Stability Mitigation Of DG Based Electric Power Grids Using An Extrinsic Inertia

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***Abstract*— Due to the advantages of installing it in power grids, the dependence of Distributed Generation (DG) units in Microgrid is increased rapidly. These DGs exploit renewable energy sources (RES) such as wind turbines, solar photovoltaic and small hydro power etc. Most of the RES are interfaced to the AC grid through inverters due to fluctuating nature of their energy production. Hence, the rotating inertia is reduced significantly because RES is characterized by either small or no rotating mass. As a result, these grids may be subjected to instability if a significant loss of load or generation take place. This paper will emphasize on stability mitigation of such grids. The research introduces a control concept which synthesis an extrinsic (virtual) inertia during transient conditions which serve to enhance grid stability.**

Keywords— swing equation; virtual inertia; Phase Locked Loop (PLL); Virtual Synchronous Generator (VSG)

I. INTRODUCTION

Electric power systems persisted on vertical structure operation more than half century ago. The power flow in this structure is unidirectional from generation to distribution system with the help of transmission system. Also, this structure depend on usage of centralized generation station for power generation. Reduction in the gaseous emission, diversification of energy sources and ease of finding sites for smaller generators are main motivations towards the use of Distributed Generation (DG) units in power grids. These DGs exploit renewable energy resources (RES) such as wind turbines, solar photovoltaic, tidal energy and small hydro power etc. as mentioned in ref [1] in addition to their friendly environment effect, these DGs present a low-cost way for the energy flow into the market since they do not suggest substantial transmission losses due to their location near to the customers [2]. Moreover, they could present a reliable and uninterruptible source for the customers especially in rural areas [3] and micro grids [4]. In addition, a possibility where the DG could be beneficial is if it could help to supply load during contingencies until the utility can build up additional delivery capacity [5].

In recent years the capacity of grid connected Distributed Generation via inverters is rapidly growing. For example, the Egyptian government has planned to have 20% of the energy generation from the renewable energy by the year 2020 [6]. Due to their fluctuating nature, the DGs/ renewable energy sources are connected to the utility through a power electronic inverter to meet the grid requirements. The inverters used in distributed generators are controlled using PLL (Phase Locked Loop) in order to synchronize with power system frequency [7]. Power systems will become unstable, if the capacity of inverter type distributed generators become larger and larger, because inverter frequency is controlled just to follow grid frequency and they have no inertia [8].

In order to preserve these power systems stability within the limits of presently available system control strategies is to incorporate additional extrinsic rotational inertia. This can be implemented by adding short-term energy storage to any DG/RES unit together with a smart control of the front end inverter which couple it to the grid. The DG unit will then operate like a virtual synchronous generator (VSG), revealing some of the desired properties of synchronous machines for short time intervals [9]. There are several control methods which are used to emulate the electrical behavior of synchronous machine in the electrical grids. However, their different topologies and distinctive labels, they are common in mimicking the rotational inertia and damping properties of synchronous machine.

This research paper will emphasize on the impact of increases DGs penetration level on the grid stability. Also it will investigate the capability of the VSG control concept to enhance stability of the test grid even for high penetration level of DGs. This paper will be organized as following: the concept of VSG control is introduces in sec II. After that the Phase Locked Loop (PLL) as a method for monitoring the grid parameters are presented. In sec IV the VSG ability to enhance stability of the test system will be investigated. Finally the conclusion drawn from this research will be outlined.

II. VSG CONTROL CONCEPT

The VSG control method is based on the known swing equation of synchronous machine which is:

$$P_{in} - P_{out} = J\omega_m \frac{d\omega_m}{dt} + D\,(\omega_m - \omega_{ref}) \quad (1)$$

Where P_{in} represents the prime mover power, P_{out} is the electrical power output from the generator. The moment of inertia and damping factor take symbols J and D respectively. In synchronous generator inertia plays an important role as it can contribute to the stable operation of grid through absorption to and release from the inertial energy when transient difference in demand and supply of the grid is occurred. Each synchronous generator converts a part of the kinetic energy stored in its rotating mass to active electric power to supply the required total active power, resulting in a slight decrease of the rotational speed and the frequency of the output voltage. Moreover, the damper windings in the rotor of synchronous generator is used to damp out the rotor oscillation when its speed deviate from synchronous speed. Due to the previous merits of the existence of synchronous generator in the electric grid, the inverter which Interface the DG/ (RES) will be controlled in the same manner

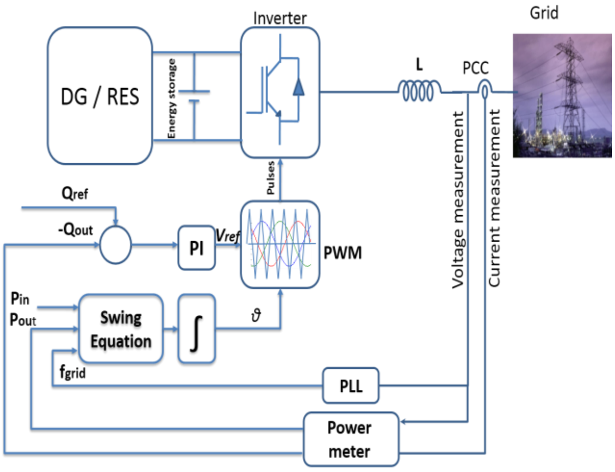


Figure. (1): *Basic structure of grid connected VSG [8].*

As shown in Figure. (1), P_{in} refer to the input power to the VSG which is corresponding to the power of the prime mover in the electromagnetic synchronous generator. P_{out} is the electrical power output of VSG. The extrinsic (virtual) moment of inertia and damping factor take symbols J and D respectively the swing equation will be solved to get the virtual rotor speed ω_m. This speed will be integrated to get the virtual rotor angle θ which is given to the Pulse Width Modulation (PWM) as a phase commend. The magnitude of reference voltage can be obtained through reactive power control. In this structure the VSG model provide the reference voltage signal to drive the inverter. There are other structures where the VSG model can provide the reference power or current. All of these controllers are reviewed and classified according to its used references and control scheme in Refs. [10, 11].

III. Phase Locked Loop (PLL) Structure

The phase locked loop (PLL) technique is used for synchronization of grid-interfaced converters. Also the PLL algorithm is used to monitor the grid voltage parameters (i.e. the voltage magnitude and frequency). Moreover, it is used to provide the phase angle of the grid voltage. There are several techniques to implement the PLL. The commonly used technique is the Synchronous Reference Frame phase locked loop or (SRF-PLL) is shown in Figure. (2). The SRF-PLL is broadly used due its good Performance when the grid voltage is balanced and not distorted [12].

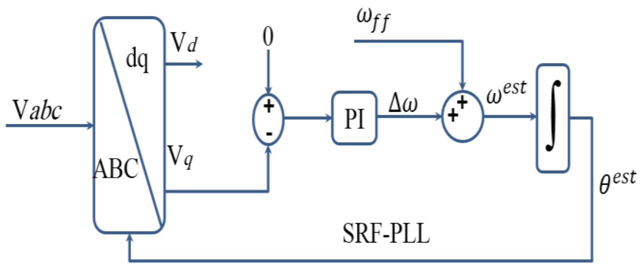


Figure. (2): *Block diagram of SRF-PLL.*

IV. Testing and Verification

In this section, the ability of the VSG control method to mitigate the test system stability will be verified through many test scenarios. The test system is composed of two generators of equal rating, each of 503 KVA. In addition to two DGs of equal rating also each of 560 KVA. The test system is shown in Figure. (3). There are two methods of controlling the inverter based DGs. In the first one, the inverter is controlled as a grid feeding converter which is known as current controlled inverter. The inverter based DG is controlled as a grid supporting converter which is known as VSG control concept in the second method. In this test both of these methods will be used to differentiate between them in regards stability enhancement. Table. (1) in the APPENDIX summarize the most important system parameters.

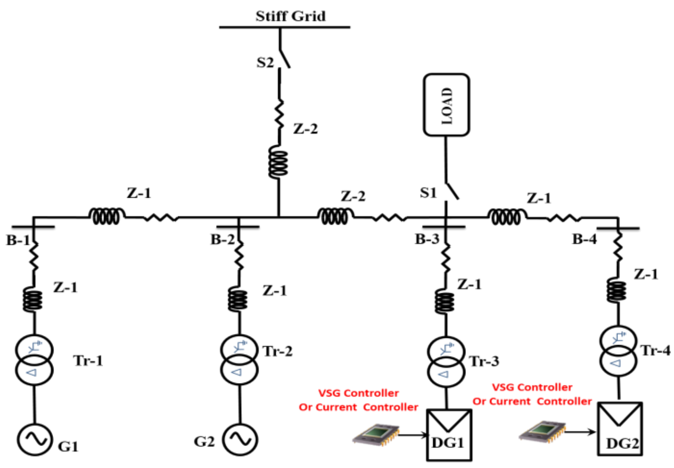
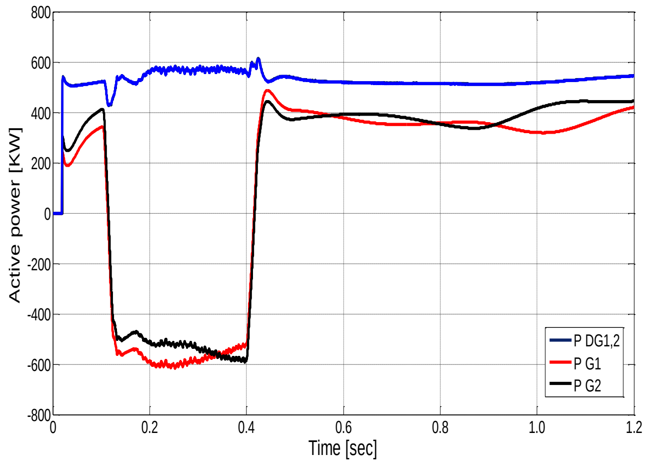


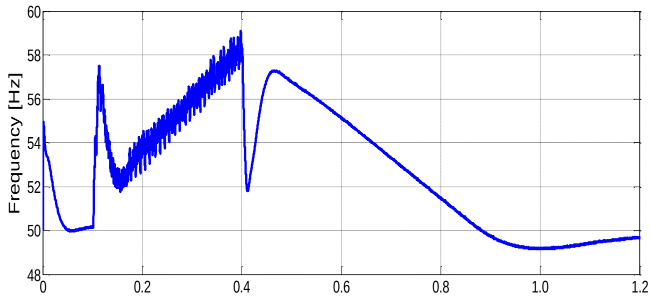
Figure. (3): *Structure of test system [13]*

A. Penetration level is 50%

In this test a resistive load of 2120 KW is connected to the test system. Both of the SGs and DGs are operating at their nominal ratings. This means that the DGs will share in load feeding by fifty percent approximately. Suppose that the load is disconnected by opening switch S1 for 0.3 s. the test results in case of using each controller is shown in Figure.(4) and Figure. (5).



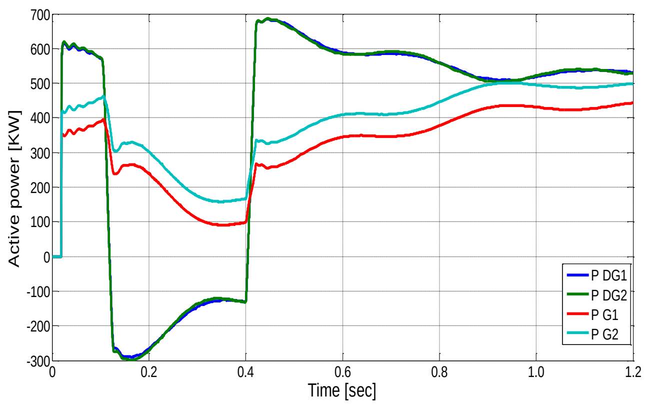
(a) Output power



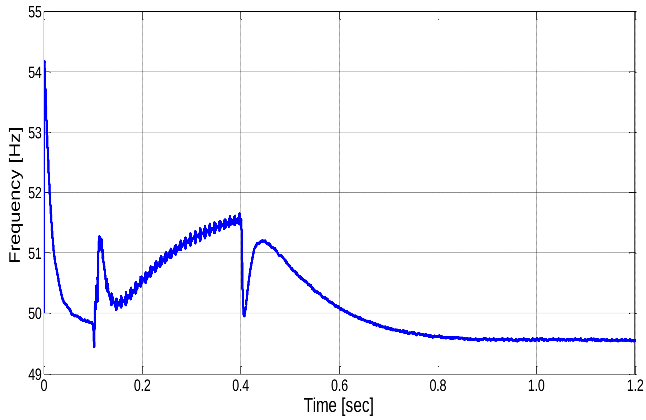
(b) Frequency

Figure. (4): *Output power and frequency* if the DGs are *current controlled.*

In case of the DGs are using current control (i.e. controlled as grid feeding converters), the SGs only will be responsible to stabilize frequency against disturbances. Due to the low inherited inertia in the test grid, the frequency rises to about 59 Hz. On the other hand, in case of using VSG control concept both of the DGs and SGs will handle this disturbance. Hence, the frequency will rise to about 51.5 Hz and returned back after load reconnection to 49.8 Hz due to increased inertia by the action of VSGs.



(a) Output power

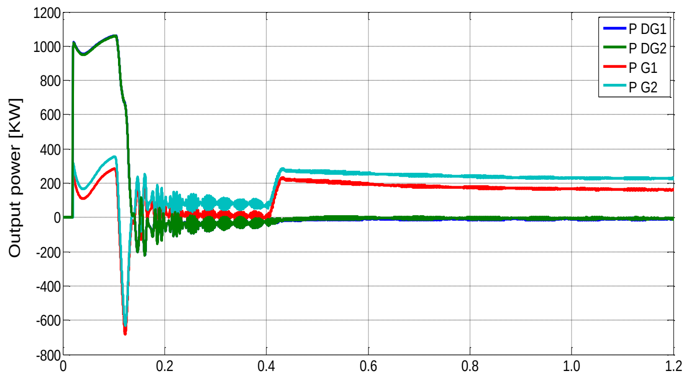


(b) *Frequency*

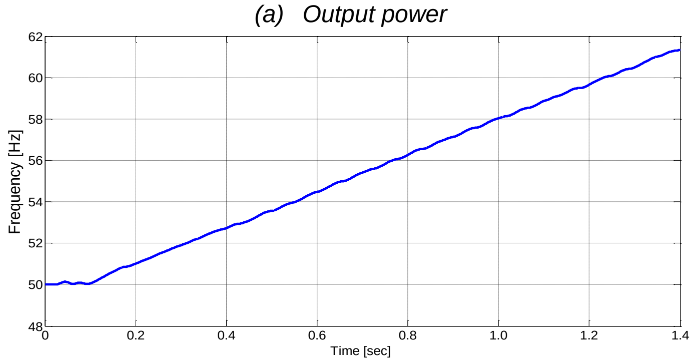
Figure. (5): *Output power and frequency if the DGs are VSG controlled.*

B. Penetration level is 100%

At the second stage of this test the rating of both DGs will be duplicated. The SGs ratings will kept constant as before. Also, the load rating will equal summation of both SGs and DGs new ratings. This test will be used to emphasize that if the penetration level of DGs are greater than SGs, the grid will be subjected to instability if the controller is not changed. The test result in case of using the current control method for DGs is shown in Figure. (6).



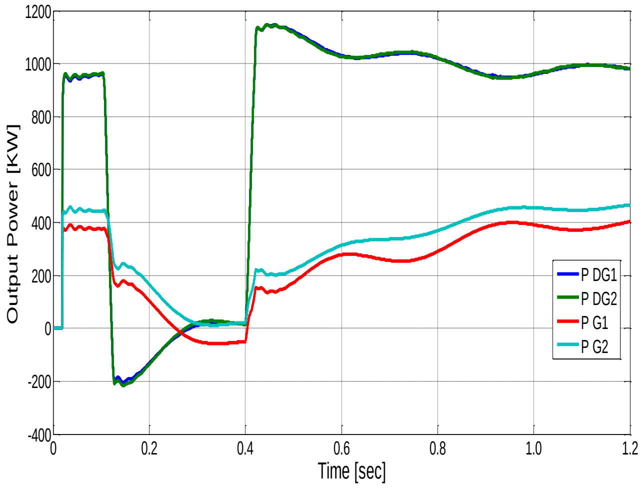
(a) Output power



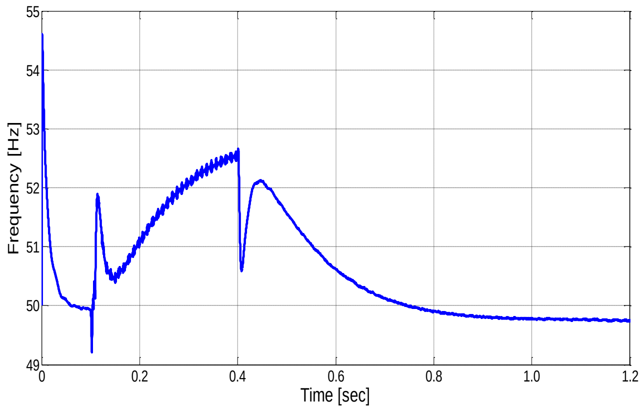
(b) Frequency

Figure. (6): *Output power and frequency if the DGs are current controlled.*

From these results, it is evident that the grid will be unstable if the penetration level is high and the DG are controlled as a grid feeding element. In the previous test the SGs are able to absorb the power mismatch because of their rating was approximately equals that of DGs. On the other hand, in case of using the VSG control concept the DGs share with the SGs to handle this power mismatch. Hence, the DGs based on VSG control concept is able to preserves system stability. The test result in case of using the VSG control method for DGs is shown in Figure. (7).



(a) Output power



(b) *Frequency*

Figure. (7): *Output power and frequency if the DGs are controlled based on the VSG control concept.*

V. CONCLUSION

The VSG as a concept for controlling the inverter based DGs are introduced. This control concept will support grid operation during transients. It provide grid with extrinsic inertia through the existence of an energy storage element and using the swing equation to drive the inverter which interface the DG unit to grid. The ability of the DG which controlled using VSG control concept to enhance the test grid stability is verified through test scenarios. It is evident that if the rating of the DGs is greater than the SGs rating the system will be unstable against disturbance if the control method is not changed.

Description	**Value**
DG (1,2)	
Rating	560 KVA
Output voltage	3300 V
Transformers	
Tr-1,Tr-2	3.3/11 KV
Tr-3,Tr-4	0.4/11 KV
Synchronous Generators	
Rating	503 KVA
Output voltage	400 V
Impedances	
Z-1	0.32+j0.38 Ω
Z-2	0.96+j1.13 Ω

APPENDIX

Table. (1): *Parameters of the system under study*

REFERENCES

[1] F. A. Abdul-Magueed Hassan, Converter-Interfaced Distributed Generation – Grid Interconnection Issues, Ph.D. dissertation, Chalmers University of Technology, Göteborg, Sweden, 2007.

[2] G. Joos, B.T Ooi, D. McGillis, F.D. Galiana, and R. Marceau, “The potential of distributed generation to provide ancillary services,” at IEEE Power Engineering Society Summer Meeting, 16-20 July 2000, vol. 3, pp. 1762 – 1767.

[3] M. A. Kashem, and G. Ledwich, “Improvement of power supply to Rural Customers via Grid Interactive Distributed Generation,” in International Journal of Global Energy Issues, vol. 26, no 3-4, 2006, pp. 341–360.

[4] N. L. Soultanis, S. A. Papathanasiou, and N. D. Hatziargyriou, “A Stability Algorithm for the Dynamic Analysis of Inverter Dominated Unbalanced LV Microgrids,” in IEEE trans. on Power Systems, vol. 22, no. 1, Feb. 2007, pp. 294 – 304.

[5] T. E. Mcdermott, and R. C. Dugan, “PQ, Reliability and DG,” in IEEE Industry Applications

Magazine, September/October 2003, vol. 9, no. 5, pp. 17 – 23.

[6] New and Renewable Energy Authority annual reports available at: http://www.moee.gov.eg/english_new/home.aspx

[7] J. Rocabert, A. Luna, F. Blaabjerg, P. Rodríguez, "Control of Power Converters in AC Microgrids," IEEE Transactions on Power Electronics, Vol. 27, No. 11, November 2012, pp. 4734-4749.

[8] Sakimoto K, Miura Y, Ise T. Stabilization of a power system including inverter type distributed generators by the virtual synchronous generator. IEEJ Trans Power Energy 2012; 132(4):341–9.

[9] T.Vu Van, K. Visscher, J.Diaz, V.Karapanos, A.Woyte, M.Albu, J.Bozelie, T. Loix, D.Federe nciuc, "Virtual Synchronous Generator: An element of future grids", 2010 IEEE PES Innovative Smart Grid Technologies Europe, October 11-13, Sweden.

[10] S. D'Arco, J.A. Suul, Virtual Synchronous Machines – classification of implementations and analysis of equivalence to droop controllers for microgrids, in: Proc. of IEEEPowerTech Grenoble 2013, Grenoble, France, 16–20 June 2013, 2013, 7 pp

[11] H. Bevrani, T. Ise, Y. Miura, Virtual synchronous generators: a survey and new perspectives, Int. J. Electr. Power Energy Syst. 54 (2014) 244–254.

[12] P.Rodriguez, A.Luna, M.Ciobotaru, R.Teodorescu, and F.Blaabjerg, "Multi resonant Frequency-Locked Loop for Grid Synchronization of Power Converters Under Distorted Grid Conditions", IEEE Transactions on Industry Electronics, 58 (2011) 127-138.

[13] N. Soni, S. Doolla, and M. C. Chandorkar, "Improvement of transient response in microgrids using virtual inertia," IEEE Trans. Power Del., vol. 28, pp. 1830–1838, 2013.