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PERFORMANCE ANALYSIS OF DISTRIBUTED GENERATOR WITH VIRTUAL SYNCHRONOUS GENERATOR

A Naveen Kumar[1], **T Penchalaiah** [2]

[1 2] *Student, Department of EEE, JNTUA, Anantapuramu, Andhra Pradesh, India*

Abstract - *Due to socio-environmental issues distributed generators are increasing significantly over conventional generation to meet ever increasing demand. Generally in order to maintain synchronism with grid the phase locked loops are used in distributed generation. When the capacity of the distributed generator increases largely then the stability is the major issue to concern. Virtual Synchronous Generator concept is one of the trending technology to control distributed generation. Since there is no power system stabilizers in VSG, sudden load changes causes the oscillations in the system. A new control strategy derived by linearizing the swing equation to suppress these oscillations effectively. In this paper VSG is employed along with fuzzy. MATLAB/SIMULINK models are created and the results are analyzed.*

Key Words: **Distributed generation, fuzzy, swing equation, virtual synchronous generator.**

1. INTRODUCTION

Today Electrical energy has become the basic need of the mankind. Day by day electrical energy consumption is increasing throughout the world. A country's per capita energy consumption indicates its growth in the modern world. To meet the ever increasing demand of electrical energy the generation of the energy must be increased. As of today the conventional means of generating the electricity is the major source of electric power. Conventional generation of electricity includes generation from fossil fuels. Unfortunately fossil fuels are exhaustive in nature, means they will end one day, more over they are causing severe pollution. To overcome this alternate sources of energy (green energy) are being given greater importance than fossil fuels in recent years. Alternate sources of energy includes energy from wind, solar, biomass, ocean etc.

The overall power generation in India has been increased from 1048.673 BU during 2014-15 to 1107.386 BU during 2015-16 with a six percentage increment. The share of Renewable energy sources power in the total is about 14% only. From the above statics it is evident that the alternate sources of energy given great preference now a days. This will lead to concept of Distributed Generation (DG).

Distributed generation may be defined as small scale power generation or storage technologies (typically in the range of 1 KW to 10000 KW) used to provide an alternative to or an enhancement of the traditional electric power system .There are no uniform national interconnection benchmarks tending to safety, power quality and reliability for distributed generation systems. With the DG there are several issues arising in the real scenario, which is to be taken into account for smooth and reliable operation. Most of the Grid connected DG's are synchronized with grid through Phase Locked Loops (PLL) [1].

In this project Virtual Synchronous Generator (VSG)[2] concept is discussed and analyzed. VSG is a control strategy which forces DG to act like a real synchronous generator, it utilizes the swing equation of the synchronous machine for this purpose. There are several methods to implement the swing equation, a linearized method [3] is used in this project.

In the real synchronous machine control there are power system stabilizers (PSS) to damp oscillations occurred due to sudden change in the load[4] [5]. But in the VSG there is no such arrangement therefore, oscillations persists. To damp oscillations a model with fuzzy logic controller is proposed which employs a linearized model of swing equation. This paper is structured as: linearization of Swing equation and mathematical formulation are presented in Section II. Sections III gives simulation and results. Conclusion is presented in Section IV.

2. MATHEMATICAL FORMULATION

VSG implementation is nothing but implementing the swing equation of the synchronous machine. However the equation is nonlinear and very difficult to find parameters. There are so many linearizing techniques are presented in the literature [6] [7]. In [3] a new noval linearizing technique is proposed. The technique is reviewed with the suitable equations.

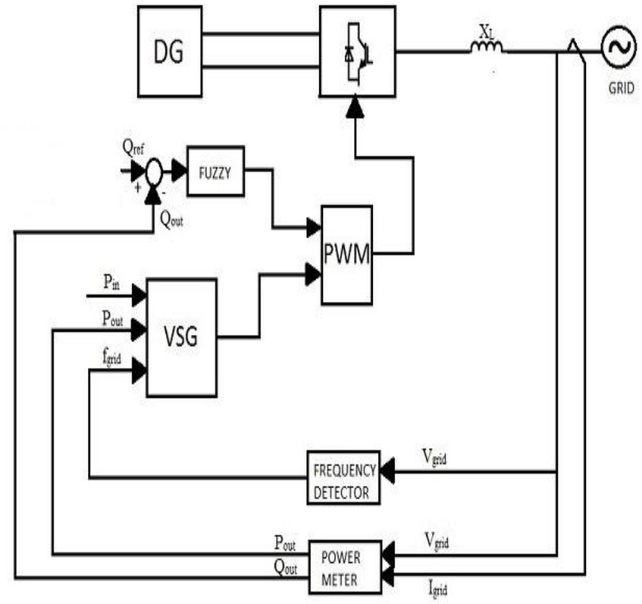

Fig -1: Structure of VSG

The kinetic energy stored in the rotor of the synchronous machine is given by

$$W = \frac{1}{2} J \omega_m^2 \qquad (1)$$

Where *J* is the rotor moment of inertia and ω_m is the speed of the rotor. This equation is differentiated and the equation (2) is obtained.

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

Where P_{in} and P_{out} are input power and output power, respectively. Damping term ($D\Delta\omega_m$) is added to the equation, because the rotor of the synchronous machine has damper windings. Here, *D* is the damping factor and $\Delta\omega_m$ is ω_g-ω_m. The ω_g is a rotating speed reference of grid voltage. The structure of the used VSG is shown in Fig. 1.

From [3], the equation (3) is obtained. Where *m* is the gradient vector.

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

This paper considers four cases. Case I considered as the conventional VSG, which uses equation (2). Case II utilizes the linearized model of swing equation (3) and the calculation of *m* is done through an algorithm and the damping factor *D* is calculated using equation (4). Where D' is nothing but *D* in the next step.

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

The gradient vector *m* is calculated through an iterative algorithm as follows [3].

1. Set initial value of *m* (here, 0.1 is used as the initial). Then, go to Step 2.
2. By temporal differentiating *P, Q, δ* and V_t, calculate *dP/dt, dQ/dt, dδ/dt* and *dVt/dt* in every iteration. Then, go to Step 3.
3. Compare the temporal differential to the previous value. When the sign of *dδ/dt* is changed and *dVt/dt* is not changed, go to Step 4). When the sign of *dδ/dt* is not changed and *dVt/dt* is changed also go to Step 4. Otherwise, go to Step 5.
4. If *dP/dt or dQ/dt* =0 (in steady state), *m* is inestimable. Thus, consider previous m value. Otherwise, go to Step 5.
5. Renew *m*. When the sign of is *dδ/dt* changed, *m*=-(*dP/dt*)/(*dQ/dt*). When 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 V_t are measured in each sampling time step. Further D is calculated in two cases distinctly. Case III utilizes the linearized model of swing equation which is equation (3). And the damping term is calculated using linear control theory, given by equation (5).Where D' is nothing but *D* in the next step.

$$D' = 2\varsigma\sqrt{AJ_m(m^2 + 1)} \qquad (5)$$

Where ζ is damping ratio, J_m is the constant used in place of $J\omega_m$. The algorithm for calculating coefficient A value is as follows.

1. Set initial value of A such that the D becomes 0.045.Then go to Step 2.
2. By temporal differentiating P, Q, δ and V_t, calculate dP/dt, dQ/dt, $d\delta/dt$ and dVt/dt in every iteration. Then, go to Step 3.
3. Compare the temporal differential to the previous value. When the sign of dVt/dt is changed and $d\delta/dt$ is not changed, go to Step 4). Otherwise go back to Step 2.
4. If $d\delta/dt$ =0 is inestimable. Thus, go back to Step2). Otherwise, A is calculated as $(dP/dt)/(\omega_m\text{-}\omega_g)$. Then, proceed to Step 5.
5. Calculate the D using (5). If D<0.045, reset the D at 0.045. Then, go back to Step 2.

In case IV the VSG is operated along with Synchronous Generator (SG) and a sharing is analyzed.

The case I which is conventional VSG is compared with remaining cases which utilizes Fuzzy logic controller. The basic structure of fuzzy logic controller is shown in Fig. 2. The rule base for fuzzy controller is tabulated below. Mamdani model of fuzzy logic controller is used. Centroid method is used for defuzzificztion. Triangular membership function is used. Fuzzy variables NB, NM, NS, Z, PS, PM, PB are defined in the distinct range for error, change in error and output variables [8] as shown in the fig-3 to 5. The rule base is created as shown in the table-1. Here the error denotes 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 PWM generator as reference input.

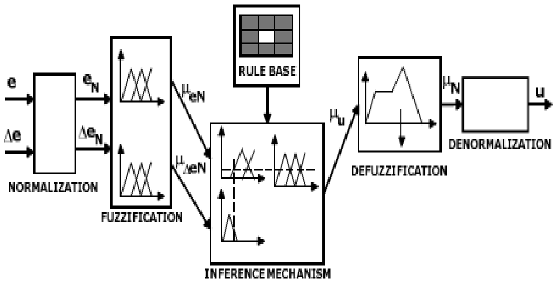

Fig- 2: structure of fuzzy controller

Table -1: Rule base for fuzzy

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

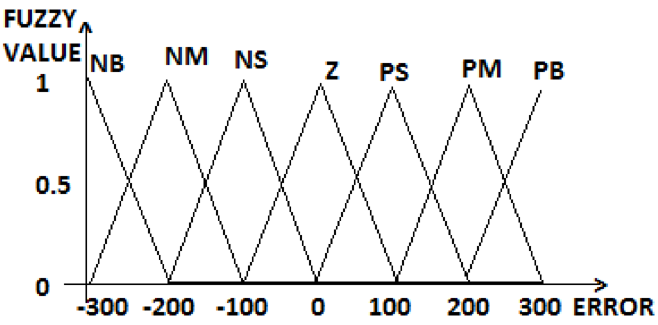

Fig-3: Membership value for error

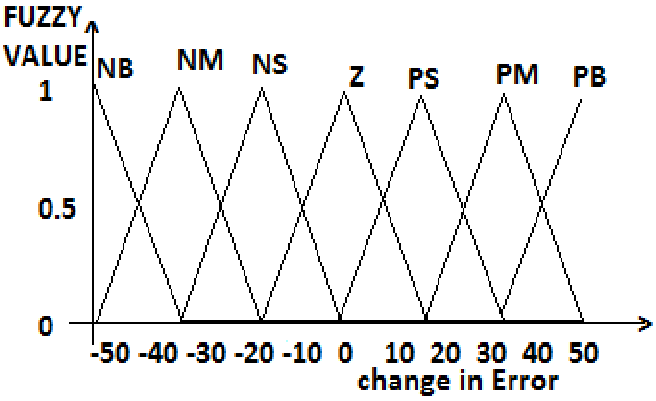

Fig-4: Membership value for change in error

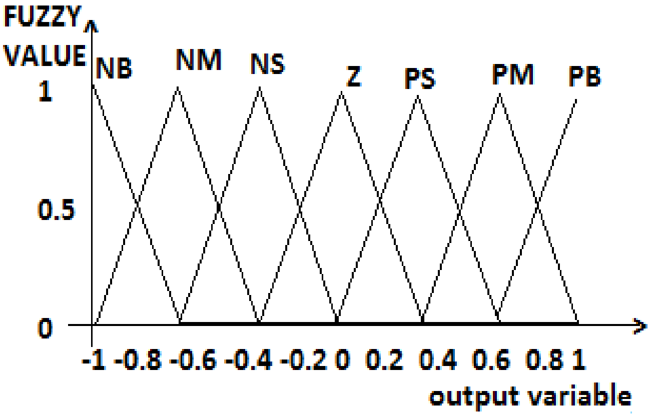

Fig- 5: membership value for output variable

3. SIMULATION AND RESULTS

Simulation is carried out to verify results. MATLAB/SIMULINK tool is used. As said earlier there are four cases are considered in total.

Case I: Conventional VSG

A simulation is carried out with conventional VSG. For that the equation (2) is employed in the control strategy. Load disturbance is created by changing reactive power at 2 sec. We observe sustained oscillations in the system response as shown in the Fig. 6.

Case II: With linearized model

In this case VSG of linearized model is employed. Equation (2) along with equation (4) is used. Equation (4) is used to calculate the damping factor. Fuzzy controller is employed. Now load disturbance is created at 2 sec by introducing reactive load. Oscillations are damped successfully as compared with conventional method as shown in the Fig. 7. The oscillations are suppressed considerably compared to conventional model.

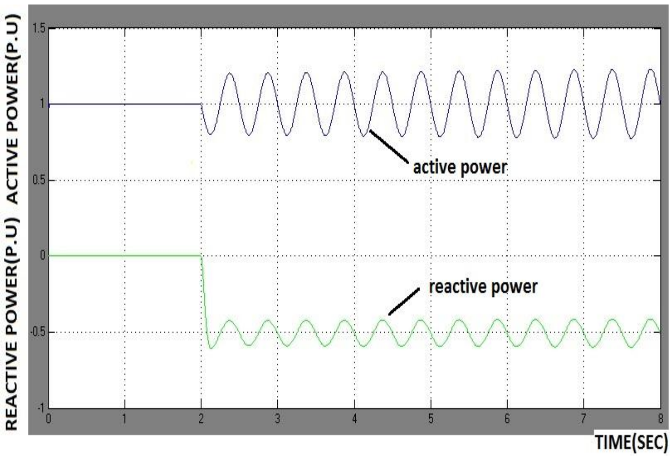

Fig-6: simulation results of conventional VSG

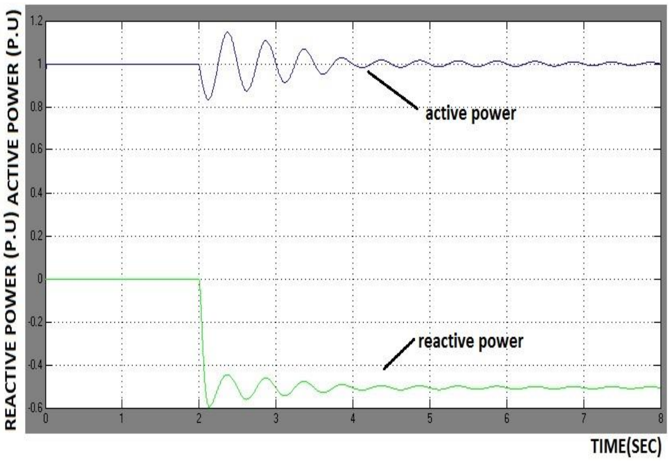

Fig-7: system response using proposed control method

Case III: By linear control theory model

In this case VSG is employed using equation (2) along with equation (5). Damping factor is calculated using equation (5). Now load disturbance is created at 2 sec by introducing active power load. The oscillation is controlled by the value of ζ. The cases of D=constant, ζ=0.707, ζ=1.5 are considered, simulation results are shown in Fig. 8, Fig. 9 and Fig. 10 respectively. The oscillations are suppressed effectively than above two cases.

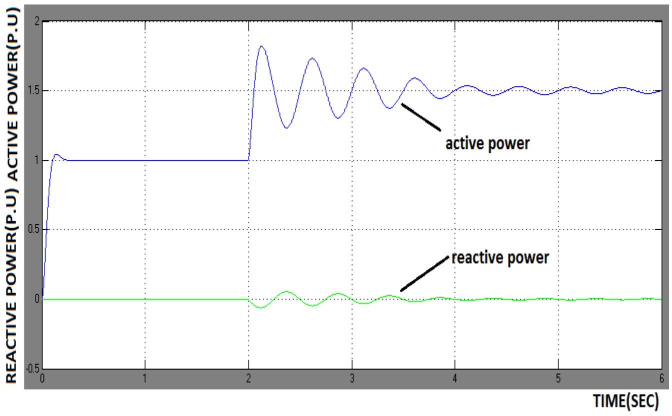

Fig-8: System response using proposed method with D=constant

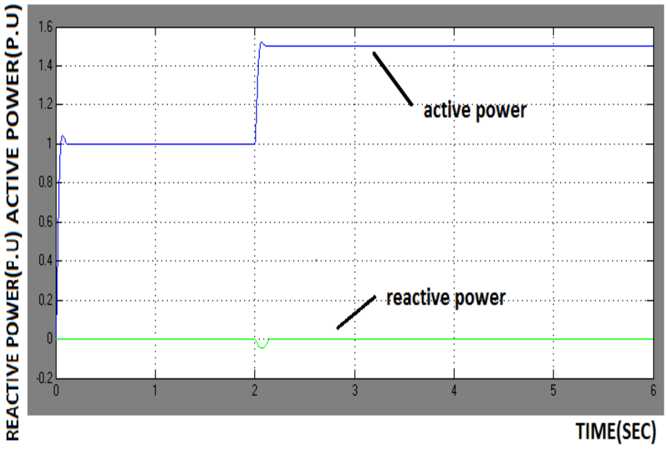

Fig-9: System response using proposed method with ζ=0.707

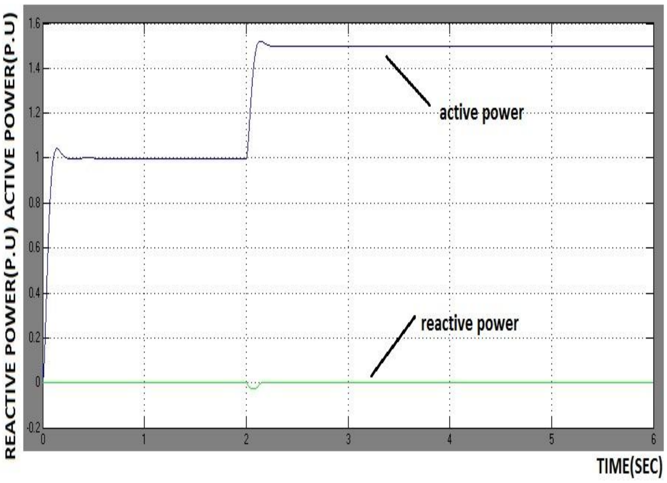

Fig-10: System response using proposed method with ζ=1.5

Case IV: VSG in parallel with SG

VSG along with synchronous generator is employed. The damping ability is verified in the case that load consumption is changed from 1.5 to 0.75 p.u with D=constant, ζ=1.5, simulation results are shown in Fig. 11 and Fig. 12 respectively.

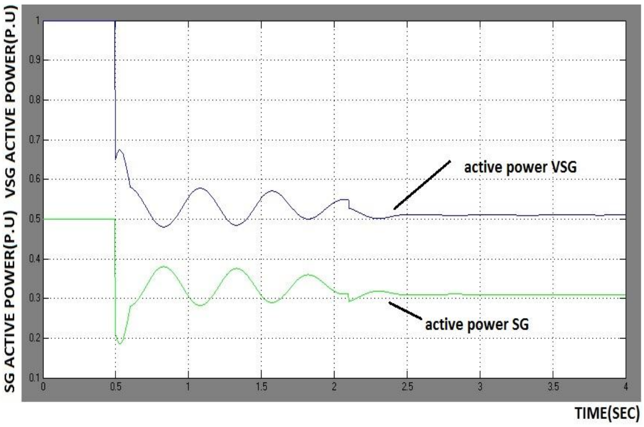

Fig-11: Power response of VSG and SG with D=constant

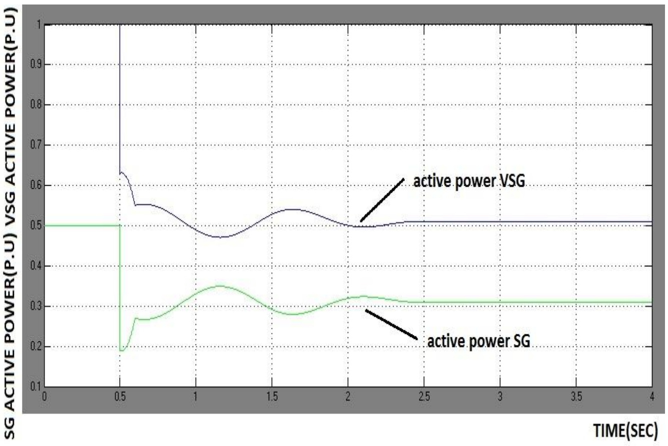

Fig-12: Power response of VSG and SG with ζ=1.5

4. CONCLUSION

To overcome the issues with gird connected DG, a control technology so called VSG is studied. The swing equation of the synchronous machine is linearized. The problem of lack of Power system stabilizers has been overcome by the proposed control. Using the developed method the oscillations can be minimized. Simulation results show that the proposed method damps the oscillation adequately.

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