Frequency Stability Control In Low Inertia Power Systems Using Virtual Synchronous Generators

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Article Information:

Received:
6 March 2021

Received in revised form:
2 May 2021

Accepted:
5 May 2021

Volume 1, Issue 1, June 2021
pp 7 – 12

http://doi.org/10.23960/jesr.v3i1.56

Abstract

The stability of the electric power system is divided into transient stability, steady-state stability and dynamic stability. Things that affect the performance of the power system include load shedding which causes frequency oscillations caused by the system not being able to meet load requirements. The addition of a Virtual Synchronous Generator is needed to improve the power system integrated with Distribute Energy Resources in maintaining system stability. When the grid is integrated with Distribute Energy Resources, without the Virtual Synchronous Generator it has a frequency response of 58.2 Hz. When the load conditions reach 40% of the grid, while the grid is integrated with Distribute Energy Resources using the Virtual Synchronous Generator, it has a response of 60 Hz even though the load conditions are 40% of the grid. This means that the Virtual Synchronous Generator can stabilize the return frequency in nominal value to the power system.

Keywords: *inertia, grid system, distributed energy, energy resource, virtual synchronous generator, frequency.*

I. Introduction

THE needs for electricity supply continues to increase, namely the addition of loads every year, making the power system requires another power system to meet the load requirements. Distributed Energy Source (DER) is a major requirement in helping the electricity supply needs of the power system. DER is always associated with power electronic components because it has no inertia. DER is integrated with the grid but has a big influence on the system which causes a decrease in the inertia performance of the power system. A decrease in the inertia performance of the power system results in frequency oscillation resulting in a load shedding condition due to a decrease in the energy supply to the load. Frequency oscillation occurs because the power system cannot meet load requirements which results in the power system is unstable and unable to meet load requirements [1]. Changes in load must be followed by changes in the power system, the aim is that the frequency can be maintained at the nominal frequency position, However, the higher the load requirements, the lower the inertia performance of the system so that it can result in failure of power system operation, safety, reliability, and efficiency of the system.

The electric power system must have good quality, including the frequency of the system must be considered. The frequency value is within the stability limit, so the quality of the power supply in the electric power system will be more optimal [2].

Small changes in load will result in changes in frequency and angular velocity will swing around synchronous speed [3].

The Virtual Synchronous Generator (VSG) concept operates like a synchronous generator which can help by demonstrating the amount of inertia and damping properties of conventional synchronous generators, this virtual inertia concept maintains a large part of the DER in future power systems without compromising the power system stability. VSG can operate in parallel with several other VSGs which are expected to maintain frequency stability in low-energy power systems.

II. METHODS

The principle of VSG is based on the integration of dynamic converter technology from static and dynamic operation to electromechanical characteristics. This can be represented by the VSG concept as shown in Figure 1. Three distinct VSG components (consisting of two power conversion stages, namely a DC to DC level and a DC to AC level), an energy storage device (battery, supercapacitor, flywheel, etc.) and a control scheme that controls the exchange of power between energy stores and power system. This power exchange supports system power by preventing frequency fluctuations similar to rotational inertia SG[4].

VSG is usually placed between the Distributed Generator (or DC source) and the grid. The DC source leading to the VSG algorithm performs the Synchronous Generator (SG) function by providing inertia and damping that supports the grid system.

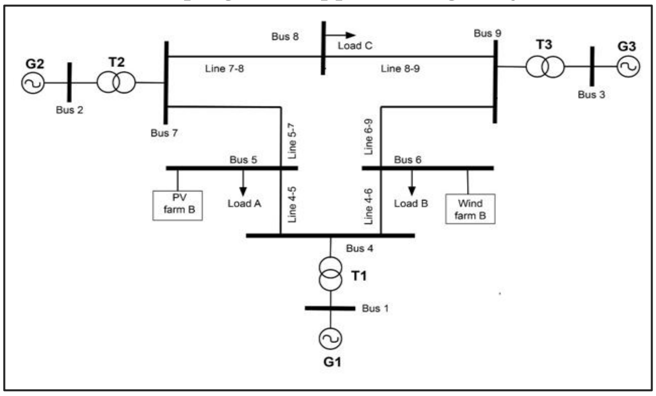

Figure 1.IEEE 9 Bus with PV and Wind Turbine

The modeling image of the low-energy power system used in this study, it is on the grid with conventional generators. The system model DERign that will be made consists of three conditions, namely the first condition, the load is connected to a conventional generator, the second condition is the DER and the third condition, namely the load connected to a conventional generator by adding DER and VSG, these three conditions will be compared. to analyze how much frequency affects inertia. The power supply in DER connected to the load by 20%, 30%, and 40% comes from the conventional power grid. The generation sources used in this renewable power system consist of photovoltaic and wind. The conventional generating capacity in this study is DERcribed in the table:

Table 1. Generating Capacity

Grid	ParameterP (MVA)	ParameterF (Hz)
Grid 1	192 MVA	60 Hz
Grid 2	128 MVA	60 Hz
Grid 3	247.5 MVA	60 Hz

To increase the voltage from the generator level to the transmission line voltage level, a step-up transformer is required. Distribution networks usually use a voltage lower than the transmission line voltage with the following capacities.

Table 2. Transformer Capacity

Grid	ParameterP (MVA)	ParameterF (Hz)
T1	18/230 kV	60 Hz
T2	13.8/230 kV	60 Hz
T3	16.5/230 kV	60 Hz

Installed loads are expenses that are distributed directly to customers, load capacities are DERcribed as follows.

Table 3. Load Capacity

Grid	Parameter P (MVA)	Parameter f (Hz)
Load A	125 MW	60 Hz
Load B	90 MW	60 Hz
Load C	100 MW	60 Hz

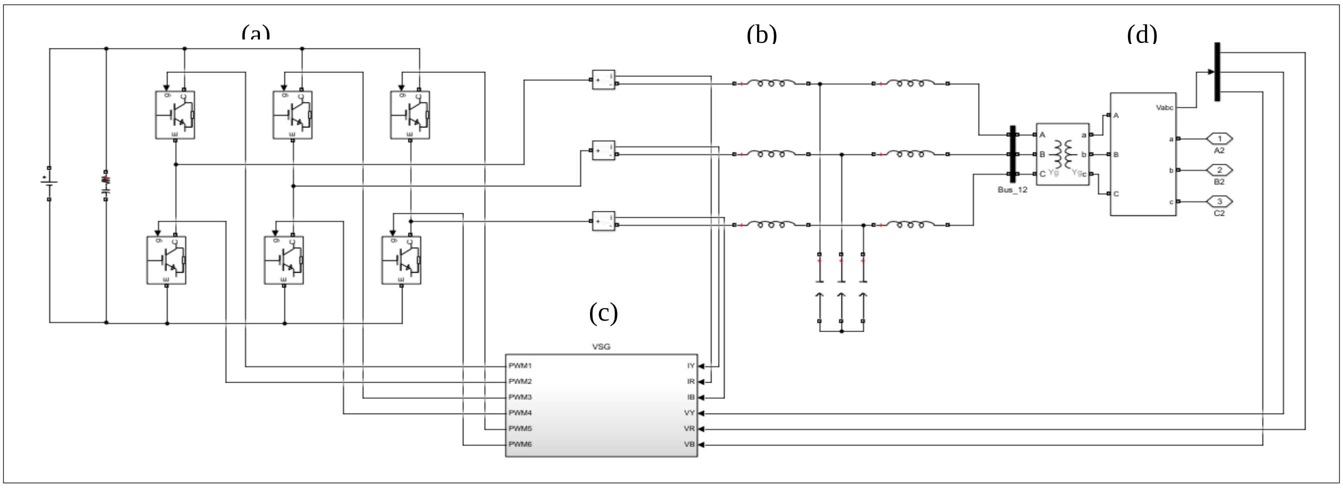

Figure 2. Principle of VSG

load connected to a conventional generator by adding

In the DER image, the DC source is connected to a power converter to convert the DC to AC voltage (a), the filter installation (b) aims to improve the voltage output and the resulting AC voltage, then direct control is carried out by VSG (c) which is installed after the transformer before the grid process (d) to the system occurs to get a continuously controlled voltage and frequency, the power that comes out or is generated from the generator can be translated as mechanical torque. In the operation of the generator in constant conditions, the value of the mechanical torque will be the same as the value of the electric torque. The basic principle of synchronous machine rotor rotation equations is that the moment of rotational acceleration (accelerating torque) is the product of the moment of inertia J (moment of inertia) of the rotor with its angular acceleration $\frac{d^2\theta_m}{dt^2}$, the rotor dynamic differential equation [5].

If $J\omega_m$ is the angular moment of the rotor, then it can be stated that M or the inertia constant. The spin period has a relationship with kinetic energy which is written in the following equation [6]

$$W_k = \frac{1}{2}\omega_m^2 = \frac{1}{2}M\omega_m \text{ or } M = \frac{2W_k}{\omega_{sm}} \tag{1}$$

The equation of swing concerning the angle of electric power is

$$\frac{2}{p}M\frac{d^2\delta_m}{dt^2} = P_m - P_e \tag{2}$$

If the value of M in equation (2) is substituted into equation (3), it will be obtained

$$\frac{2}{p}.\frac{2W_k}{\omega_{sm}}.\frac{d^2\delta}{dt^2} = P_m - P_e \tag{3}$$

Equation (4) will be obtained when substituting $H = {W_k}/{S_B}$ into equation (3).

$$\frac{2}{p}.\frac{2H}{\omega_{sm}}.\frac{d^2\delta}{dt^2} = P_m - P_e\,(pu) \tag{4}$$

The electric rotational speed in relation to the mechanical rotational speed is $\omega_{sm} = \frac{P}{2}\omega_s$ so that equation (4) becomes

$$\frac{2H}{\omega_s}.\frac{d^2\delta}{dt^2} = P_m - P_e\,(pu) \tag{5}$$

Substituting $\omega_S = 2\pi f$ into equation (5) we get

$$\frac{H}{\pi f}.\frac{d^2\delta}{dt^2} = P_m - P_e\,(pu) \tag{6}$$

Equation (5) or (6) is called the swing equation which is the basic equation that regulates the dynamics (motion) of synchronous engine rotation in stability studies (Grainger, 1994; Saadat, 1999). The change in the value of the grid capacity against the fixed load which is assumed to be -20%, - 30%, and -40% of the initial capacity, namely G1 = 192 MVA, G2 = 128 MVA, G3 = 247.5 MVA causes frequency resonance and affects system stability. The load and power equation in this study has different variations, represented by the following equation (7)

$$\Delta P_{in,g} - \Delta P_{out,g} = M_g\left(d\Delta\omega_g/dt\right) \tag{7}$$

It is assumed that $H_{gov,g}(s)$is a representation of the governor function, then equation (7) e becomes,

$$-H_{gov,g}(s)\Delta\omega_g - \Delta P_g = M_g s\Delta\omega_g \tag{8}$$

And

$$G_{P\omega,g}(s) = \frac{\Delta\omega_g}{\Delta P_g} = -\frac{1}{M_g s + H_{gov,g}(s)} \tag{9}$$

To get the result of the expansion of$H_{gov,g}(s)$, it is simplified to become $H_{gov,g}(s) = K_g/(1 + sT_g)$, then we get,

$$G_{P\omega,g}(s) = -\frac{T_g s + 1}{M_g T_g s^2 + M_g s + K_g} \tag{10}$$

From equation (10) it can be explained that resonance occurs if the load power fluctuates in frequency if the frequency exceeds the tolerance limit, then VSG is needed to overcome the resonance that occurs, the VSG equation can be obtained by setting $T_{vsg} = 0$then the equation becomes,

$$G_{P\omega,g}(s) = -\frac{1}{M_{vsg} s + K_{vsg}} \tag{11}$$

Because $G_{P\omega,g}(s)$ does not have frequency resonance, VSG can avoid unnecessary interference between parallel grids, therefore the relationship of the equation $\Delta P_{vsg} + \Delta P_g = \Delta P_L$ is obtained by $\Delta P_{vsg}$and ΔP_gas follows,

$$\begin{cases} \Delta P_{vsg} = \frac{P'_{vsg}P'_g}{P'_{vsg}+P'_g}\frac{\omega_0(\Delta\omega_{vsg}-\Delta\omega_g}{s} + \frac{P'_{vsg}}{P'_{vsg}+P'_g}\Delta P_L \\ \Delta P_g = \frac{P'_{vsg}P'_g}{P'_{vsg}+P'_g}\frac{\omega_0(\Delta\omega_g-\Delta\omega_{vsg}}{s} + \frac{P'_g}{P'_{vsg}+P'_g}\Delta P_L \end{cases} \tag{12}$$

ΔPL pu to the frequency deviation Δωr pu is derived from Figure 2 and expressed as (12) which is shown at the bottom of this page.

$$G_{PL\rightarrow\omega r}(s) = \frac{\Delta\omega_{r\_pu}}{\Delta P_{L\_pu}} = \frac{-R(1+sT_G)+(1+sT_{RH})(1+sT_{RH})}{(2H_S+D)(1+sT_G)(1+sT_{RH})\,R + sF_{HP}\,T_{RH}\ +1} \tag{13}$$

III. RESULTS AND DISCUSSIONS

This study tested 4 different parameter conditions, namely the initial condition, 20% condition, 30% condition, 40% condition of the network and the load parameter values which can be seen in Table 1, Table 2 and Table 3.

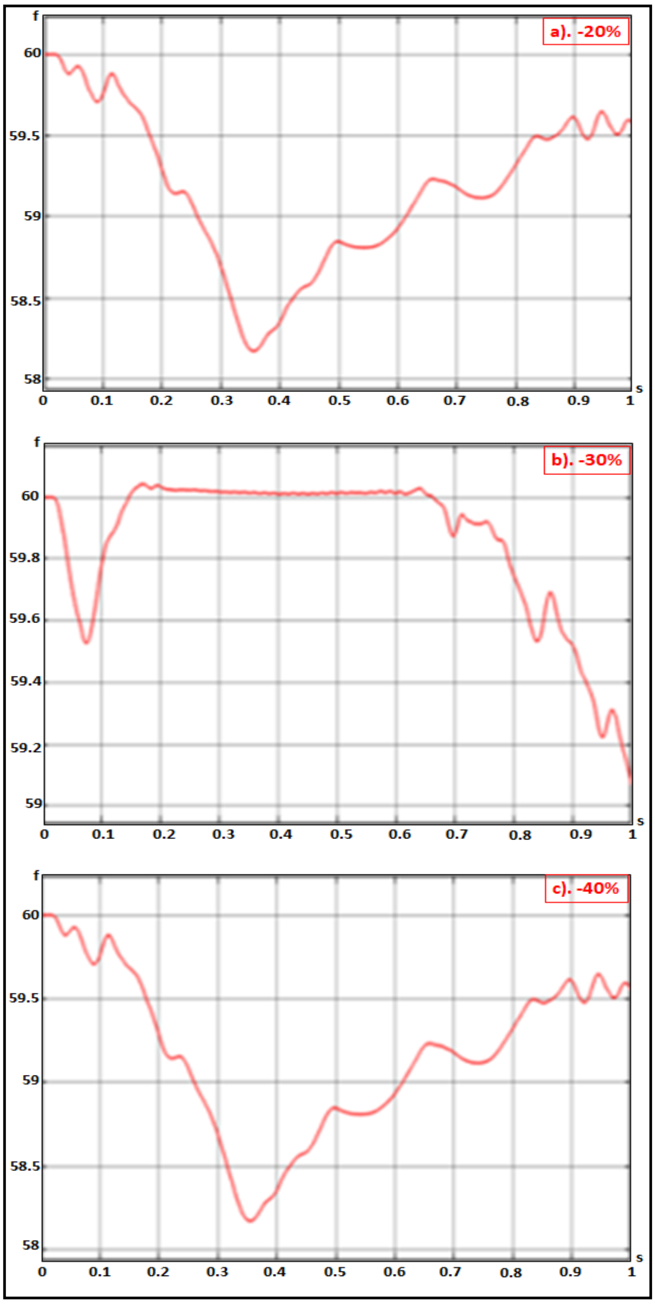

Figure 3. Integrated IEEE 9 BUS System Frequency Response DER without VSG, a). Condition 1, b). Condition 2, c). Condition 3

The addition of DER without VSG control causes significant frequency oscillation with time, seen in Figure 3 part (a) shows the change in frequency due to condition 1, namely -20% oscillations occur in realtime and continues to reach the highest value of 58.53 Hz for 1 second from the frequency it should be, (b) changes in frequency due to condition 2, namely -30% also experience the same thing as graph (a) occurs in real-time and continues with the highest deviation of 59.1 Hz for 1 second, (c) changes in frequency due to condition 3, the integration between conventional generators and DER without VSG has a frequency response of 58.2 Hz when the generating capacity is -40% of the initial state for 1 second and changes in real-time and continuously. The three graphs are triggered by the state of the conventional grid coupled with DER without VSG which causes system instability DER the change in grid capacity of -20%, -30%, and -40% from the initial state, which affect frequency oscillation, with reduced grid capacity. the power supply to the load is reduced and this can cause voltage drops.

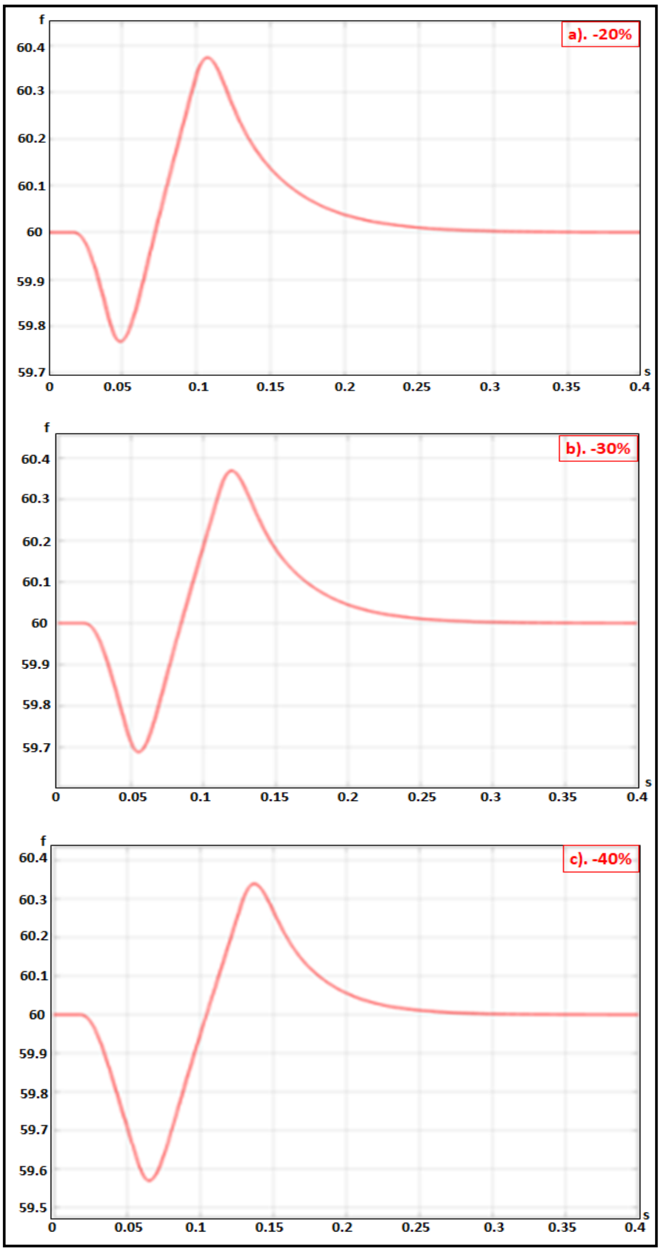

Figure 4. Integrated IEEE 9 BUS System Frequency Response with VSG a). Condition 1, b). Condition 2, c). Condition 3

The addition of VSG aims to control the frequency oscillations that occur due to the addition of DER, DER does not have inertia, so VSG control is needed so that it can be properly integrated. VSG control makes DER have artificial inertia. Judging from Figure 4.7 the frequency response after the addition of VSG, graph (a) shows that after condition 1 occurs, which is -20% and experiences the lowest deviation of 59.78 Hz, overshoot reaches 60.38 Hz and returns stable 0.3 seconds lasts, (b) the frequency response of condition 2 is -30% experience the same effect and the lowest deviation reaches 59.69 Hz, 60.38Hz overshoot returns to stability after 0.3 seconds, (c) the frequency response of condition 3 is -40%, the lowest deviation reaches 59.58 Hz, while integration between conventional generators and DER with VSG has a steady state response of 60.32 Hz even though the generating condition is -40% of the initial capacity of the generator . From the three graphs, changes in grid capacity affect system stability due to a lack of power supply capacity to the load, however, with the addition of VSG in DER, it can maintain system stability over time.

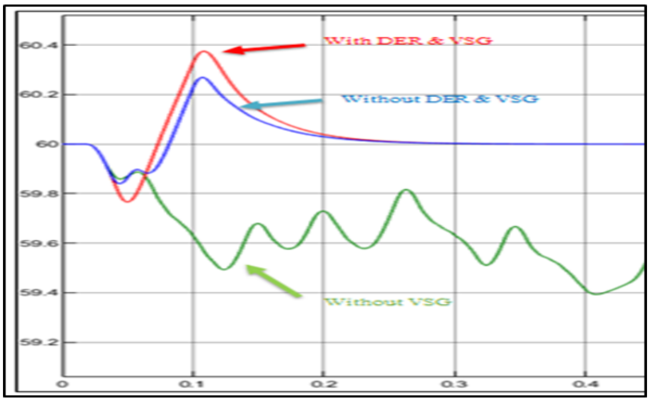

Figure 5. Frequency output systems with DER and VSG, systems without DER and VSG, systems with DER without VSG

In Figure 5, the frequency fluctuation of 60.27 Hz occurs due to the influence of loads and differences in capacity between grids, because the system has the same frequency, which is 60 Hz and the sufficient load does not significantly affect the system, from the three outputs with different systems it can be seen that the integrated DER system with VSG has a good frequency response due to the influence of control from VSG, on the other hand, a system without VSG has an unstable response due to DER integration without VSG control.

IV. Conclusions

VSG can change the nature of DER, based on power electronics to make it appear as if there is a synchronous generator by controlling the inverter through the switching process in PWM (pulse width modulation).

VSG can return the nominal frequency value of 60 Hz when there is a power drop of 20%, 30%, and 40% of the network when the conventional grid is integrated with DER.

References

[1] Nor Shahida Hasan, Norzanah Rosmin, Nor Julia Mohd Nordin, Aede Hatibc Mustaamal,Siti Maherah Husin, Apripriharta, Ira Devi Sara,"*Virtual Inertia Support For Wind Turbine System,"* Indonesian Journal of Electrical Engineering and Computer Science, 2020.

[2] Mohammed,O.O, A. O. Otuoze , S. Salisu , O. Ibrahim dan N. A. Rufa'I, "*Virtual Synchronous Generator: An Overview*." Nigerian Journal of Technology (NIJOTECH),Vol. 38, No. 1, pp. 153 – 164. 2019.

[3] Padiyar, K.R, "*Power System Dynamic Second Edition,"*Indian Institute of Science, Bangalore, 2008.

[4] Lu, Nanjun, Jingyang Fang, Yi Tang and Branislav. Hredzak, "*A Frequency Deadband-Based Virtual Inertia Control for Grid-Connected Power Converters*," IEEE Transactions on Industrial Electronics, 2017.

[5] Bevrani, Hassan and Jorg Raisch, "*On Virtual inertia Application in Power Grid Frequency Control*," International Conference on Power and Energy Systems Engineering, 2017

[6] Saadat, Hadi, "Power System Analysis,"New York: McGraw-Hill," 1999.

[7] Liu J, Yushi Miura and Toshifumi Ise, *"Comparison of Dynamic Characteristics between Virtual Synchronous Generator and Droop Control in Inverter-Based Distributed Generators*," IEEE Transactions on Power Electronics,2015.

[8] Kamdar, Renuka etc, "*Transient Stability Analysis and Enhancement of IEEE-9 Bus System*," Electrical & Computer Engineering: An International Journal (ECIJ) Volume 3, Number 2, India, 2014.

[9] Kundur, Prabha, "*Power System Stability and Control*," New York: McGraw-Hill Book, 1993.

[10] Jingyang, Hongchang Li, Yi Tang, Frede Blaabreg, "*Distributed Power System Virtual Inertia Implemented by Grid-Connected PowerConverters*," IEEE Transactions On Power Electronics, Vol. 33, No. 10, 2018.

[11] Rahman, Rifai Hasan, "*Analisis Pengaruh Pemasangan Kompensator Seri Terhadap Stabilitas Sistem SMIB dan Sistem IEEE 14 Bus*," Universitas Diponegoro, 2008.

[12] D' Arco, Salvatore dan Jon Are Suul," *Equivalence of Virtual Synchronous Machines and Frequency-Droops for Converter-Based MicroGrids*",IEEE TransSmart Grid,vol.5,no.1,.pp.394-395, 2014.

[13] Grainger, Jhon J & Stevenson, William., "*Power System Analysis*,"Singapore: McGraw-Hill, Inc., 1994.

[14] Ahammad, Fakir Uddin Ali dan Mandal Sharmistha, "*Robust Load Frequency Control in Multi Area Power System An LMI Approach*," IEEE First International Conference On Control, Measurement and Instrumentation (CMI), 2016.