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Dynamic Voltage Stability Enhancement by using Microgrid Voltage Stabilizer

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Abstract:
The micro grid concept has the potential to solve major problems arising from large penetration of distributed generation in distribution systems; a micro grid is not a robust system when compared to power system. Therefore, proper control strategies should be implemented for a successful operation of a micro grid .this project proposes the use of a coordinated control of reactive sources for the improvement of dynamic voltage stability in micro grid. The associated controller is termed as micro-grid voltage stabilizer. The MGVS is a secondary level voltage controller which takes the weighted average voltage deficiencies at the load buses and generates a control signal . This control signal is divided among the reactive power sources in the micro grid in proportion to generate certain amount of reactive power. The MGVS is implemented in a micro grid test system is carried out for the cases of with and without MGVS for various disturbances. Both grids connected and islanded modes of operation are considered. Results shows that, with the addition of MGVS, the dynamic voltage profile of micro grid system, especially at the load buses, improve drastically.

Keywords: power quality (PQ), renewable energy, MGVS System

I.INTRODUCTION

The increase in power demand is stressing the transmission and generation system capabilities, leading to frequent power outages. The central plants are at best 35% efficient due to transmission and generation losses. The greenhouse gas emissions have risen owing to the less efficient power system. This led to increased research aiming to meet the growing energy demand without adding the transmission system capabilities. The use of distributed generation (wind turbines, CHP plants, PV arrays, etc.,) at the distribution system seems to be a viable solution. But unplanned application of these new distributed generation technologies can bring in more problems than solving them. Therefore, a new peer-to-peer network architecture for distribution system, namely micro-grid was proposed. A micro-grid has on-site power generation and operates as a single controllable unit in parallel to the main grid. Micro-grid can enable easy penetration of renewable energy sources, reduce greenhouse gas emissions, reduce the stress on the grid, lower the energy bill, create green jobs, and improve the critical reliability and security of the electric grid. It can also be a part of potential solution for greenhouse gas goals. Micro-grids are almost 85% efficient as they have very less transmission losses. During power outage or disturbance, micro-grids can island themselves and retain power availability, avoiding blackouts and lost productivity. With the power source located on-site, micro-grids are less vulnerable to cyber attacks on the grid since they do not rely on transmission lines and have the security of redundant systems. Micro-grids have the ability to address the world's energy crisis by reducing the power load on our utility grid; reducing energy security risks and providing clean energy resources that are more reliable and economical. Sufficient amount of dynamic reactive capabilities are needed to avoid voltage collapse in micro-grid as well as in power systems. In principle, a coordinated effort among the reactive power sources could result in better effectiveness of these resources. However, in typical power systems where the electrical distances between the reactive power sources and the reactive loads are long, a coordinated effort may not be suitable due to the excessive voltage drop resulting from the transfer of reactive power within long distances. That is why in practice, reactive compensation is usually coming from local sources. In micro-grids, the electrical distances between the sources of the reactive power and the loads that need the reactive compensation is not long; thus a coordinated compensation of reactive sources for dynamic voltage stability should be desirable.[2]

II. SYSTEM DESCRIPTION

Micro-grid consists of DGs such as wind turbines, photovoltaic arrays, micro turbines, diesel engines, and some inductive and resistive loads. These elements of the micro-grid are augmented by local controllers and a static switch. During disturbances, the micro-grids disconnect themselves from the main grid, isolating the loads from disturbances without harming the transmission grid's integrity, thus maintaining high level of service to the customers. The small size of DGs, such as diesel engines, allows them to be placed near heat loads and use the waste heat. Micro-grid can be defined as a single controllable low-voltage network with interconnected loads and distributed generation [10]. Micro-grid needs extensive custom engineering as its nature changes with the presence of different types of DGs and loads. So a peer-to-peer and plug-and-play model is presented in the paper [10]. This concept eliminates the master slave approach, so that the micro-grid can continue to operate with any loss of component or generator. It also gives flexibility to place the DGs without redesigning the controls.

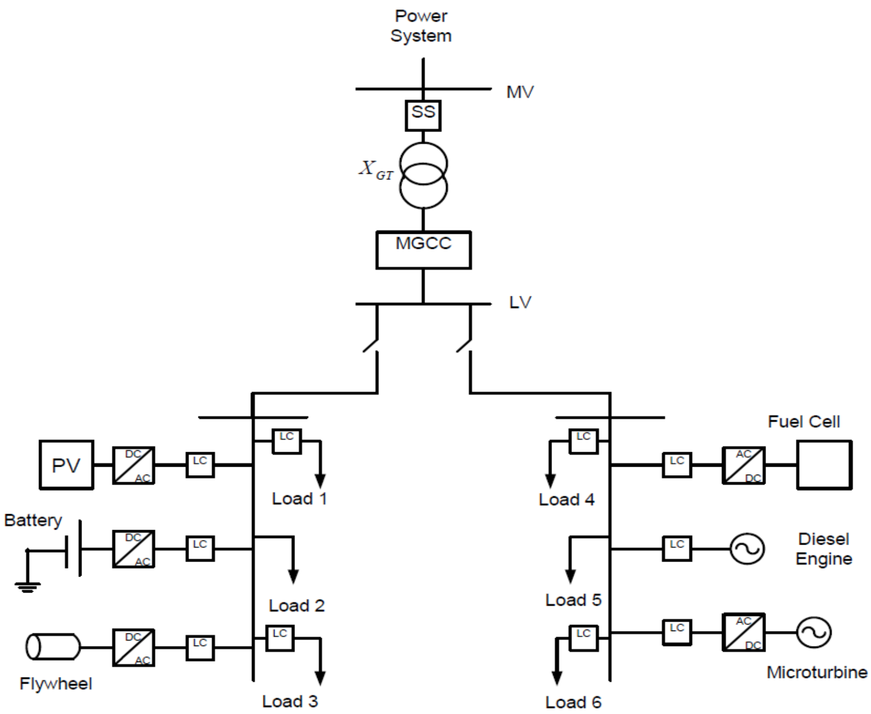

Figure.1. Schematic of proposed Micro-grid Architecture

III. MODELING OF DISTRIBUTED GENERATORS AND MICRO-GRID

The governor is mechanical or electromechanical device for automatically controlling the speed of an engine by relating the intake of the fuel. Several types of governors exist such as mechanical-hydraulic, direct mechanical, electro-hydraulic, electronic, and microprocessor based. The flywheel represents the complex dynamic effects of the engine inertia, the angular speed of a flywheel ω_ω the viscous friction coefficient ρ and the loaded alternator. Its model is assumed to have an integrator with flywheel acceleration constant J which serves to filter out a large proportion of the disturbance and noise effects. The noise itself is an inherent property of all internal combustion engines. Reference [27] proposes an integrator to be added between the reference signal r and the engine actuator. It is necessary to eliminate the speed droop in the steady-state operation by raising the order of the whole system as shown in Figure 4.3, where the overall transfer function model of the diesel engine is presented.

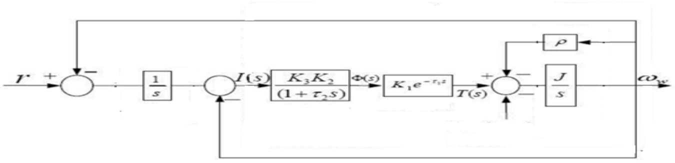

Figure.2. Block Diagram of Diesel Engine Genarator

This prime-mover (internal combustion engine) is coupled to a generator. The generator may be a permanent magnet generator with a rectifier and a voltage source converter or a synchronous generator with an exciter and a governor. A synchronous generator is generally used as it does not require expensive power electronic devices (voltage source inverters). But, as the generator and the prime-mover are mechanically coupled, the dynamics of the SG are not electrically decoupled from dynamics of the output of the generator. The prime-mover maintains the frequency with the help of a governor and the generator maintains the output voltage with the help of an exciter. A synchronous generator can produce both active and reactive power, thus forming an important part of the micro-grid. As DEGs have mechanical controller (governor), it has slow response when compared to other VSI interfaced DGs in the micro-grid. The SG is modeled in a d-q frame of reference in a form suitable for simulation after neglecting the sub-transient reactance and saturation. A linear damping term assumed. Also, the turbine governor dynamics affecting torque and the limit constraints on Voltage are neglected.

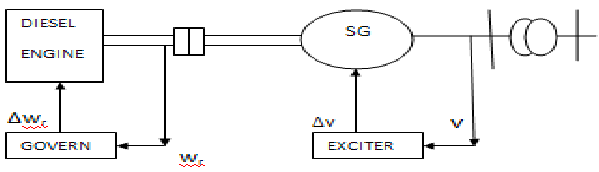

Figure.3. Synchronous Generator with Governor and Exciter

Generator model:

The model takes into account the dynamics of the stator, field, and damper windings. The equivalent circuit of the model is represented in the rotor reference frame (q d frame). All rotor parameters and electrical quantities are viewed from the stator. The following equations which guide the dynamics of synchronous machine.

Short-circuit model

The current contributed to a fault by a synchronous machine varies with time, from a high initial value to a moderate final steady-state value. Equations (1),(2),(3) depict this variation of current as a function of time for a three-phase short circuit at the terminals of a machine operating initially unloaded.

$$I_{ac} = E\left[\frac{1}{X_d} + \left(\frac{1}{X'_d} - \frac{1}{X_d}\right)e^{\frac{-t}{T'_d}} + \left(\frac{1}{X''_d} + \frac{1}{X'_d}\right)e^{\frac{-t}{T''_d}}\right] \quad (1)$$

$$I_{dc} = \frac{\sqrt{2}E\cos\alpha}{X''_d}e^{\frac{-t}{Ta}} \quad (2)$$

$$I_T = \sqrt{I_{ac}^2 + I_{dc}^2} \quad (3)$$

The rms value of the total current I_T is made up of two components:

a) A power frequency ac component I_{ac}, the RMS value of which decreases with time *t*, in accordance with Equation (2). This component is called the symmetrical current. b) A dc component I_{dc}, which decreases with time in accordance with Equation (3). The initial magnitude of I_{dc} is a function of the angle a of the voltage wave at which the short Circuit occurred. It determines the amount of offset of the current wave and is proportional to the rate of change of voltage at the instant of short circuit. The offset is maximum at a = 0 because the rate of change of voltage is maximum when the voltage is 0. The offset is 0 at a = 90° of change is 0 at the positive or negative peak voltage values. In the above equations, E is the open circuit voltage X_d X'_d X''_d are the direct-axis sync hronous, transient, and sub transient reactance, Respectively T_d, T'_d, T''_d are the armature and the direct-axis transient and sub transient short-circuit Time constants, respectively For typical values of reactance's and time constants, and with the maximum offset condition (cos a = 1), the equations will reduce to the following:

At time *t* = 0 (under sub transient conditions)

$$I''_{ac} = \frac{E}{X''_d} \quad (4)$$

$$I''_{dc} = \frac{\sqrt{2}E}{X''_d} \quad (5)$$

$$I'_T = \frac{E}{X''_d}\sqrt{1+2} = \frac{E}{X''_d}\sqrt{3} \quad (6)$$

$At\ t = \infty$

$$I_{ac} = \frac{E}{X_d} \quad (7)$$

$$I_{dc} = 0 \quad (8)$$

$$I_T = I_{ac} = \frac{E}{X_d} \quad (9)$$

Because T'_d is much small than T''_d, there is a small time t' smaller than T'' and larger than T''^{d}, that will make e^{-t'/T'_d} approximately equal to 1 and e^{-t'/T''_d} approximately equal to 0. In this case the original equations reduce the following.

$$I'_{ac} = \frac{E}{X'_d} \quad (10)$$

$$I'_{dc} = \frac{\sqrt{2}Ee^{-t'/T'_a}}{X''_d} \quad (11)$$

Should there be an impedance *ZL* = *RL* + j*XL* between the machine terminal (still at no load) and the point of fault, Equations (11), (12), and (13) will become,

$$I''_{ac} = \frac{E}{R_L + j(X_L + X''_d)} \quad (12)$$

$$I'_{ac} = \frac{E}{R_L + j(X_L + X'_d)} \quad (13)$$

$$I_{ac} = \frac{E}{R_L + j(X_L + X_d)} \quad (14)$$

The armature time constant *T*a will be shortened appreciably by addition of resistance *RL* in the external circuit. So Equation (14) will become

$$I'_{dc} = \frac{\sqrt{2}Ee^{-t/T'_a}}{X''(T'_a < T_a)} \quad (15)$$

The offset current will decay more rapidly the farther away (electrically) the machine is from the point of fault. The voltage *E*, in all the above equations, is equal to the terminal voltage V_t, since it was assumed that the machine was carrying no load before the short circuit. If the machine was carrying a current *IL* before the short circuit, the voltage *E* will be different in each equation, to satisfy pre fault conditions. For the case of a generator, the voltages in Equations (16), (17), and (18) will be

$$E'' = V_t + I_L X''_d \quad (16)$$

$$E' = V_t + I_L X'_d \quad (17)$$

$$E = V_t + I_L X_d \quad (18)$$

respectively. These voltages have been called voltage behind sub transient reactance (*E''*), voltage behind transient reactance (*E'*), and voltage behind synchronous reactance (*E*). It is not practical; in short-circuit studies, to calculate the system currents for the entire period from the time of fault to the time that the current reaches a steady-state value. The normal procedure is to solve the network at times *t* = 0 or *t* = *t'*, or both, using the models Network solutions at *t* = a are meaningless since the machine field excitation has likely changed by that time. Depending on the study objectives, the effect of the offset current I_{dc} may or may not be important. In power circuit breaker applications, however, it is a very important consideration. To obviate the difficulties in solving Equation (18), the breaker standards specify multipliers for the X''_d and X'_d current components. These are functions of machine type and of the time from the inception of the short circuit. IEEE Std 122-1991 lists those multipliers, gives examples of their use, and expands on this important aspect of short-circuit studies. The models of Figures 4.5 and 4.6 are also applicable to synchronous motors and synchronous condensers (using motor convention for the Kirchhoff's Voltage Law equations), the difference being that the *E''*, *E'*, and *E* voltages are calculated with the following:

Figure.4. Models of synchronous machines for short-circuit studies

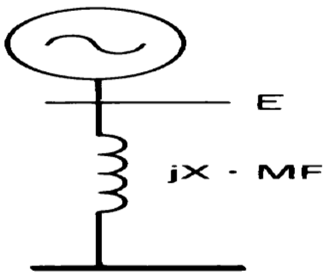

Figure.5. General model for ac machines in short-circuit studies

Establish a trend in the system performance. This may cover a period shorter than 1 s for transient stability or several seconds for dynamic stability studies.

$$\frac{d\delta_i}{dt} = w_i - w_s \qquad (19)$$

$$\frac{2H_i}{w_s}\frac{dw_i}{dt} = T_{mi} - E'_{qi}I_{qi} - E'_{di}I_{di} - (X_{qi} - X'_{qi})I_{di}I_{qi} - D_i(w_i - w_s) \qquad (20)$$

$$T'_{doi}\frac{dE'_{qi}}{dt} = -E'_{qi} - (X_{di} - X'_{di})I_{di} + E_{fdi} \qquad (21)$$

$$T'_{qoi}\frac{dE'_{di}}{dt} = -E'_{di} + (X_{qi} - X'_{qi})I_{qi} \qquad (22)$$

IV. MATLAB MODELEING AND SIMULATION RESULTS

There are six load buses and three generator buses so there will be six load weighted factors and three generator priority factors. The load weighted factors are calculated by the load variation with voltage or by giving priority to particular bus. In project load weighted factors are taken as random values. Load bus 15 has given greater priority because it holds maximum amount of load. Generator priority factors are calculated according to their reactive power generating capacity (proportionally).

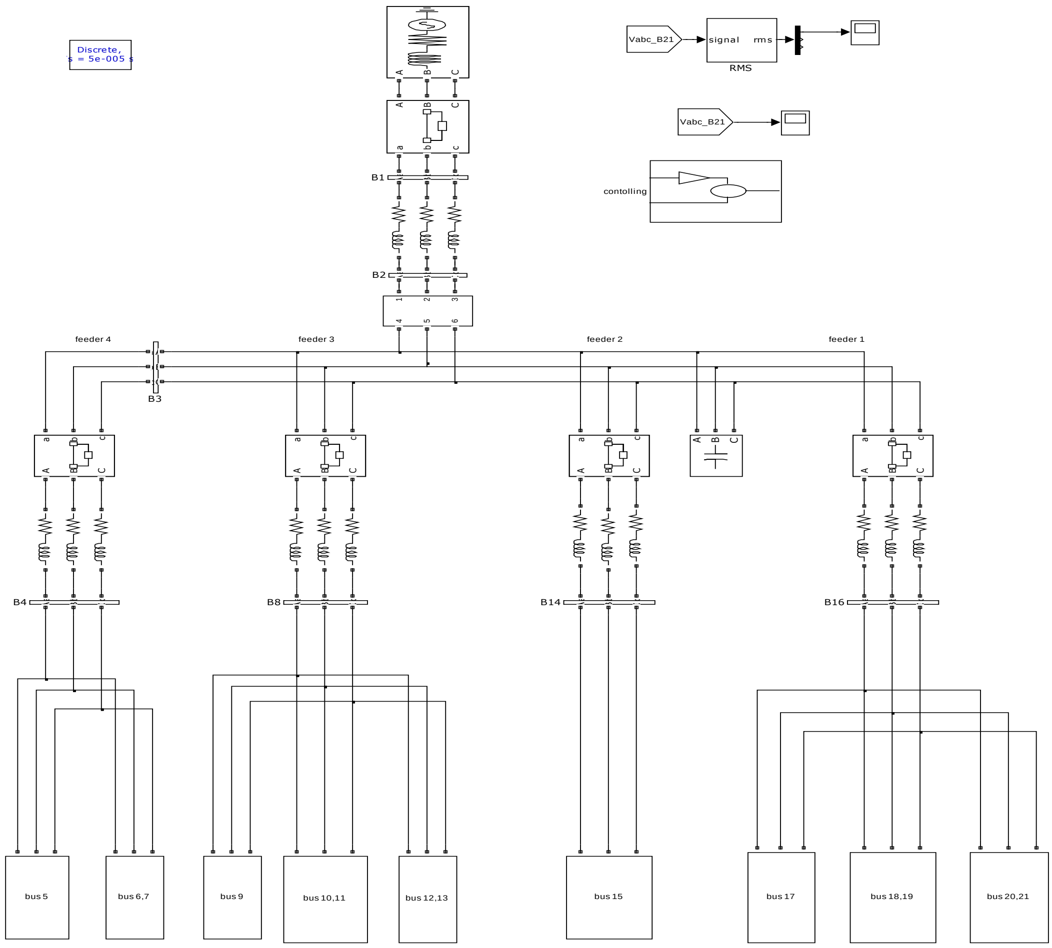

Figure.6. Matlab/Simulink Model of Proposed Model of 21 Bus System With 3 D.Gs

Fig.6 shows the Matlab/Simulink Model of Proposed 4-Leg VSI with Balanced Linear Load Condition using Matlab/Simulink Platform.

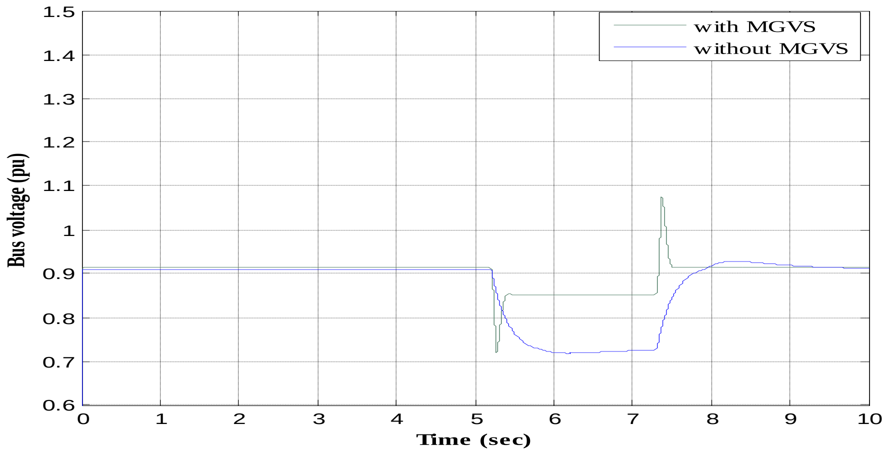

Figure.7. Load switching disturbance at bus 15 with and without MGVS

Fig.7 shows the Source Current, Load Current, Inverter Injecting Current, and Grid Voltage of Proposed 4-Leg VSI with Balanced Linear Load Condition. At t=0.1s, the grid interfacing inverter is now connected to network. Fig.7 shows the grid current starts changing to sinusoidal balanced from balanced nonlinear current. At this instant, active power injected by the inverter from RES is shown in Fig.6. The load power demand is less than the generated power and the additional power in fed back to the grid.

Voltage at Bus 15 with and without MVGS under load switching at 15th bus along with ideal operation in grid connected mode

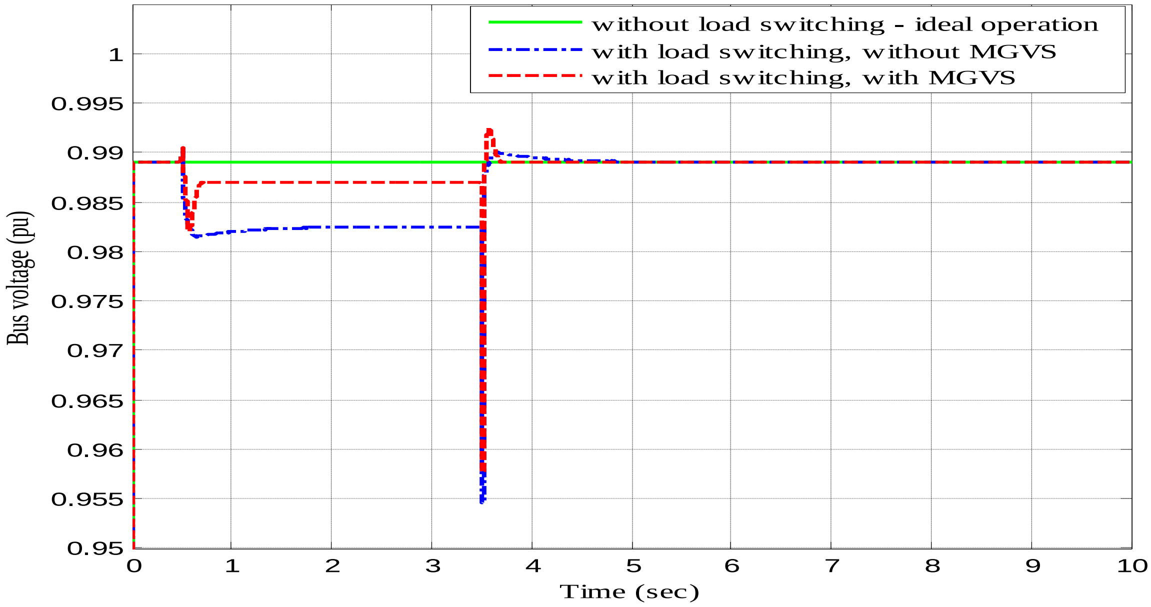

Figure.8. Voltage at Bus 15 with and without MVGS under load switching at 15th bus along with ideal operation in grid connected mode

Table.1. Comparisons of voltages with and without MGVS with Load Increment

Bus Voltages	With extra load	
	Without MGVS	With MGVS
V_3	0.972	0.975
V_7	0.975	0.979
V_{11}	0.980	0.984
V_{19}	0.981	0.985
V_{15}	0.983	0.986

Voltage at Bus V_{19} When 3 Phase Fault Occurs At 15th Bus in Grid Connected Mode (With and Without MGVS)

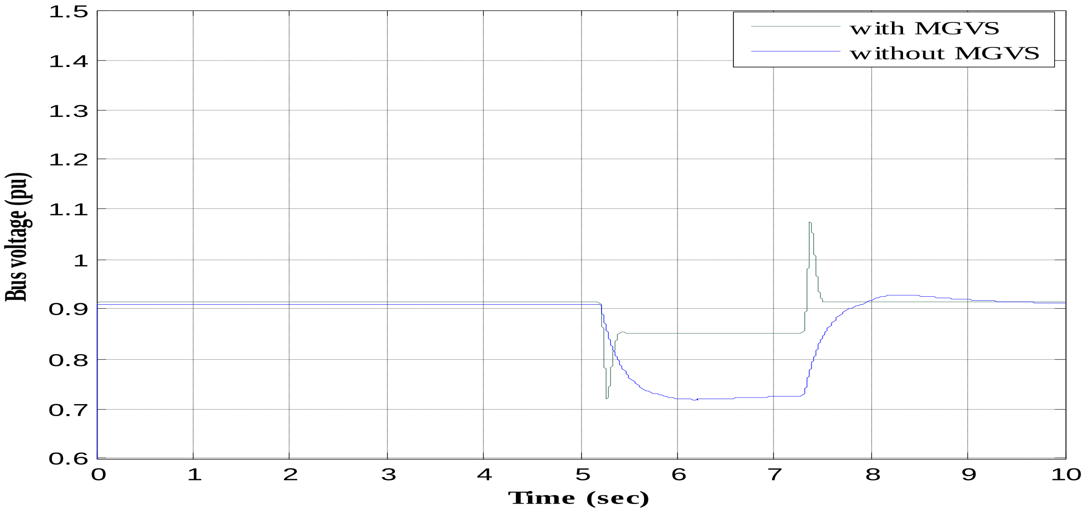

Figure.9. Voltage at Bus V_{19} When 3 Phase Fault Occurs At 15th Bus in Grid Connected Mode (With and Without MGVS)

Table.2. Voltage Comparison of Buses with and without MGVS

Bus Voltages	Normal condition without Fault		With 3phase short circuit Fault	
	Without MGVS	With MGVS	Without MGVS	With MGVS
V_3	0.714	0.81	0.71	0.79
V_7	0.708	0.849	0.86	0.89
V_{11}	0.718	0.93	0.715	0.89
V_{19}	0.727	0.88	0.72	0.92
V_{21}	0.716	0.92	0.77	0.90

Voltage Stability Analysis of the Micro grid in Islanded Mode

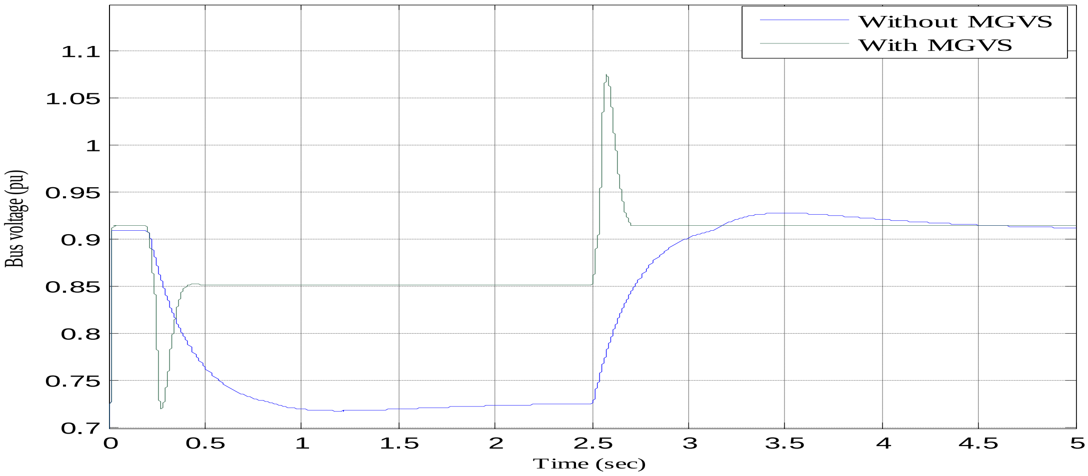

Figure.10. Voltages at Bus 19 When Three Phase Fault Created at 15th Bus in islanded mode of operation (With and Without MGVS)

The micro-grid test system is used to study various disturbances in grid connected mode. DGs are present at Buses 5, 9 and 17. The main grid is assumed to be a large generator. Loads are considered to be constant power loads and are present at Buses 7, 11, 13, 15, 19 and 21. The load at Bus 15 is the largest load in the micro-grid consisting of almost 30% of the total load. An increase in load at Bus 15 is applied and the load switching disturbance starts at t=5s and lasts for two seconds. A sudden and large increase in bus load causes a voltage drop. Figure 7 to 10shows the sudden drop in voltages at the instant of load switching. But the voltage recovers in the presence of an MGVS can be observed A three phase fault is applied at Bus 15. The disturbance starts at t=5s and ends after 120 cycles. The total time of simulation is ten seconds. Figure 9 shows the voltage under fault condition and shows that the bus voltages at all the load buses improve in the presence of an MGVS. From the tables we can observe that on an average 7-10 percentage increment in load bus voltages. We can also see that MGVS generate error such that it inject maximum amount of reactive power from generators during faults The similar analysis which is done for grid connecting mode can be done for the islanding mode. Hear also we can observe that by using MGVS there will be considerable amount of increment in load bus voltages

V. CONCLUSION

This project investigates the 13.8 KV multiple DG feeder micro-grid regarding voltage stability enhancement by a micro-grid voltage stabilizer. It works as secondary loop control for automatic voltage regulator (AVR) same as power system stabilizer. MGVS is modeled in MATLAB/Simulink and implemented for 21 bus test system. Results show that there is a considerable increment in voltage of all load busses after implementing MGVS. It is also observed that there is considerable decrement in line losses as well as increment in line power flows.

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