A VOLTAGE STABILIZER FOR A MICROGRID SYSTEM WITH TWO TYPES OF DISTRIBUTED GENERATION RESOURCES

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ABSTRACT: Microgrids are used as controllable units connected to power grid, in which the electrical distances between reactive power sources and the loads that need the reactive compensation are small. Thus, a coordinated compensation of reactive sources has to be implemented to avoid a fast voltage collapse by proposing a Microgrid Voltage Stabilizer (MGVS). This stabilizer is desirable to improve the dynamic voltage profile and is tested at a 21-bus IEEE microgrid system. In order to verify the performance of this stabilizer, three distributed generation (DG) resources are utilized in this microgrid (Two PV resources which are categorized as power-electronic converter based on DG and a diesel generator which is known as synchronous machine also based on DG). At first, the mentioned resources and all of their needed equipments are modeled. Then, a control model of the stabilizer with appropriate parameters for the proposed microgrid is presented. Voltage deficiency of the system is the input of the stabilizer, and the output signal of the stabilizer is divided between the DGs in order to provide required reactive power. The dynamic voltage profile of buses in the presence of MGVS and its absence has been compared by implying disturbances. Simulation results in MATLAB/SIMULINK show that the dynamic voltage profile of the buses improves satisfactorily with the addition of MGVS.

ABSTRAK:Grid mikro digunakan sebagai unit kawalan yang disambungkan kepada grid kuasa, di mana jarak elektrikal antara sumber kuasa reaktif dan bebanan yang memerlukan kompensasi reaktif tidak terlalu besar. Dengan itu, kompensasi yang selaras dengan sumber reaktif perlu diimplimentasikan untuk mengelak kegagalan voltan pantas dengan menggunakan Grid Mikro Penstabil Voltan (*Microgrid Voltage Stabilizer - MGVS*). Penstabil ini sesuai digunakan untuk meningkatkan profil voltan dinamik dan telah diuji ke atas sistem mikro grid 21-bus IEEE. Untuk memastikan keupayaan penstabil ini, tiga sumber penjanaan agihan (*distributed generation - DG*) telah digunakan (dua sumber PV yang dikategorikan sebagai pengubah kuasa elektronik berdasarkan DG dan penjana diesel yang dikenali sebagai mesin segerak berasaskan DG). Mulanya, semua sumber dan alatan yang diperlukan, diilustrasikan. Kemudian, satu model penstabil kawalan bersama parameter yang sesuai dengan mikro grid yang dikemukakan. Ketakcukupan voltan dalam sistem merupakan input penstabil, isyarat keluaran penstabil kemudiannya dibahagikan antara kesemua DG agar ia dapat menyalurkan kuasa reaktif yang diperlukan. Profil voltan dinamik setiap bus dengan kehadiran MGV dan ketidakhadirannya dibandingkan denganmengimplikasikan gangguan. Keputusan simulasi menggunakan MATLAB/SIMULINK menunjukkan bahawa profil voltan dinamik setiap bus meningkat pada kadar yang memuaskan dengan kehadiran MGVS.

KEYWORDS: *Microgrid; Voltage Stabilizer; Photovoltaic Resource; Diesel Generator; Dc-Bus-Voltage-Controlled Inverter; Closed Loop Dc-Dc Boost Converter.*

1. INTRODUCTION

Considering restructuring the electricity market in recent years, power systems move toward the application of distributed generation (DG) recourses. Widespread application of DGs in power system caused challenges related to stability and reliability of power system. Therefore, a new structure is suggested for grid called microgrid, which is a controllable unit that works in parallel with main grid. Microgrid is composed of DGs, loads, and controllers and in black out and disturbance situation can change into islanding mode through a Static switch, hence power accessibility is remained in an agreeable level and overall black out is prevented [1]. Regarding above-mentioned descriptions, it can be mentioned that microgrids prevent voltage instability due to sudden change of load in main gridand improve stability and reliability of the power system. On the other hand, presence of weak microgrids can leads to extreme voltage drop or overvoltage and even voltages collapse of the system. Proper dynamic reactive capability is required for preventing fast voltage drop. In fact, a coordinated effort amongthe reactive sources increases the efficiency of these resources. In microgrids, electrical distances between reactive sources and loads that require reactive compensation are not too much. In addition, some loads may be sensitive to voltage variations and all DGs have not the capability of reactive power compensation in dynamic mode. Therefore, a coordinated compensation between reactive sources should be performed to enhance dynamic voltage stability of the microgrid and improving voltage profile of the buses [2-4].

Some researches are carried out for voltage stability in microgrids using different methods. For instance, a DSTATCOM is presented at [5] to enhance the stability of the system. During Power imbalance in the microgrid, the DSTATCOM holds the microgrid voltage for few cycles and allows the protection system to shed load and stabilize the system. A rapid detection of the load shedding requirement is very crucial for the success of this scheme. If the load is not shed within 2-3 cycles, the system voltage will collapse even in the presence of DSTATCOM. Another drawback of this strategy is increasing the cost of the system due to use of power electronics devices in stabilizer circuit instead of using control devices.Also [6] presented a stability-type algorithm suitable for the analysis of an inverter dominated LV microgrid. The stability approach is adapted so that it can be applied to inertia-less systems, where sources are interfaced to the network via inverters. Presented research activities did not proposed any approach for the microgrids containing synchronous machine based DGs and inverter-based DGs together.In [7], the small-signal model of the supercapacitor energy storage (SES) has been established and the control strategies to enhance the voltage stability of the microgrid, is presented. Besides using expensive SES, an optimal placement should be considered which in turn adds more complexity to the system.In [8], a control strategy for stability enhancement of microgrid is proposed based on sliding mode control (SMC). Although this controller is very practical for microgrids but it can be used only in microgrids with synchronous DGs.

Therefore, proposing a method is essential to overcome these problems. Hence, a microgrid voltage stabilizer (MGVS) has been designed by presenting a control model in this paper. Main objective of this paper is to apply the MGVS in microgrids containing distributed generation resources with two types of AC and variable DC outputs. Type 1 is a photovoltaic resource, that is a kind of power electronic converter based DG, and type 2 is diesel generator resource, that is known as a kind of synchronous machine based DG.

The IEEE 21-bus microgrid is considered as a test case. The suggested dynamic model of microgrid and controller are simulated in MATLAB/SIMULINK. In this analysis, the applied dynamic disturbances to the grid are three-phase short circuit and load switching fault. The simulation results are compared in two modes (with and without MGVS).

In next section, models of DGs that are used in the test case microgrid and all of their elements are discussed in detail. In section 3, the suggested MGVS, for such a microgrid is investigated. Simulation results and conclusion are presented in section 4 and 5, respectively.

2. MODELING THE MICROGRID INCLUDING TWO TYPES OF DG; PHOTOVOLTAIC AND DIESEL GENERATOR RESOURCES

As mentioned before, the under survey microgrid contains two types of DG which are photovoltaic (PV) resource and diesel generator. Model of each resource and its elements, are given in sections 2-1 and 2-2**.**

2.1Modeling the PV Distributed Generation Resource and Its Important Elements

In this section, elements model of photovoltaic systems including closed-loop DC-DC boost converter, DC-bus-voltage-controlled inverter, batteries and etc. are presented**.** It should be noted that main reason for the use of mentioned type of inverter is its appropriation for the microgrid voltage stabilizer that has been explained in section 2.1.1 in detail.

In general, the different parts of a PV system can be classified as follows [7]:

a) Solar cells section (solar modules or panels)

b) Consumer or electric load

c) Medium section or desired power section

Figure1 shows equivalent circuit of a PV cell in which I is module current, V module voltage, I_{ph} photo current, m number of series cell in a module, R_s series resistance of cell and R_p shunt resistance of poly-crystalline cell. Many of these cells in a solar module are connected in series in order to achieve higher level of voltage. Photovoltaic source in this research consists of six cells which are connected to each other in series to form a module with an approximate voltage of 100 volts. The specifications of each cell and the derived module are given in appendix.

In medium sectionor desired power section, electric energy of PV systems is managed in proportion to the demand of consumer. These devices are usually formed by storage and support system (battery), charge control, inverter and etc.

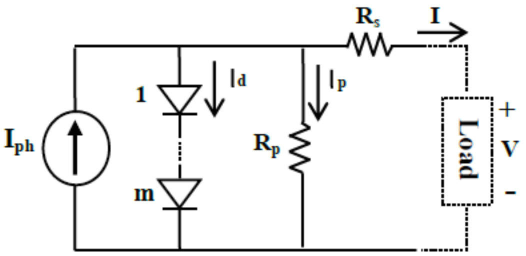


Fig. 1: Simple equivalent circuit of PV cell.

2.1.1 Closed-Loop DC-DC Boost Converter and Inverter Model Appropriate for MGVS

Output power of the solar panels is in the DC form and should be converted to AC power via inverter in order to inject this power to the grid. Figure 2 shows schematic view of inverters connection to the PV systems. As shown in this figure, DC output of the solar cell should be increased using a step-up DC-DC converter and then regarding to the type of system performance it is connected to AC grid through a typical inverter.

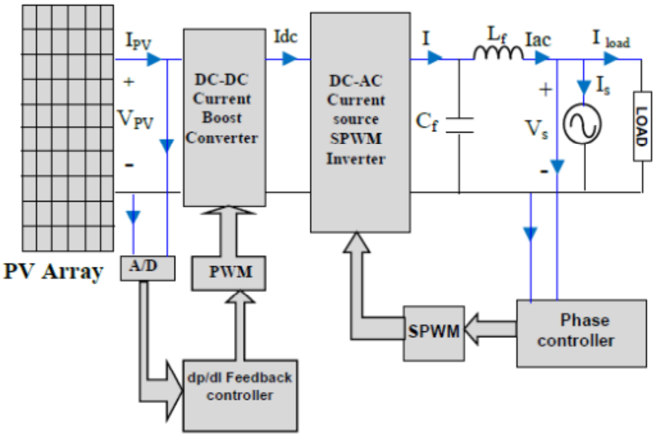


Fig. 2: Inverters connection to the PV systems.

Generally speaking, since output of DC-DC converter has ripple, this issue affects the accuracy of the results. Hence, closed-loop DC-DC converter has to be used in order to deliver a smooth DC output (or with minimum ripple) to the inverter [8-9]. Figure 3 shows simulated sample of this converter in MATLAB/SIMULINK. Fig.4 shows a schematic ofinverter appropriate for MGVS, which is an average model and "DC-bus-voltage-controlled" type of inverter [10].

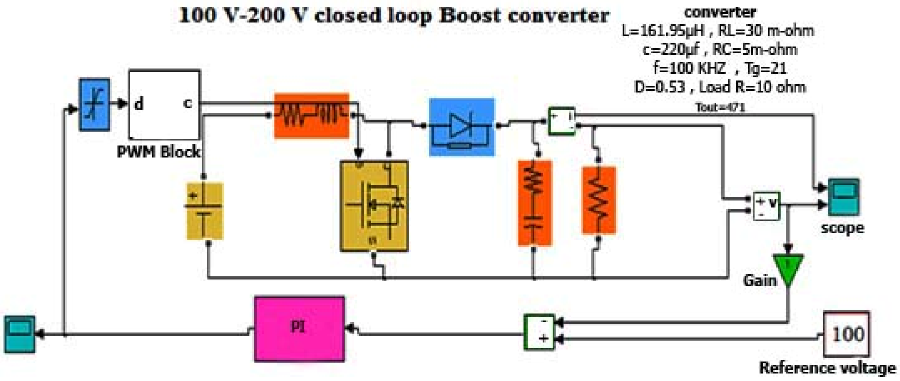


Fig. 3: Simulation of "Closed-loop DC-DC boost converter" in MATLAB/Simulink.

When the microgrid is connected to the main grid, the inverter is controlled to inject a given active and reactive power. This mode is known as PQ mode control. However, the under-study microgrid is considered in the islanded mode of operation, in which the inverter control mode deviates from PQ controllermode and switches to voltage and frequency control mode [11-12].

Hence, the utilized inverter should primarily be capable to control active and reactive power. If so, regarding the "frequency - active power" and "voltage - reactive power" droop curves, the frequency and voltage can be controlled too, in the islanded microgrid.

It should be mentioned that three phase symmetrical voltage and current are considered for operation of the proposed inverter. As a result, their zero components are zero. Therefore, if the reference frame of dq is selected in a manner which rotates synchronized to the microgrid voltages then we would have V_q=0 and active and reactive powers equations could be shortened as Eqn. (1) and Eqn. (2).

$$P = V_d I_d \tag{1}$$

$$Q = -V_d I_d \tag{2}$$

Therefore, having reference values of active and reactive power and also regarding to equations (1) and (2) and voltage measurementof bus-bar, related to connecting the inverter to the microgrid, in each instant, the reference values of d and q axis currents could be derived as Eqn. (3) and Eqn. (4).

$$I_{d,ref} = \frac{P_{ref}}{V_d} \tag{3}$$

$$I_{q,ref} = -\frac{Q_{ref}}{V_d} \tag{4}$$

As a result, generated active and reactive power could be controlled by controlling the inverter's d and q axis currents.

As it would be explained in detail in section 3, the output of the proposed voltage stabilizer is distributed between the DGs located in the microgrid, but that part of the output which is related to PV resource (or each power electronic converter based resources) should be applied on its inverter. Since the signal type of this controller output is voltage, the control section of the employed inverter should have the capability to deal with output voltage of PV, reference voltage and also output voltage of MGVS, as three input signals, in addition to active and reactive power control (by I_d and I_q control). Therefore, as it shown in Fig.4, the employed inverter is a "DC-bus-voltage-controlled" type inverter, which, in turn, is a kind of "average model" inverters. In this case, the share of PV resource from stabilizer output, should be added to the collector block, located in the control section of the inverter and prior to "DC bus regulator" block(that in fact a PI controller block), as the 3rd input

2.1.2 Energy Storage System (Battery)

The last section of PV systems is energy storage section, which is required due to limitation of solar energy. The storage process is performed through electrochemical batteries in PV power-plants. Batteries increase the service time and electricity supply in nights or in hours that solar light cannot provide required power for consumers [13]. These storage elements should compensate the effects of sudden changes of PV power-plants. Thus the capacity of storage system could be calculated by computing the maximum variations, on the basis of system parameters.Figure 5 shows how to connect a battery to the photovoltaic system.

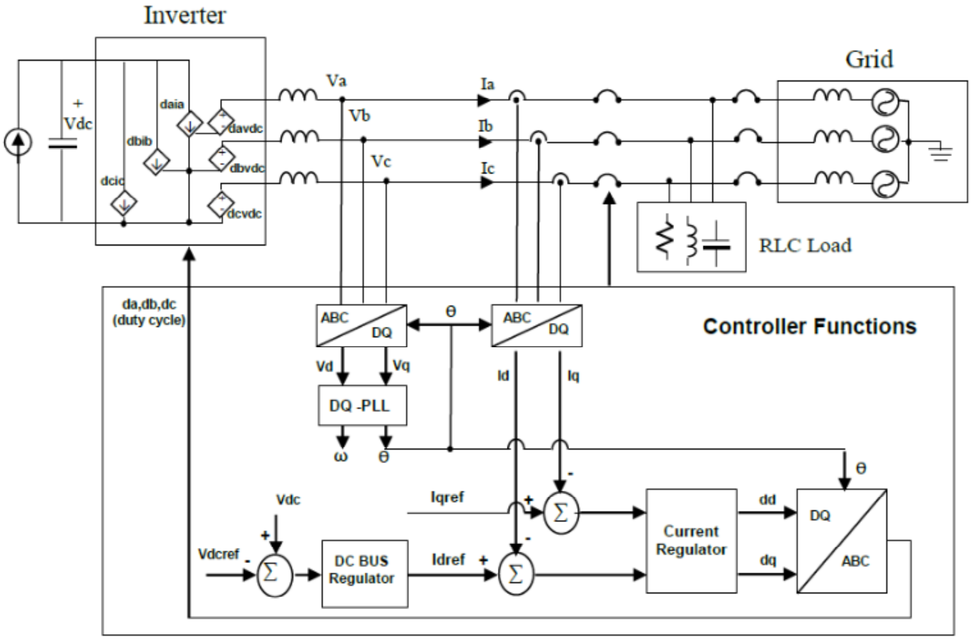


Fig. 4: DC-bus-voltage-controlled inverter schematic.

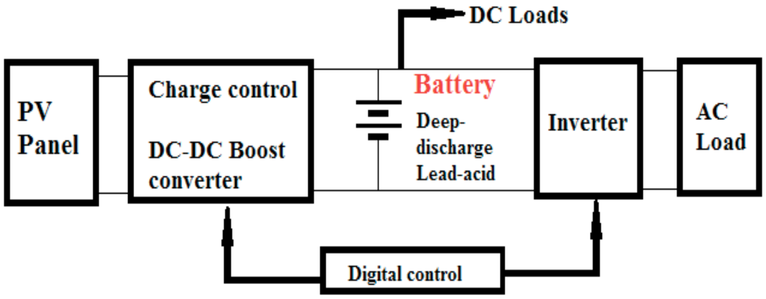


Fig. 5: Connection a battery to photovoltaic system.

2.2Modeling of the Diesel-Generator and Its Elements

Diesel generator resource is known as a synchronous machine based distributed generation resource, and as it has seen in Fig.6, the electrical part of it, is a synchronous generator equipped by the excitation system, and its mechanical part, is containing governor and turbine.

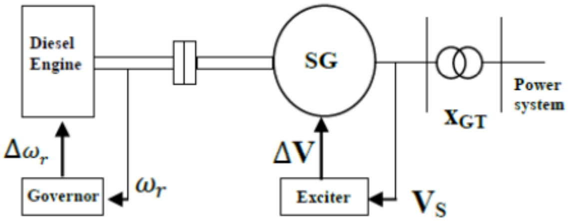


Fig. 6: Synchronous generator with its exciter and governor.

2.2.1 Governor Modeling

Governors adjust turbine waste gate in a manner that enable the frequency to return to its nominal or planned value. Governors are equipped with specifications to let them decrease speed by increasing load in order to distribute the load between two or more parallel units in a stable manner. As shown in Fig.7, speed droop specification could be put into practice by adding a feedback loop of steady state to integrator turn. This figure shows the governor's model used in simulation analysis and Fig.8 shows the simplified model of it. Parameter "R" in these two figures, is the ratio of speed deviation ($\Delta\omega_r$) or frequency deviation (Δf) to turbine waste gate displacement (ΔY) or output power (ΔP).

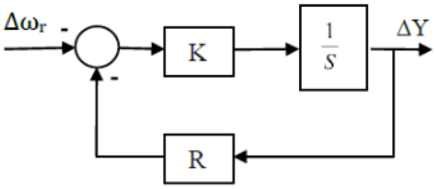


Fig. **7**: The model of governor.

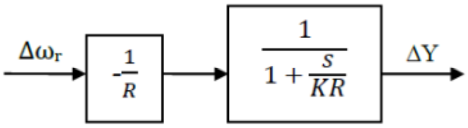


Fig. 8: Simplified model of governor.

2.2.2 Turbine Modeling

Turbines convert the initial mechanical energy to the electrical one, in synchronous generators. Since the turbines of the synchronous machine based resources are low dynamic equipments, the turbine model could be considered as a transfer function with time constant (see Fig.9). In the simulation, T_T is equal to 0.3.

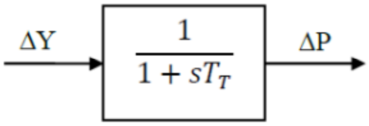


Fig. 9: The turbine model.

2.2.3 Modeling of the "Secondary Control of Frequency"

In the studied microgrid, in addition to governor we need a loop to recover the frequency due to the fact that the diesel generator resource is responsible for the secondary control of frequency (returning frequency to its nominal value in microgrid in islanded mode of operation) and to model it as exhibited in Fig.10, an integrator with a time constant of T_I was used. It should be mentioned that the time constant of the integrator is usually selected a large value in order to enable the performing of the secondary control after the initial control of frequency when rotor fluctuations are damped. Also, it should be mentioned that parameter of T_g in this figure is $\frac{1}{KR}$.

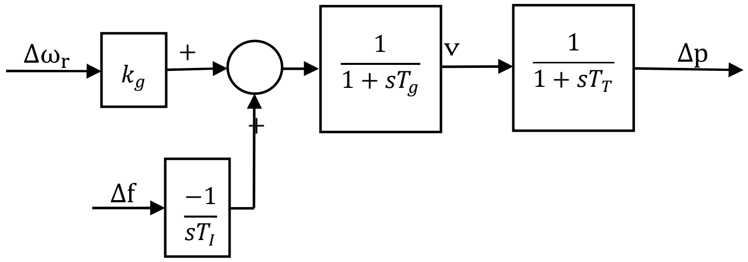


Fig. 10: The perfect exhibition of governor system, turbine and the loop of secondary control of frequency.

2.2.4 Excitation System Modeling

Output voltage of synchronous generator is remained constant using an excitation system. In fact, the main task of the excitation system is to supply required excitation current of synchronous machine within the allowable range of generator and adjust it automatically in order to adjust the terminal voltage of the machine at a constant value. Figure 11 shows the model of excitation system used in the synchronous machine based resource. In the simulation of this research, T_a=0.1, T_b=0.2, T_e=0.2 and K=180 is considered.

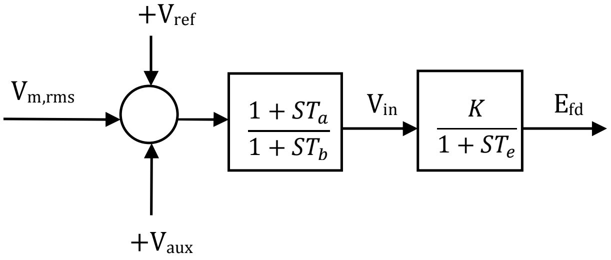


Fig. 11: Model of excitation system related to synchronous machine based DG.

3. MODELING OF "MICROGRID VOLTAGE STABILIZER" AND APPLYING IT TO MICROGRID

In every system, bus voltages are considered as important performance factors which should lie within a specific range. Different disturbances could result in voltage drop. On the other hand, in microgrids, electrical distances between resources and loads are not too much and reactive power could be transferred from resource to load, therefore, a stabilizer which acts on this basis could be used in microgrids. "Microgrid Voltage Stabilizer" (MGVS), works similar to PSS (power system stabilizer) in traditional power systemsand its main purpose is to ensure that the voltage remains within the set point values by adjusting reactive power generated or consumed. For example, at the time of voltage drop, this controller provides more reactive power for microgrid and so prevents any voltage collapse [14-15].

At the input of this controller, the terminal voltages are compared with the reference voltage and the error voltage, that is the difference value between them, is filtered using a low pass filter and multiplied by a gain constant and so the "droop control" is obtained in this way. Moreover, with respect to the "reactive power-voltage" droop curve, the injected reactive power required by distributed generation resources, to adjust terminal voltage at a set point value, could be estimated from output signal of this controller.

Corresponding differential equations that indicate the performance of MGVS are given in Eqn. (5) and Eqn. (6):

$$\dot{x}(t) = -\frac{1}{T_1}x(t) + \frac{K(T_1-T_2)}{T_1^2}\Delta V_{err} \tag{5}$$

$$V_{MGVS}(t) = x(t) + K\frac{T_2}{T_1}\Delta V_{err} \tag{6}$$

Model of MGVS that formed by a Lead-Lag block, is shown in Fig.12, but for easy implementation in MATLAB/SIMULINK, the equivalent block diagram of it, can be used (Fig.13).**.**Input of MGVS is a fractional of system voltage in dynamic mode. Per unit difference (ΔV_{ierr}) between ideal voltage (V_{ides}) and dynamic voltage (V_{idyn}) is calculated for all load buses (Eqn. (7)).

$$\Delta V_{erri}=\frac{V_{des\,i}\text{-}V_{dyn\,i}}{V_{des\,i}} \quad , i = 1,2,\dots\ ..l \tag{7}$$

Then, for determination of total fractional voltage, according to Eqn. (8), weighted average (ΔV_{err}) is carried out on fractional voltage of all load buses.

$$\Delta V_{err} = \frac{\alpha_1\Delta V_{err\,1}+\alpha_2\Delta V_{err\,2}+\cdots.....\alpha_i\Delta V_{errl}}{\alpha_1+\alpha_2+\cdots.....\alpha_i} \tag{8}$$

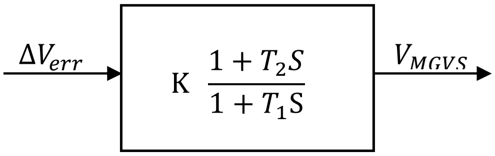


Fig. 12: Model of "microgrid voltage stabilizer".

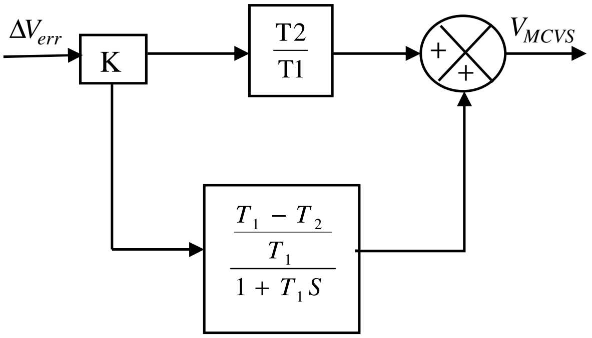


Fig. 13: Simplified model of "microgrid voltage stabilizer".

Weighting factor of each bus is defined based on importance of that bus (for example induction motor loads comparing to resistive loads are more sensitive to disturbances). For i=1 to i=L load buses, their termed as $\alpha_1,\alpha_2,\dots,\alpha_L$ and their values for the test-case microgrid are given in Table1.

Table 1: Weighting factors for load buses.

α_{21}	α_{19}	α_{15}	α_{13}	α_{11}	α_7	α_3
0.073	0.216	0.302	0.096	0.119	0.094	0.1

As shown in Fig.13, ΔV_{err} is supplied by a lead-lag block with gain constant K and time constants T1 and T2. The values of T_1, T_2 and K for the under-study microgrid (contains two PV resources and one diesel generator), that resulted by the use of eigen values method, are given in Table2.

Table 2: MGVS control parameters

K	T_1	T_2
10	1.5	0.2

Output of MGVS i.e. V_{MGVS} is distributed between DGs based on generation reserve, nature of DGs and closeness of them to the voltage sensitive loads. Equation (9) shows how of this distribution on the basis of weighting factors. These factors for generator buses (1 to g), are $\beta_1,\beta_2,\ldots, \beta_g$ and their values are given in Table3.

$$V_{MGVSi} = \beta_i V_{MGVS} \quad ,i = 1,2,\ldots\,..g \qquad (9)$$

Table 3: Weighing factors for generator buses

β_1	β_2	β_3
0.3581	0.3663	0.2756

In the tested microgrid, $V_{MGVS1}$and V_{MGVS2} are shares of MGVS output which should be applied on two PV resource. As explained in section 2-1-1, they are added as the 3rd input to the control part of the inverters of first and second PV resources, respectively. Furthermore, V_{MGVS3} is a share of V_{MGVS}, which is related to diesel generator. It is added to the excitation system of third resource, as per the Fig.14.

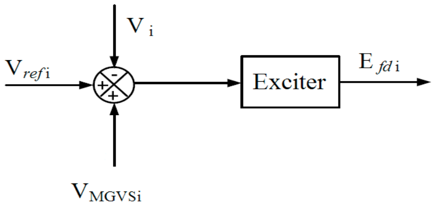


Fig. 14: Addition of MGVS output signal to excitation system of diesel generator resource.

4. SIMULATION RESULTS

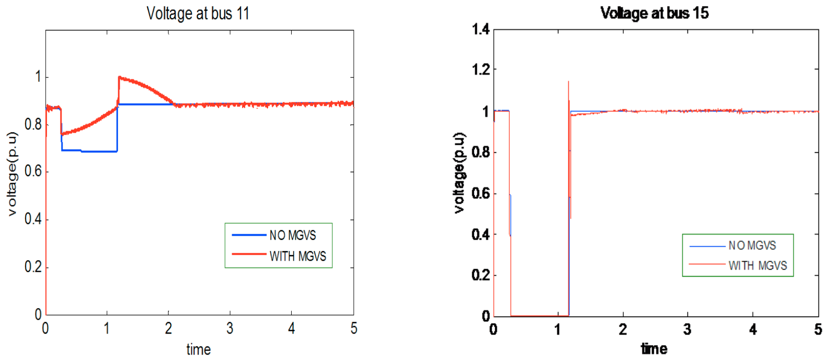
Before fault occurrence,the difference between desired voltage and real voltage of the load buses (ΔV) that is the input of MGVS is zero. Therefore, the stabilizer does not operate.During fault, ΔV has a non-zero valueand the operation of MGVS starts at this time.Output voltage signal of MGVS is applied to the PQ controlled inverters of DGs and then according to "voltage - reactive power" droop curve, the required reactive power have been injected to the microgrid. Therefore, the voltage profile will be enhanced proportional to the rate of reactive power injection.

After fault clearance, ΔV is changed to zero again and MGVS has not any signal in its output to apply to the inverter. Therefore, reactive power values of PV resources return to their previous values. Due to this gradual reduction of reactive power, the value of voltage will be reduced gently and the magnitude of voltage will reaches at its pre-fault value.

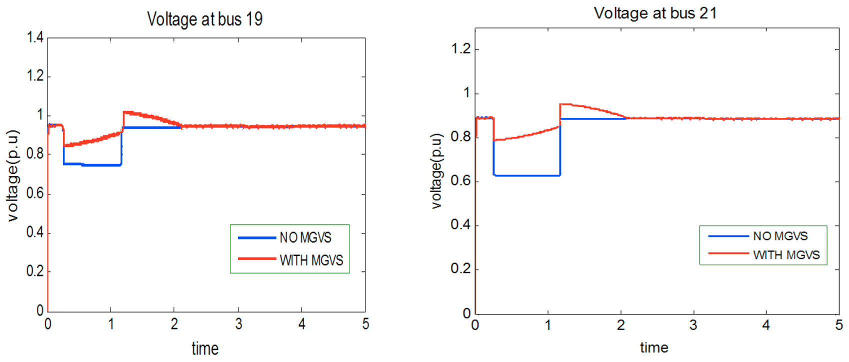
An IEEE 21-bus microgrid in islanded mode of operation is considered as test system of this paper (see Fig.18). Simulations are carried out in MATLAB/SIMULINK. Two types of faults (a three-phase short circuit fault and a load switching fault applied to bus 15) are investigated in this analysis.

The applied three-phase fault in this simulation, starts at 15th cycle (t=0.25) and continues to the end of cycle 70th (t= 1.167).The improvement rate of dynamic voltage profile by the use of MGVS is investigated in this analysis.During short-circuit fault, flowing of large currents from generator buses to faulted load bus results in the drop of the voltage of other buses. At this time, MGVShelps the microgrid to use the reactive power reserve efficiently and improve the dynamic voltage stability.

Simulation results related to load buses are shown in Fig.15. Comparison of the dynamic voltages of load buses in the systems with and without MGVS shows that the dynamic voltage profile is improved satisfactorily by the use of MGVS.In addition, Fig.16 contains two sample figures that exhibit comparison of reactive power generation related to microgrid resources, in the presence of stabilizer and its absence.

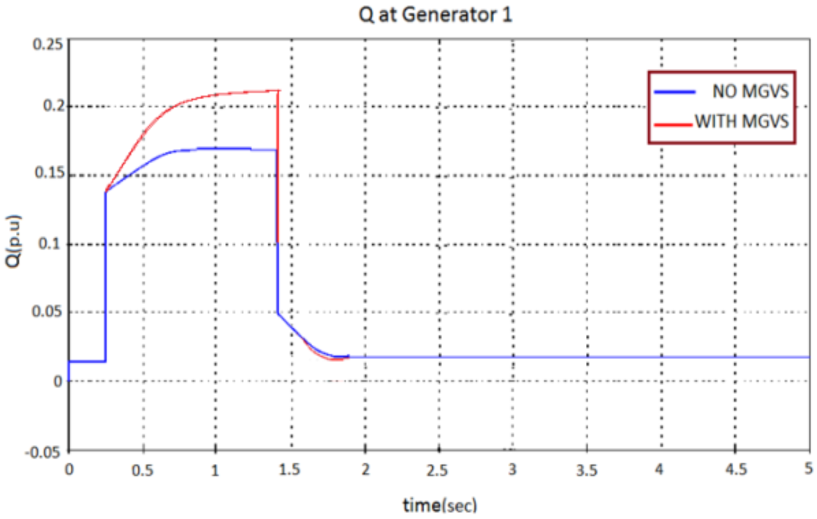


a) Voltage profile of bus 11 b) Voltage profile of bus 15 (faulted bus)

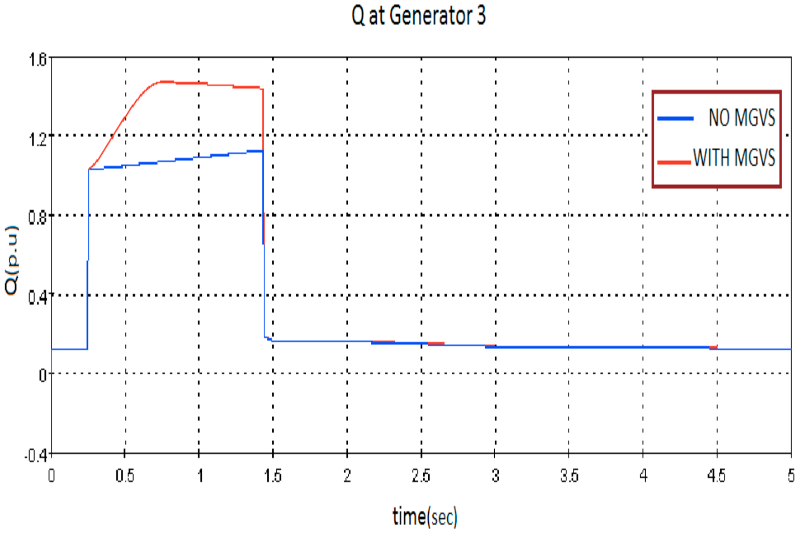


c) Voltage profile of bus 19 d) Voltage profile of bus 21

Fig.15: Comparison of load bus voltages for a 3-phase short circuit fault at bus 15, with MGVS and without it.

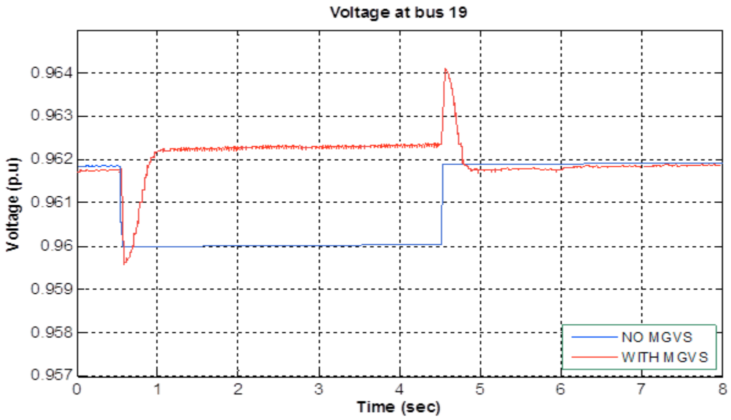


a) Reactive power generation of resource 1.

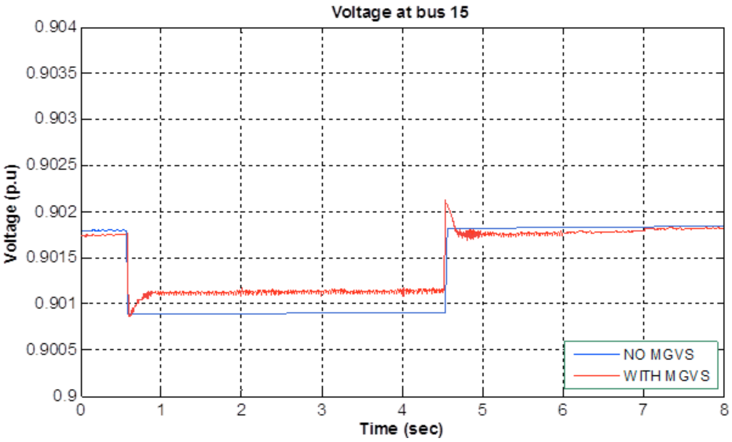


b) Reactive power generation of resource 3.

Fig.16: Comparison of reactive power generation for a 3-phase short circuit fault at bus 15, with MGVS and without it.



a) Voltage profile of bus 19.



b) Voltage profile of bus 15 (faulted bus).

Fig. 17: Comparison of load bus voltages for a 30% load increase at bus 15, with MGVS and without it.

5. CONCLUSION

Disturbances that occur in microgrids cause variations in buses voltage. These variations are sometimes very intensive so that they could likely result in the collapse of microgrid if the fault lasts more. Hence, a voltage stabilizer is used that improves voltage profiles of the microgrid buses in this investigation. This stabilizer is formed by a set of control blocks and its output is a voltage signal that would be divided between the DGs in the microgrid. Indeed, output signal of MGVS is effective to coordinate the DGs reactive power generation and supply the lost generation. Therefore, since the generated reactive power of resources depends on voltage, each resource generates an amount of reactive power causing to improve the dynamic voltage of the load buses in the microgrid.

In this paper, a microgrid containing two types of DGs, photovoltaic (PV) resource and diesel generator is tested. Regarding the obtained results, it can be concluded that utilizing microgrid voltage stabilizer with proper control parameters, improves dynamic voltage profile of buses in any types of microgrids (containing power electronic converter based DG or synchronous generator based DG or combination of them).

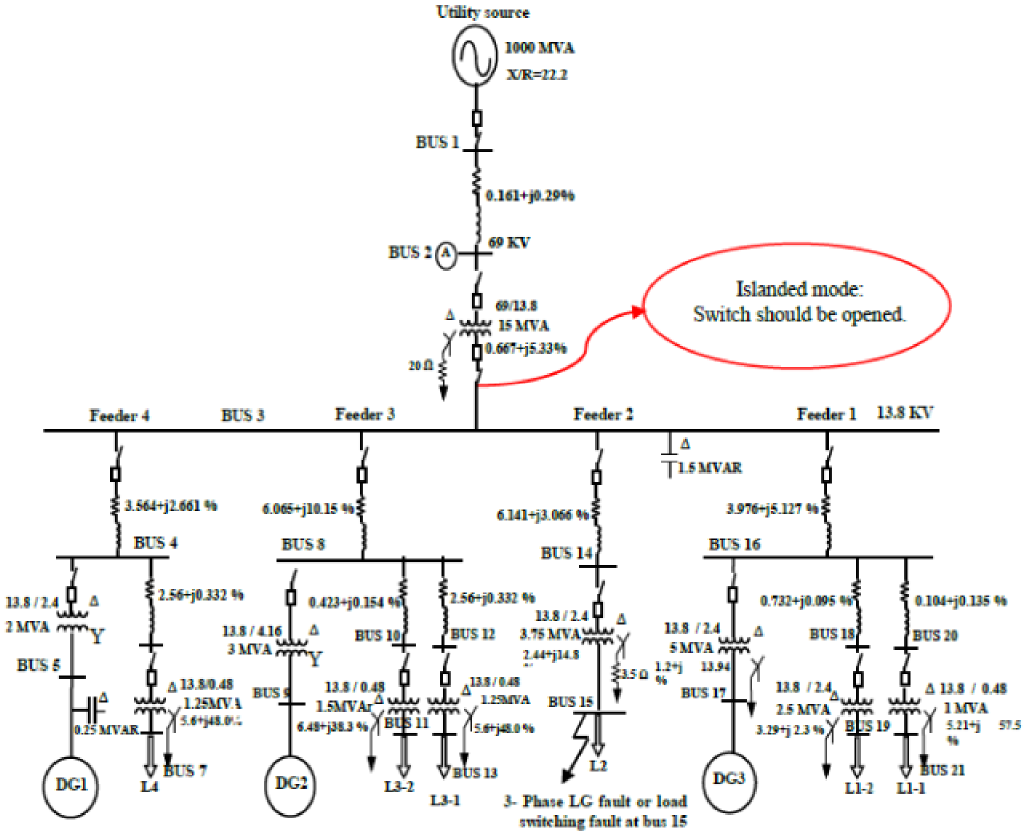


Fig.18: Test system- IEEE 21bus microgrid in islanded mode.

REFERENCES

[1] L. Robertr, A. Akhil, M. Chris, S. John, D. Jeff, G. Ross, A. S. Sakis, Y. Robert and E. Joe, "Integration of Distributed Energy Resources: The CERTS MicroGrid Concept," ." *Lawrence Berkeley National Laboratory* (2002).

[2] B. A. Robbinsy, A. D. Domínguez-Garcíay, C. N. Hadjicostisz, "Control of distributed energy resources for reactive power support," *North American Power Symposium (NAPS)*, 2011. IEEE,2011.

[3] P.Kundur, "Power system stability and control," McGraw-Hill, Inc.1994.

[4] J. A. Peças Lopes, C. L. Moreira and A. G. Madureira, "Defining Control Strategies for Analysing MicroGrids Islanded Operation," *IEEE Transactions on Power Systems*, (21 (2006).

[5] R. Majumder,A.Ghosh, G. Ledwich, & F. Zare, "Enhancing the Stability of an Autonomous Microgrid using DSTATCOM,"*International Journal of Emerging Electric Power Systems*, (2009).

[6] N. L.Soultanis, S. A.Papathanasiou, N. D.Hatziargyriou, "A stability algorithm for the dynamic analysis of inverter dominated unbalanced LV microgrids,"*IEEE Transactions onPower Systems*, 22: 294-304.

[7] M. S. Zabihi, E. A. Soleimani, S.Farhangi, "Photovoltaic Manufacturing, System Design and Application Trend in Iran," *Elsevier Science, Renewable Energy*,

[8] The MathWorks Inc. (2009) MATLAB Help. Help Document.

[9] A. Kalirasu, S. Sekar Dash, "Simulation of Closed Loop Controlled Boost Converter for Solar Instalation," *Serbian Journal of Electrical Engineering*, 7.1 (2010): 121-30.

[10] Z. Ye, R. Walling, L. Garces, R. Zhou, L.Li, and T.Wang, "Study and Development of Anti-Islanding Control for Grid-Connected Inverters," *General Electric Global Research Center Niskayuna,* New York 2004:21.

[11] J. A. Peças Lopes, C. L. Moreira, A. G. Madureira, F. O. Resende, X. Wu, "Control Strategies for MicroGrids Emergency Operation," *International Conference on Future Power Systems*, Nov. 2005.

[12] R. M. Kamel, A. Chaouachi, K. Nagasaka, "Detailed Analysis of Micro-Grid Stability during Islanding Mode under Different Load Conditions,"*Engineering journals of SCIRP*, May 2011.

[13] A. Engler, "Control of parallel operating battery inverters," in PV Hybrid Power System, Kassel, (2000):1-4.

[14] H. Laaksonen, P. Saari, and R. Komulainen, "Voltage and frequency control of inverter based weak LV network microgrid," in *International Conference on Future Power Systems,* Amsterdam, (2005): 1-6.

[15] P. L. Jeffrey, "Modeling of Dynamic Loads for Voltage Stability Studies*," Tennessee Technological University*, Cookeville, MS Thesis, (2007).

NOMENCLATURE

DG	Distributed Generation
MGVS	Micro-Grid Voltage Stabilizer
PSS	Power System Stabilizer

APPENDIX

Table 4: The specifications of each photovoltaic cell and the derived module.

Module		**Photovoltaic cell**			
V_{pv}	P_{pv}	$V_{o.c}$	$I_{s.c}$	Voltage at P_{max}	P
103.2	510.8	22.2	5.45	17.2	85.14