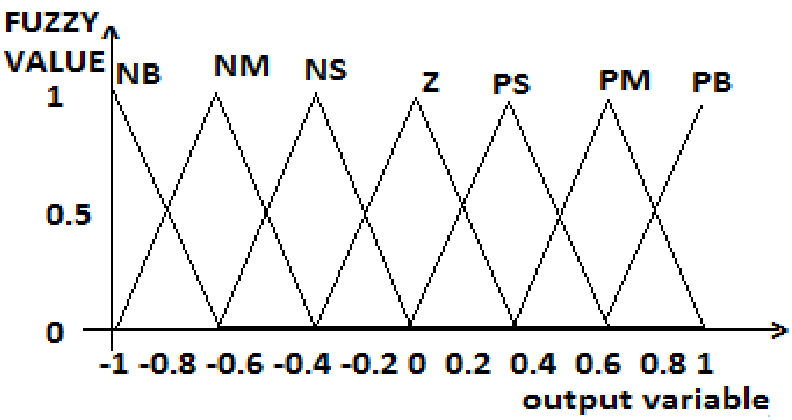

Figure 5. Triangular membership value for output variable

III. SIMULATION MODELS AND RESULTS

A. Case I: Conventional Virtual Synchronous Generator

Simulation of conventional Virtual Synchronous Generator model control strategy were designed by using equation (2). Due to sudden change in load disturbance creation at t=2 sec by a reactive power load, the required powers are counter balanced by VSG from t= 2 sec onwards and then stable the system after few sustained oscillations cycles in the system response as shown in the Figure 6.

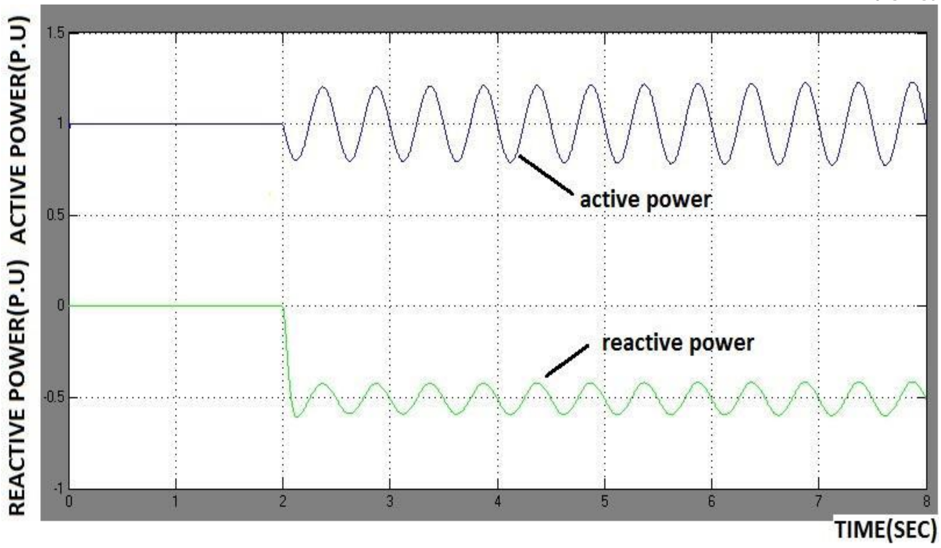

Figure 6. Conventional VSG simulation results

B. Case II: Linearized model

In linearized model case, VSG of is employed. By using the equation (2) along with equation (4) were used for this model. Equation (4) is also used for determining the damping factor. In addition to that FLC system is employed to this system. Now also sudden change in load disturbance is created at 2 sec by a reactive power load. The system produces again sustained Oscillations like previous case but these oscillations are damped successfully as shown in the Figure 7. The oscillations are intensity levels were considerably decreases as compared to conventional model sown in case 1.

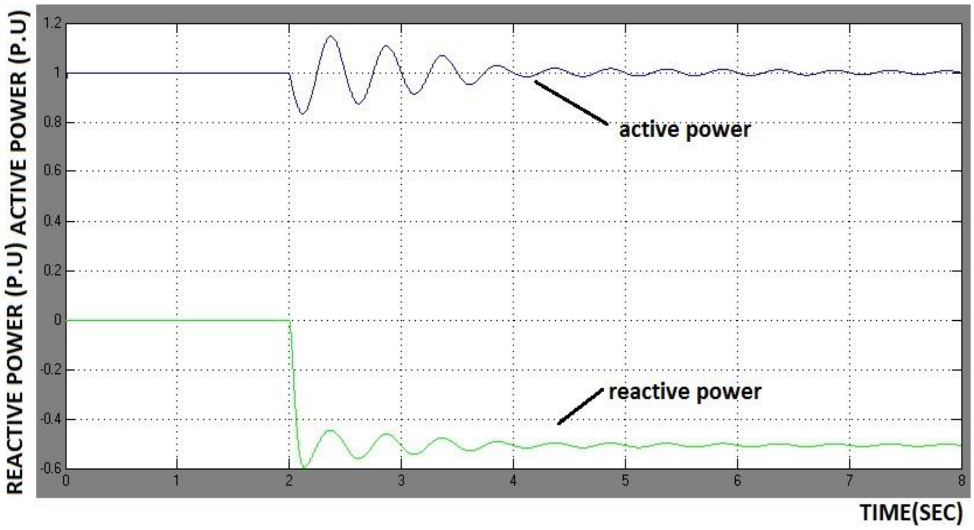

Figure 7. Proposed control method system response

C. Case III: Model of a linear control theory

In linear control theory model case, VSG of is employed. By using the equation (2) along with equation (5) were used for this model. A sudden change in load disturbance now is created at 2 sec by introducing active power load. The oscillations are damped in this method by the value of ζ. For this model Equation (5) is used for determining the damping factor. We can consider any damping value but here two values only taking and observing the corresponding system response. These values are ζ=0.707, ζ=1.5 and also D = constant is considered, simulation results were shown in Figure 8, Figure 9 and Figure 10 respectively. The oscillations are damped effectively when compared with the above two cases.

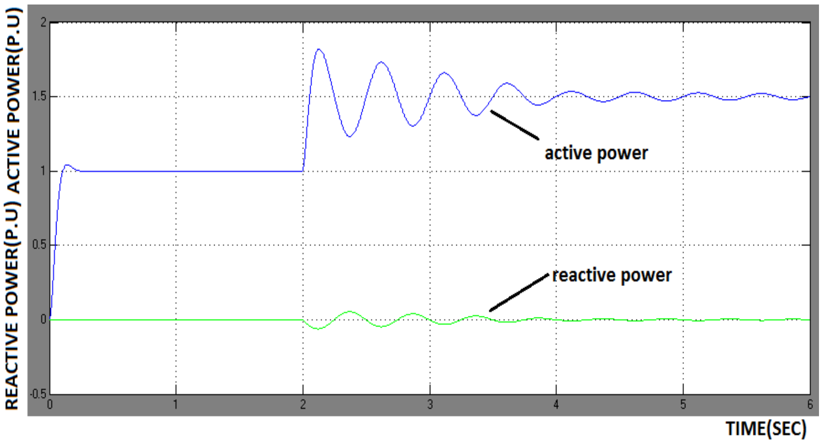

Figure 8. Proposed method system response with *D*=constant

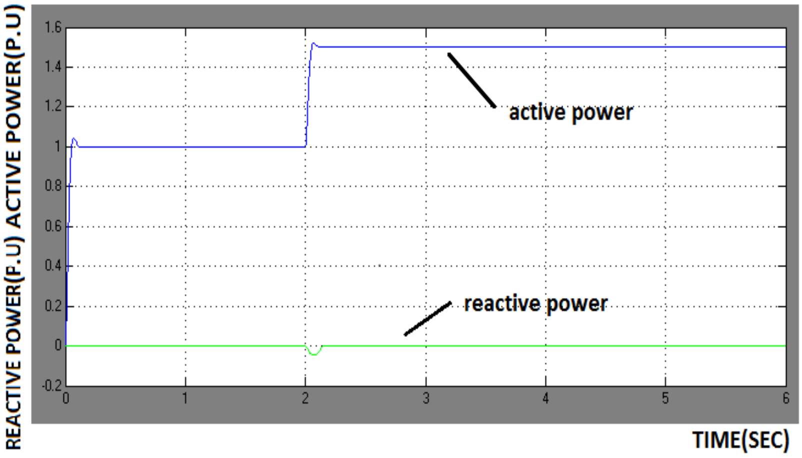

Figure 9. Proposed method system response with ζ=0.707

Figure 10. Proposed method system response with ζ=1.5

D. Case IV: Virtual Synchronous Generator in parallel with Synchronous Generator

VSG and synchronous generator (SG) combined in this case. The load consumption of the system is changed from 1.5 to 0.75 p.u with constant 'D' value and with a damping ratio value ζ=1.5 is to be considered, system simulation results were shown in Figure 11 and Figure 12 respectively.

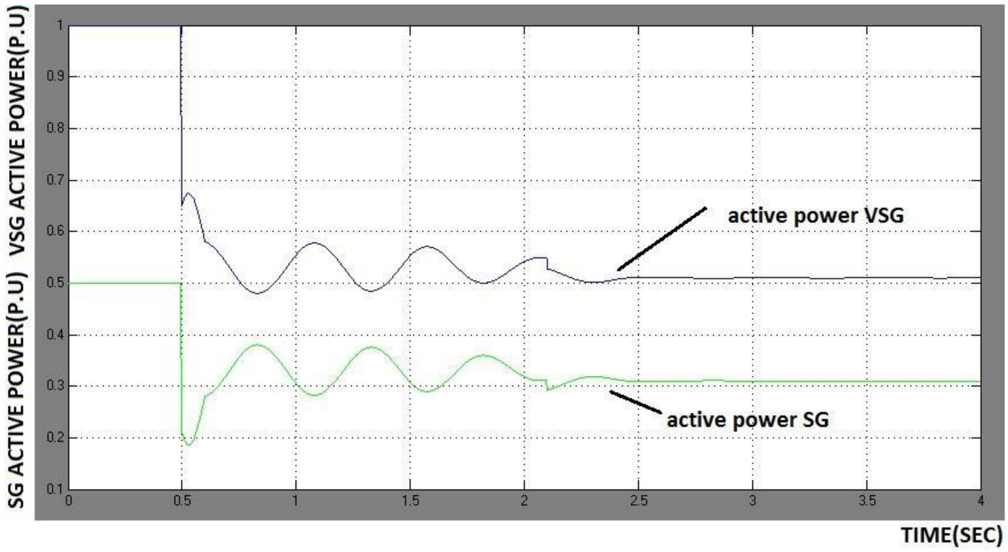

Figure 11. VSG and SG power response with *D*=constant

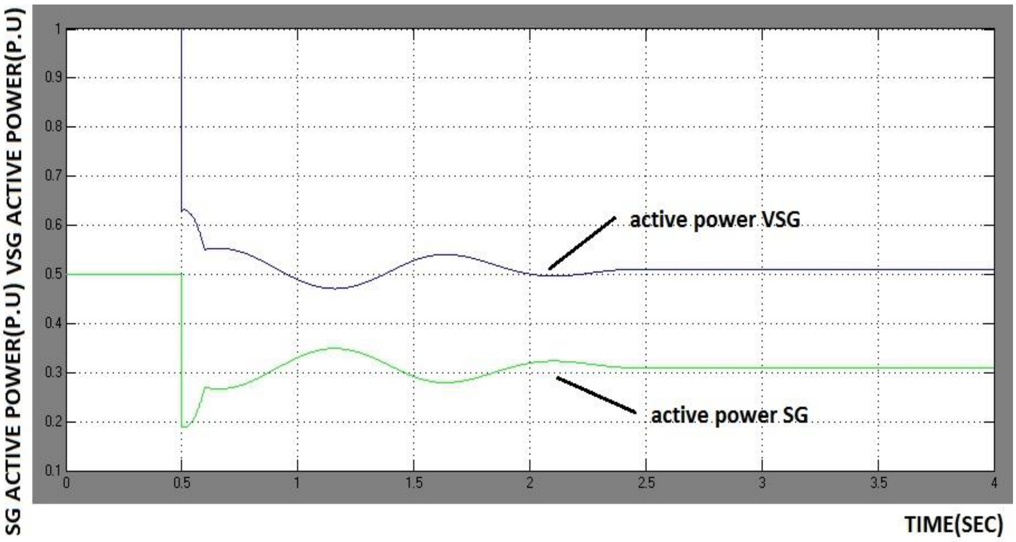

Figure 12. VSG and SG Power response with ζ=1.5

IV. Conclusion

The gird connected DG's issues is to be overcome effectively with different control strategies discussed in above along with VSG. The linearized swing equation of the SG is also developed for accurate model design and also lack of PSS in the system has been overcome by control methodologies are used in the system for minimizing the oscillations and damped effectively after few cycles later. Finally, the systems to be stabilize effectively by using this kind of control strategies due sudden change in load conditions environments.

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