Dynamic Voltage Stability Enhancement using Microgrid Voltage Stabililzer

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Abstract- The microgrid concept solves major problems arising from large penetration of distributed generation in distribution systems. A microgrid is not a robust system when compared to a power system. So proper control strategies are used successful operation of a microgrid. This paper proposes the use of a coordinated control of reactive sources for the improvement of the dynamic voltage stability in a microgrid. The associated controller is termed as a Micro Grid Voltage Stabilizer (MGVS). The MGVS is a secondary level voltage controller which takes the weighted average of the voltage deficiencies at the load Buses and generates a control signal. This control signal is divided among the reactive power sources in the microgrid in proportion to their available capacities; thus each source will be required to generate certain amount of reactive power. The MGVS is implemented in a micro grid test system in MATLAB environment. A dynamic simulation of the test system is carried out for the cases of with and without the MGVS for various disturbances. Both grid-connected and islanded modes of operation are considered. Results show that, with the addition of MGVS, the dynamic voltage profile of the micro grid system, especially at the load Buses, improve drastically.

Keywords – MGVS. DEG, DG, DAE, IO

I. INTRODUCTION

The increase in power demand is stressing the transmission and generation system capabilities, leading to frequent power outages.. The use of distributed generation (wind turbines, PV arrays, etc) at the distribution system seems to be a viable solution. But, unplanned application of individual distributed generators, while solving some problems, can cause additional problems [1]. The microgrid concept has the potential to solve major problems arising from large penetration of distributed generation in distribution systems. Microgrids are almost 85% efficient as they have very little transmission losses. During power outage or disturbance, microgrids can island themselves and retain power availability, avoiding blackouts and lost productivity Sufficient amount of dynamic reactive power capabilities are needed to avoid a fast voltage collapse.

In principle, a coordinated effort among the reactive sources could result in better effectiveness of these resources. However, in typical power systems, where the electrical distances between the reactive sources and where these reactive powers are needed 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 power compensation is usually coming from local sources. In micro-grids, the electrical distances between the sources of the reactive power and the loads, which need the reactive power compensation, is not much; thus a coordinated compensation of reactive power sources for dynamic voltage stability should be desirable. Several blackouts have been associated with voltage stability problems in a power system [2] [3]. The presence of weak microgrids with insufficient amount of dynamic reactive power capabilities can also cause blackouts in microgrids and consequently the main power system. In this paper, the modeling of a microgrid is presented and a novel coordinated control method for dynamic reactive power sources is proposed. The associated controller is termed as a Micro Grid Voltage Stabilizer (MGVS). MGVS is used to improve the dynamic voltage stability of the microgrid and to prevent voltage collapses. The input to the MGVS is a voltage deficiency of the microgrid in dynamic state and the output of the MGVS is divided between the Distributed Generators (DGs) depending on the nature of DG and its proximity to the voltage sensitive loads. A 21-Bus microgrid test system is used to verify the performance of the proposed controller. The dynamic modelling of the microgrid and the proposed controller has been done using MATLAB programming.Simulations are run for various dynamic events and thevoltages of the load Buses are compared with and without the presence of MGVS. The effectiveness of MGVS is studied inboth grid-connected and islanded modes of microgrid.In the following section, the modeling of microgrid and its components is discussed. In section III the proposed MGVS explained. Simulation results and conclusion are explained in the section IV and section V.

II. MODELING OF MICROGRID

In this paper, the modeling of the microgrid includes the modeling of the Diesel Engine Generators, system loads and the transmission system. Following, the dynamic model for Diesel Engine Generators including the dynamic and algebraic equations is presented and discussed. In addition, the network equations including the power flow equations at different buses are presented.

A. Modeling of Diesel Engine Generator

A diesel engine generator (DEG) is widely used in remote locations, household, commercial and industrial applications. The prime-mover is an internal combustion engine which is coupled to a synchronous generator with exciter and a governor. 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 [4]. The SG is modeled in d-q frame of reference.The sub-transient reactances, saturation, the turbine governor dynamics effecting T_{Mi} and the limit constraints on V_{RI} areneglected. A linear damping term $T_{FWi}=D_i(W_i-W_s)$ isassumed. The differential equations for the machine with theIEEE-Type I exciter and a turbine governor are given below in(1)-(7) [5].

$$T'_{doi}\frac{dE'_{qi}}{dt} = -E'_{qi} - (X_{di} - X'_{di})I_{di} + E_{fdi} \tag{1}$$

$$T'_{qoi}\frac{dE'_{di}}{dt} = -E'_{di} + \left(X_{qi} - X'_{qi}\right)I_{qi} \tag{2}$$

$$\frac{d\delta_i}{dt} = \omega_i - \omega_s \tag{3}$$

$$\begin{aligned}\frac{2H_i}{\omega_s}\frac{d\omega_i}{dt} = T_{Mi} - E'_{qi}I_{qi} - E'_{di}I_{di} \\ - \left(X_{qi} - X'_{qi}\right)I_{di}I_{qi} \\ - D_i(\omega_i - \omega_s)\end{aligned} \tag{4}$$

$$T_{Ei}\frac{dE_{fdi}}{dt} = -\left(K_{Ei} + S_{Ei}(E_{fdi})\right)E_{fdi} + V_{Ri} \tag{5}$$

$$T_{Fi}\frac{dR_{fi}}{dt} = -R_{fi} + \frac{K_{Fi}}{T_{Fi}}E_{fdi} \tag{6}$$

$$\begin{aligned}T_{Ai}\frac{dV_{Ri}}{dt} = -V_{Ri} + K_{Ai}R_{fi} - \frac{K_{Ai}K_{Fi}}{T_{Fi}}E_{fdi} \\ + K_{Ai}(V_{Ref\,i} - |V_i|)\end{aligned} \tag{7}$$

The stator algebraic equations are derived from the dynamic equivalent circuit as shown in Figure 1[5] and are given below in (8)-(9).

$$E'_{di} - |V_i|\sin(\delta_i - \theta_i) - R_{si}I_{di} + X'_{qi}I_{qi} = 0 \tag{8}$$

$$E'_{qi} - |V_i|\cos(\delta_i - \theta_i) - R_{si}I_{qi} - X'_{di}I_{di} = 0 \tag{9}$$

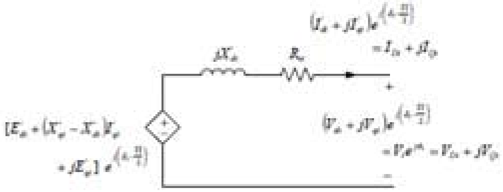

Figure 1. Dynamic equivalent circuit of a Synchronous Generator

B. Modeling of DEGs and loads Connected to the Microgrid

The loads and DEGS are connected to the distribution network with a known Y-matrix is shown in Figure 2. The overall microgrid system is modeled by writing the powerflows equations for all Buses [5] as shown below.

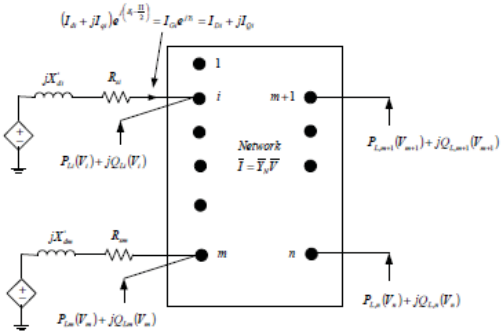

Figure 2. Dynamic equivalent circuit with loads and generators

The power flow equations for load Buses are given below in (12)-(13).

$$P_{Li}(|V_i|)+\sum_{k=1}^{n}|V_i|\,|V_K||Y_{ik}|\cos(\theta_i-\theta_k-\alpha_{ik}) = 0 \tag{12}$$

$$Q_{Li}(|V_i|)+\sum_{k=1}^{n}|V_i|\,|V_K||Y_{ik}|\sin(\theta_i-\theta_k-\alpha_{ik}) = 0 \tag{13}$$

The above set of differential and algebraic equations from (1)-(13) gives the overall model of the microgrid.

III. MICROGRID VOLTAGE STABILIZER

The MGVS gives an input to the excitation systems or reactive power loops of DGs, which acts to kick in morereactive power into the microgrid to prevent any voltagecollapse. Any small increase in reactive load can be met by the DGs, avoiding the use of expensive dynamic reactive sources,such as STATCOM, SVC or capacitor banks. The microgrid voltage stabilizer model and its simplified version are shownin Figure 3 and Figure 4 [6].

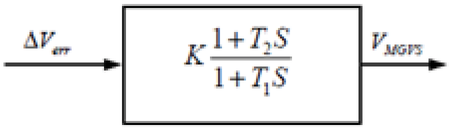

Figure 3. Microgrid Voltage Stabilizer

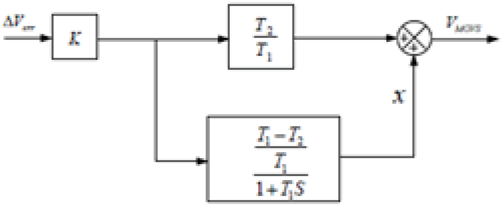

Figure 4. Simplified Model of Microgrid Voltage Stabilizer

The input to the MGVS is a measure of the voltage deficiency of the microgrid. The per unit voltage devation($\Delta V_{err\ i}$) between the desired voltage ($V_{des\ i}$) and the dynamicvoltage (V_{desi}) is calculated for all the load Buses (i = 1…l) as shown below in (14)

$$\Delta V_{err\,i}=\frac{V_{des\,i}-V_{dyn\,i}}{V_{des\,i}} \tag{14}$$

Weighting factors for all Buses, based on the importance of the Bus (i.e. induction motor loads are more sensitive to disturbances than the resistive loads) are defined. A weighted average of $\Delta V_{err}$is taken, to get an aggregate voltage deficiency (ΔVerr) of the system as shown below in (15). The weighting factors for all the load Buses, i= 1 to *l*are $\alpha_1, \alpha_2, . . \alpha_n$.

$$\Delta V_{err} = \frac{\alpha_1 \Delta V_{err\,1} + \alpha_2 \Delta V_{err\,2} + \dots\dots\alpha_l \Delta V_{err\,l}}{\alpha_1 + \alpha_2 + \dots\dots\alpha_l} \qquad (15)$$

$$\dot{x}(t) = -\frac{1}{T_1}x(t) + \frac{K(T_1 - T_2)}{{T_1}^2}\Delta V_{err} \qquad (16)$$

$$V_{MGVS}(t) = x(t) + K\frac{T_2}{T_1}\Delta V_{err} \qquad (17)$$

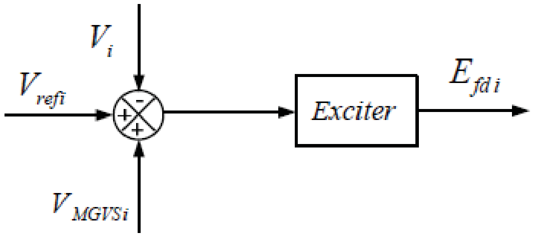

Figure 5. Excitation system of a generator

V_{MGVS} represents the total MGVS correcting signal, whichis divided between the DGs depending on the generationreactive reserve, proximity to inductive loads, etc. The weighting factors for the generator Buses (1 to g)are β_1, β_2, … … . . βn. $V_{MGVS\,i}$isthe input to the ith generator'sexcitation system as shown in Figure 5.

IV. SIMULATION RESULTS

A 21-Bus microgrid test system is used to verify the performance of the proposed controller [7]. The modeling and the simulation of the microgrid system and the MGVS isdone in MATLAB environment. In this section, simulation results are presented for dynamic voltage analysis for various dynamic events under both, grid-connected and islanded microgrid modes of operation and also during the islanding process. The dynamic events include line outage, three-phase short circuit fault, and load switching. The results arecompared with and without the presence of the proposed MGVS in each case. This will show the effectiveness of the MGVS to use reactive power compensation to improve the voltage profile of the microgrid in case of such different disturbances. The microgrid test case, as shown in Figure 6,have three distributed generators and six constant power loads.The microgrid is connected to the main grid, represented by large synchronous generator. The basic simulation includes,calculating the steady state power flow of the system and the initial value calculation of the state variables of the system.Then, the dynamic case is initialized with the initial values and run for the simulation time. The disturbances are included by changing the corresponding values of the system

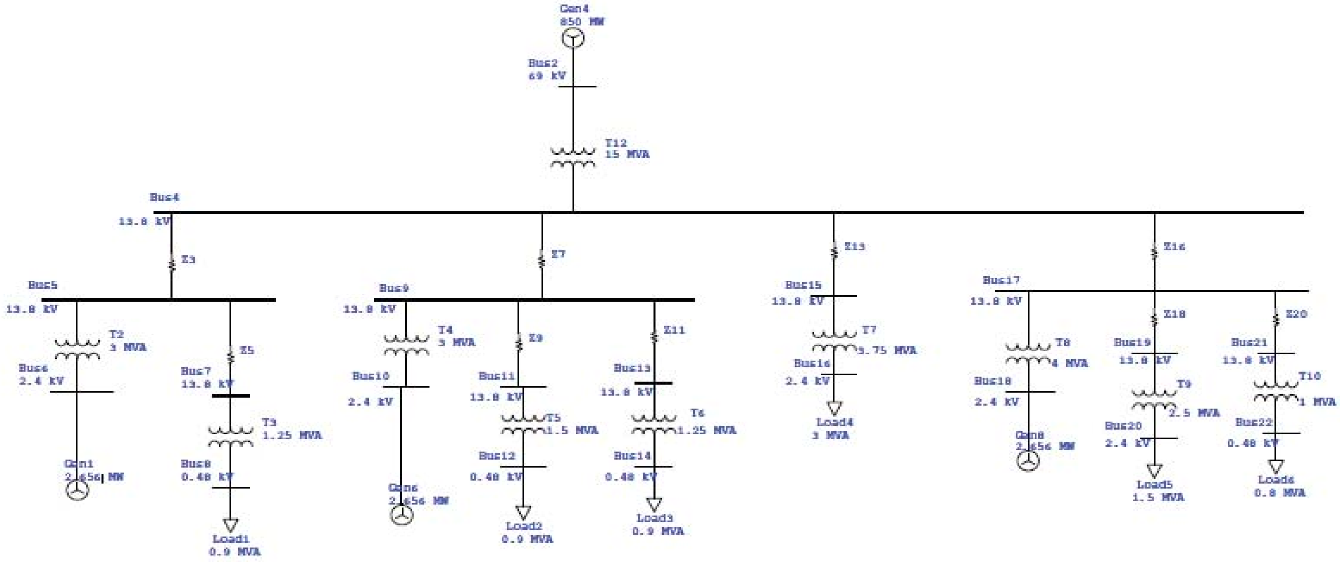

Figure 6.Microgrid test system

A. Voltage Stability Analysis of the Microgrid System in Grid-Connected Mode

In the grid connected mode, the microgrid test system is connected to the main grid. The load at Bus 15 is the largest load in the microgrid. So, the load Bus weighing factor is highest for Bus 15. The MGVS data table consisting of load Bus weighting factors, generator Bus weighing factors and MGVS control parameters are given as follows.

Table 1. Load Bus Weighing Factors

α_3	α_7	α_{11}	α_{13}	α_{15}	α_{19}	α_{21}
0.1	0.0954	0.1192	0.0938	0.3023	0.2167	0.0726

Table 2. Weighing Factors for Generator Buses

β1	**β2**	**β3**
0.3333	0.3333	0.3333

Table 3. MGVS Control Parameters

Gain constant(k)	T_1	T_2
10	1	0.1

A three phase short circuit fault is applied at Bus 15. The disturbance starts at 5% of the total time (i.e. 10 sec), and ends after 2 secs. The results show that the load bus voltages improve by more than 10 % in the presence of a MGVS as shown in Figure 7 at Bus 19.

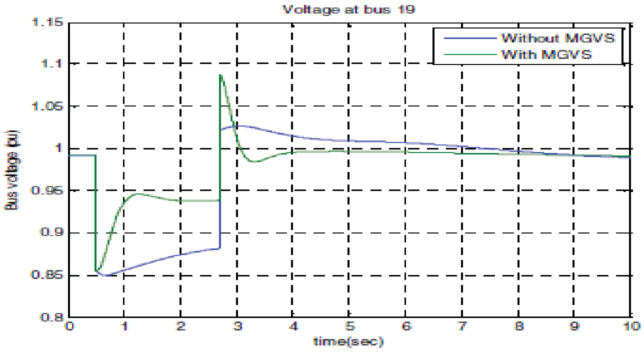

Figure 7. Three phase fault: Comparison of voltage a Bus 19 with and without MGVS in grid connected mode

Table 5. Comparisons of voltages With and Without MGVS at Normal Condition without Fault and with 3phase Short Circuit Fault

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	0.702	0.86
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

In other case, the load at Bus 15 has been increased by30%. The disturbance starts at 5% of the total time (i.e. 10sec), and ends after 5 seconds. The results show that the voltage at Bus 15 improves in the presence of a MGVS as shown in Figure 8.

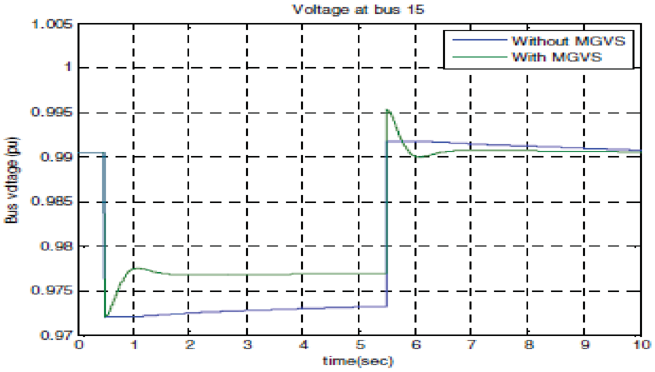

Figure 8. Load Switching: Comparison of voltage of Bus 15 with and without MGVS for 30% increase in load at Bus 15 in grid connected mode.

Table 4. 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_{15}	0.981	0.985
V_{19}	0.983	0.986

B. Voltage Stability Analysis of the Microgrid System during Islanding Operation

During the islanding operation, the line between Bus 2 and Bus 3 is removed effectively disconnecting the microgrid from the main grid. Now the total load is supported by DGs at Buses 5, 9 and 17. The load parameters remain unchanged, but the power generation at the generators changes during the dynamic events. The disturbance starts at 5% of the total time(i.e. 10 sec), and ends after 3 seconds. The results show that the voltage at Bus 19 improves by more than 7 % in the presence of a MGVS as shown in Figure 9.

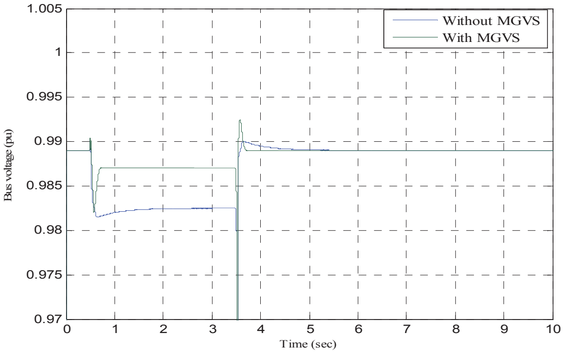

Figure 9. Islanding operation: Comparison of voltages a bus 15 with and without MGVS

C. Voltage Stability Analysis of the Microgrid System in Islanded Mode

In the islanded mode of operation, the main grid is removed and the total load is supported by DGs.

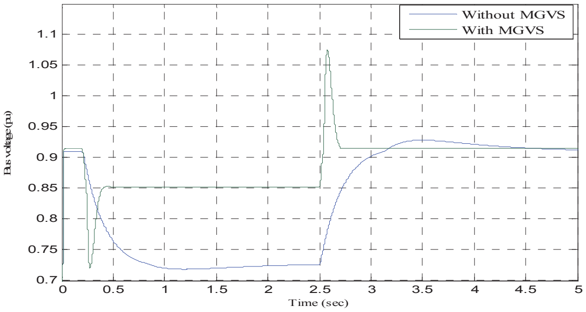

Figure 10. Three phase fault: Comparison of voltage a bus 19 with and without MGVS in islanded mode

D. Voltage Comparison of Buses with and without MGVS:

A three phase short circuit fault is applied at Bus 15. The disturbance starts at 5% of the total time (i.e. 5 sec), and end after 70 cycles. The results show that the load bus voltages improve by more than 15 % in the presence of a MGVS as shown in Figure 10 at Bus 19.

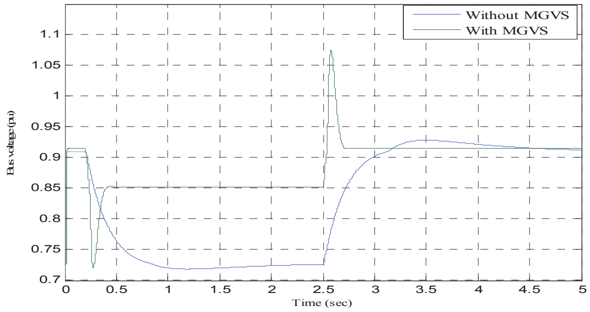

Figure 11. Line outage: Comparison of voltage a Bus 19 with and without MGVS in islanded mode.

V. CONCLUSION

In this paper, the concept of the MGVS is introduced. Then, the modeling of a microgrid with DGs and MGVS forvoltage stability analysis was studied. The differential algebraic equations (DAEs) related to the microgrid system were derived. Various disturbances and faults like three-phase short circuit fault, load switching, and line outage were simulated with and without MGVS in both grid connected and islanded modes of operation and also during the islanding operation. Simulation results show that the MGVS can significantly improve the voltage profile of the system for various disturbances. During three phase short circuit fault the MGVS improves the voltages at all the un-faulted load Buses.During load switching disturbance, MGVS reduces the reactive power dependence on the main grid by sharing most of the reactive load between the DGs. During line outage and islanding operation, MGVS is effective to coordinate the DGs reactive power generation and supply the lost generation from the grid.

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