On load shedding design in Microgrids.

Hajimohammadi N, Bevrani H

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On Load Shedding in Microgrids

First N. Hajimohamadi, and Second H. Bevrani, University of Kurdistan

***Abstract*— similar to conventional systems, having acceptable voltage and frequency is necessary in a MG. MGs have variable nature due to the existence of the generators like PVs. Because of this, the control issue in MGs is important. The stable performance in MGs is realized by grid in grid-connected mode. But it depends on proper controllers in primary, secondary and emergency levels, in islanded mode. Security in MG following a severe disturbance can be established through emergency control like shutdown of any unit, demand side management, islanding and load shedding. In this paper, a MPPT algorithm is used to extract maximum power from PV sources. A controller is designed to stabilize MG performance during islanding. Also, a load shedding plan as one of the last actions to prevent blackout of isolated system is presented.**

***Keywords*— Distributed generation (DG), frequency, load shedding, microgrid, voltage.**

I. Introduction

Microgrid concept as a quasi-power system is introduced because of various reasons like environmental pollution, economical issues, depletion of fossil fuel resources, and market [1]. A cluster of loads and microsources operating as a single controllable system that provides both power and heat to its local area is defined Microgrid (MG) [2]. Wind turbine, solar cell, fuel cell, microturbine are the examples of MG sources with clean energies [3]. Depending on source type, it is connected via synchronous generator, induction generator or power electronic converter/inverter as interface [4, 5].

Generation units are usually small units (<100 KW) [6]. They are located in distribution voltage level and near to costumer. This vicinity brings with itself the advantages such as losses reduction and efficient increase [7]. Moreover, the ability of operation in both grid-connected and isolated modes increases reliability [8]. Despite of MG advantages there are several problems like the absence of standard about power quality and voltage and frequency profiles, difficulty of control and protection plans [7, 9].

Normally, a MG is connected to main grid and exchanges power with it. It is expected to DGs generate pre-specified power for example minimize power import from the grid. It is different from one system to another system [10]. In this mode, grid serves as backup and eliminates unbalancing. But islanding either by planned or unplanned events separates main grid. Such events are described in [11]. MG is disconnected from distribution grid via breaker by point of common coupling (PCC).

In transit from grid-connected mode to islanded mode, MGs depend on their previous conditions such as amount of interchanged power. They absorb usually power from grid, in grid-connected mode. As a result, unbalancing power is created in islanded mode [12]. For this purpose, a controller is presented to stabilize isolated MG in this paper.

Similar to conventional systems, isolated MGs can face different events such as tripping generator, unbalancing between generation and consumption, power quality issues. So, stable operation needs proper controllers. Various control loops of local, global, secondary and emergency [5] are used to keep MG. The role of controllers is to maintain system integrity and restore the normal operation subjected to a disturbances but each controller could response to some disturbances [13]. Small disturbances do not need critical actions but large disturbances need emergency control to prevent blackout system. In this paper, load shedding as one of the emergency control ways is studied. Emergency control can occur in both demand and generation sides. Load shedding plan is related to demand side. It curtails amount of loads until available generation could supply remind loads [14].

The agents such as low inertia, small electric distances and uncertainty of some dependent resources on solar and wind energies differ load shedding in MGs from one in conventional systems [15]. About photovoltaic (PV) resources a maximum power point tracking (MPPT) algorithm could be used to extract maximum power.

Frequency and voltage indexes separately or together are usually used for load shedding [14-17]. Their thresholds are the starter of load shedding in each stage [18]. At first, it is preferred to shed low importance loads. Also, weak buses are the suitable locations of curtailing load [19].

Economy and policy influence on load shedding. For example, legal issues related to investment and cooperation of customers [20]. Also, optimizing which sheds minimum loads is effective on economy [21].

This paper organized as follow: a model of PV and MPPT algorithm is showed in section 2. System of MG is introduced

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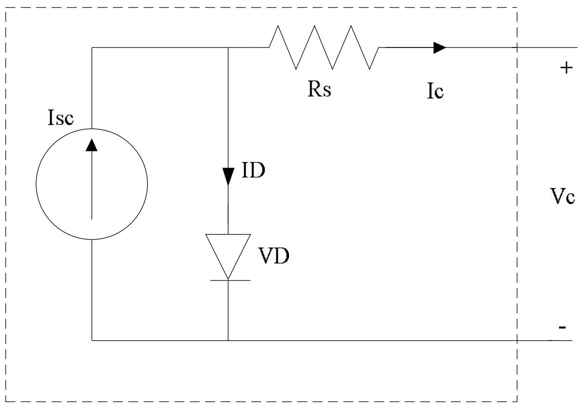
in section 3. Proper controller is studied in section 4 to stabilize system in islanded mode. Load shedding plan following large disturbances and when controllers cannot response is proposed in section 5. Conclusions are represented in section 6.

II. PV MODEL AND MPPT ALGORITHM

The simplified equivalent circuit model and output voltage equation of a PV cell is presented in the following.



PV Cell

Fig. 1: PV circuit [22]

$$V_C = (A\ k\ T_C/e\ )\ Ln\ ((I_{SC} + I_D - I_C)\ /\ I_D) – R_S\ I_C \quad (1)$$

Where e is electron charge, k is Boltzmann constant, Ic is cell output current, I_{SC} is photocurrent, I_D is reverse saturation current of diode, R_S is series resistance of cell, T_C is reference cell operating temperature and V_C is cell output voltage .

The PV cell output voltage is a function of the photocurrent depending on the solar irradiation level during the operation. Equation 1 is valid for a certain cell operating temperature T_C with its corresponding solar irradiation level S_C. If the temperature and solar irradiation level change, the voltage and current outputs of PV array will follow this change. Hence, the effects of the changes in temperature and irradiation levels should also be included in the final PV array model. These effects are represented by the coefficients C_{TV}, C_{TI} in another ambient tempreture T_X and C_{SV}, C_{SI} in another irradiation level S_X, respectively for voltage and photocurrent [22].

$$C_{TV} = 1 + ß_T\ (T_a – T_x) \quad (2)$$

$$C_{TI} = 1 + y_T/S_C\ (T_x – T_a) \quad (3)$$

$$C_{SV} = 1 + ß_T\ α_S\ (S_x – S_c) \quad (4)$$

$$C_{SI} = 1 + 1/S_C\ (S_x – S_c) \quad (5)$$

So, the new values of the cell output voltage V_{CX} and photocurrent I_{SCX} are obtained as follows:

$$V_{CX} = C_{TV}\ C_{SV}\ V_C \quad (6)$$

$$I_{SCX} = C_{TI}\ C_{SI}\ I_{SC} \quad (7)$$

The output power of PV is the product of the voltage by the current. By varying one of these two parameters, the power can be maximized. Applying a variation on the voltage (or on the current) toward the biggest or the smalllest values, its influence appears on the power values. If the power increases, one continues varying the voltage (or the current) in the same direction, if not, one continues in the inverse direction. This algorithm is shown in Fig. 2.

Several MPPT methods exist [23] in order to maximize this output power and to fix its values, in steady-state, at its high level as shown in Fig. 3. In this figure, the temperature and the sunshine values are constants.

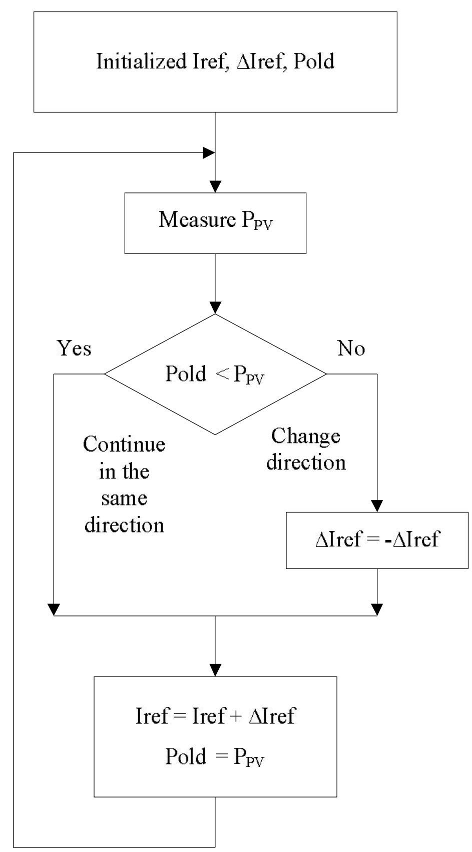


Fig. 2: Flowchart of MPPT algorithm

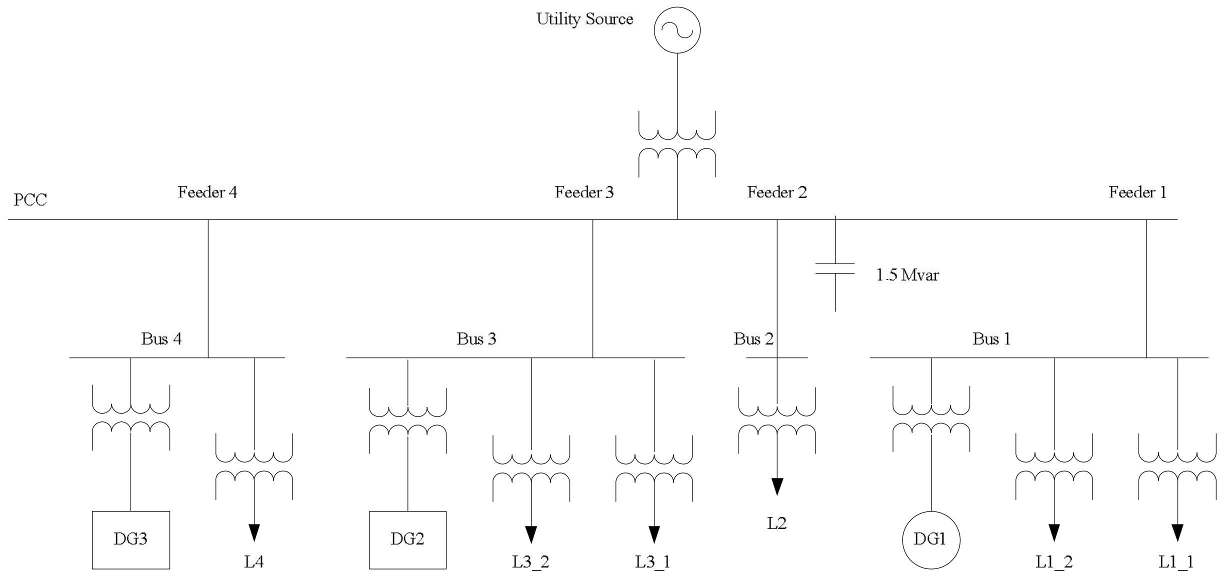


Fig. 4: Model of MG [24]

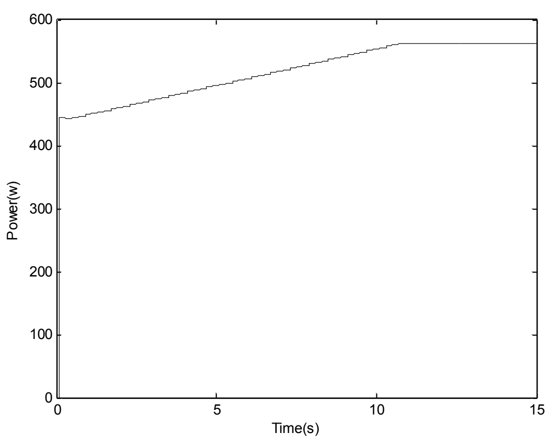


Fig. 3: Output power using MPPT

III. System Model

MG system in medium voltage (MV) level with its elements is shown in Fig. 4 [24]. MV system with base voltage of 13.6-KV is connected to the 69-KV grid by substation transformer and breaker. System includes four feeders and three generation units. Two electrically interfaced DGs and one conventional unit are located in feeders 3, 4, and 1, respectively. Available loads are considered as critical and non-critical to shed in necessary conditions.

IV. The Control Strategy of Microgrid

Reality, a MG has two operation modes, i.e., 1) grid-connected, 2) islanded. Also, there is a transient between the two modes. Stability and security in each mode can be achieved by proper controllers. In grid-connected mode, DGs are in PQ control mode and generate specified power. Any differences between generation and consumption which cause frequency, voltage or both of them to be out of acceptable ranges are compensated by main grid. In islanded mode, control issues are more important due to the absence of grid as sponsor. So, MG must itself supply its local loads or minimum critical loads.

During islanding, the power balance does not match at the moment. So, if there is not adequate controller the frequency and the voltage of MG will fluctuate, and system can experience blackout. Therefore, islanding is usually accompanied with control mode change in one or several electrically interfaced DG to set parameters alone [25]. But conventional units have slow response for this mode change and contribution in transient control [26].

In this work, a controller is used for both modes. Control of frequency and voltage are realized separately. The controller has a structure as shown in Fig. 5.

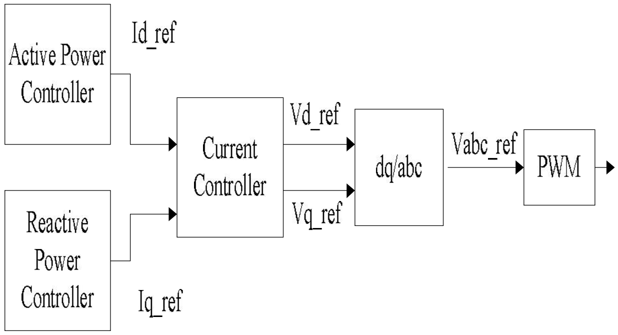


Fig. 5: Control Structure

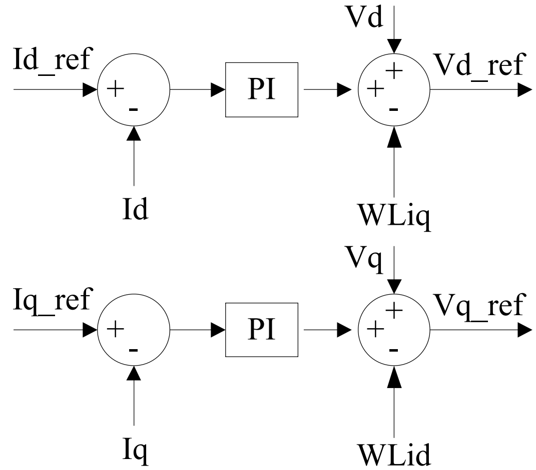


Fig. 7: Current Control

Controller includes active power controller and reactive power controller which generate d- and q-axis current commands for a d-q frame-based current controller. Subsystems are shown in Figs. 6, 7. In grid-connected mode, both reference and measured values of voltage and frequency are equal. As a result, the error is zero and reference values of active and reactive powers are generated by DGs. It acts similar to a PQ control way.

In islanded mode, measured voltage and rotor speed of synchronous generator in role of measured frequency are compared with their references. These differences cause DGs to change their generations to remain stable voltage and frequency similar to grid-connected mode. The use of rotor speed as one of the states of system can be more reliable for frequency.

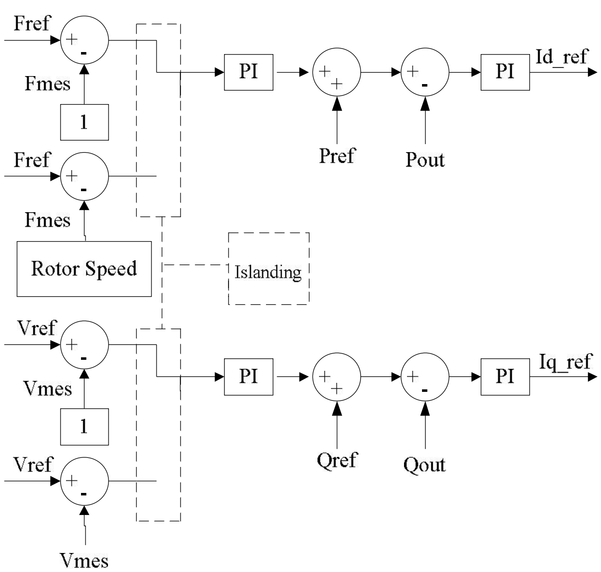
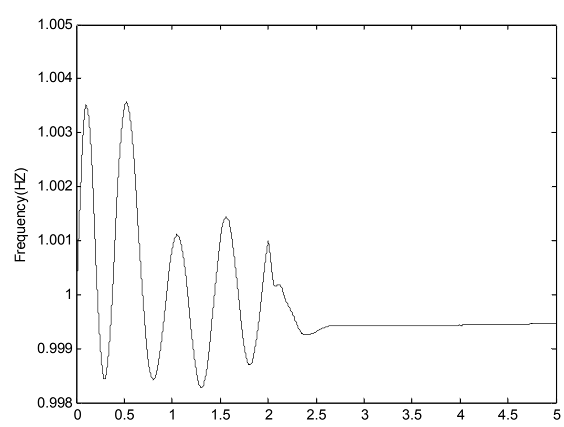


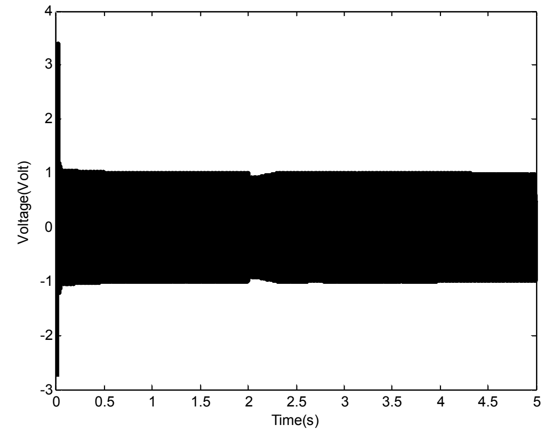
Fig. 6: Active and Reactive Controller

The performance of controller during islanding at t=2s is studied. The results are presented in Fig. 8. In grid-connected mode, DGs generate constant power and MG is importing power from grid. In islanded mode, MG increases power to supply its loads. But, DGs have limitations and cannot generate infinite power.

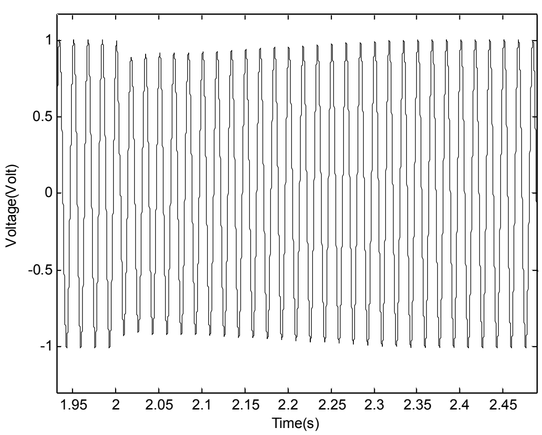
This controller could stabilize system following islanding. In the other word, it establishes a stable islanded MG. But, it cannot always suitable for all events. Because various controller loops in different levels have a certain ability to compensate disturbance. Islanding and tripping generator / load change simultaneously could be a large disturbance and need emergency actions. Load shedding as one of these actions are presented in next section.



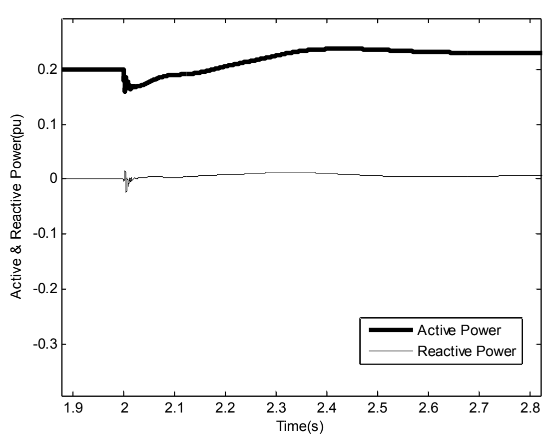
(a)



(b)



(c)



(d)

Fig. 8: Evaluation of controller performance after islanding (a) frequency of MG, (b) voltage of DGs, (c) zoomed view of voltage, (d) zoomed view of active and reactive power of DGs

V. LOAD SHEDDING

The proposed flowchart of load shedding scheme is shown in fig. 6.

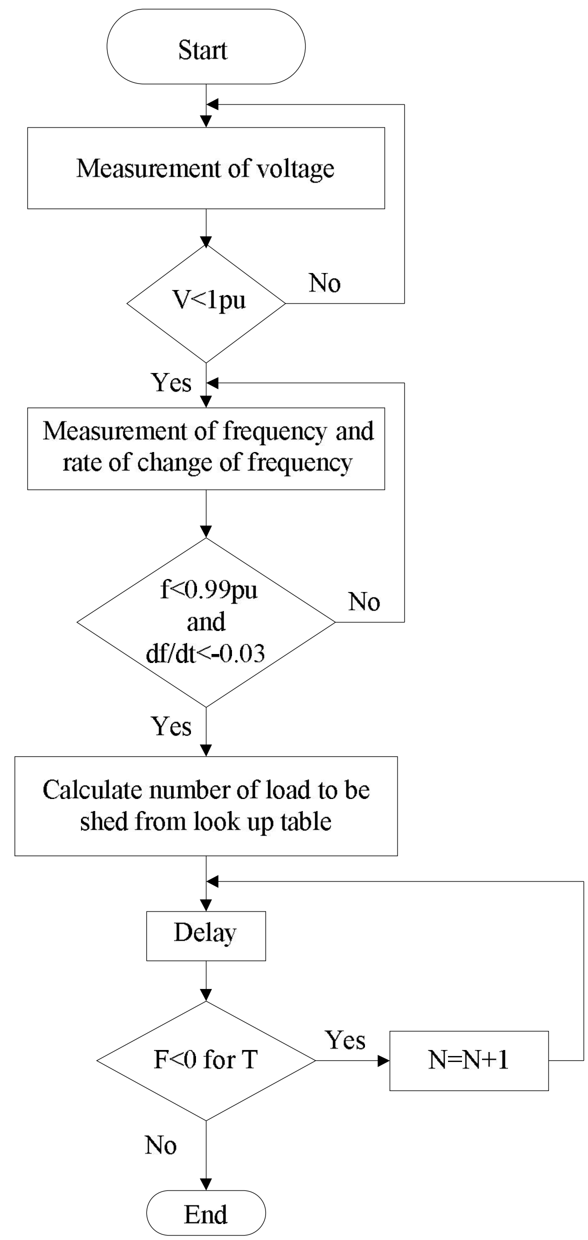


Fig. 9: Flowchart of load shedding

The plan is based on both frequency and voltage parameters. Reduction of voltage is as a factor to determine abnormal events. If frequency and rate of change of frequency (ROCOF) go out of their thresholds the disturbance will be large. In this situation load shedding will be started. The number of load to be shed is calculated from look up table. This table is determined based on voltage and amount of reduction of it for each event. The performance of consumption increase and generation decrease is equal. So, record the voltage drop for different events and formation of look up table could be achieved by increasing loads until system is stabilized by eliminating all the main loads. Table. 1 shows the look up table. Amount of ROCOF is obtained based on the disturbance which needs to shed only one load to stabilize.

After removal of the first group of load from table, algorithm load shidding will wait for some time before it will measure the frequency again. The delay will account for breaker operation time. The distribution system does not have the luxury of spinning reserve and secondary control like the transmission system. Thus, the only way to bring the frequency above the lower limit is to shed loads [27]. This means that being negative of frequency for T will make sure the frequency is not coming back to its nominal value.

Table 1: Look up table for load shedding

Limitations of voltage	Amount of load sheddin (LS)
$V \geq 0.776$	0
$0.776 < V \leq 0.733$	1
$0.733 < V \leq 0.71$	2
$0.71 < V \leq 0.696$	3
$0.696 < V \leq 0.68$	4
$0.68 < V \leq 0.67$	5
$V \leq 0.67$	Total load

The proper performance of algorithm is shown by a DG outage in t = 0.7 s as disturbance and start load shedding to stabilize system. The results are presented in figs. 10, 11 for before and after load shedding. The measured voltage after the disturbance is about 0.775. According to look up table, one step of load shedding is enough and after that system go to normal operation. For some cases like this, the voltage is close to the margin. So, load shedding could be initiated from previous phase to prevent overload. For this case, no load is eliminated in the first and after 0.05 delay only one load is shed.

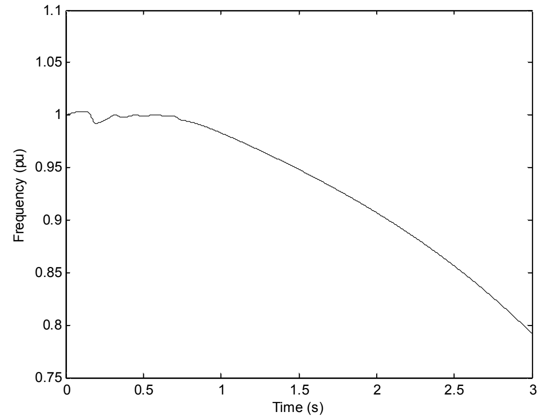
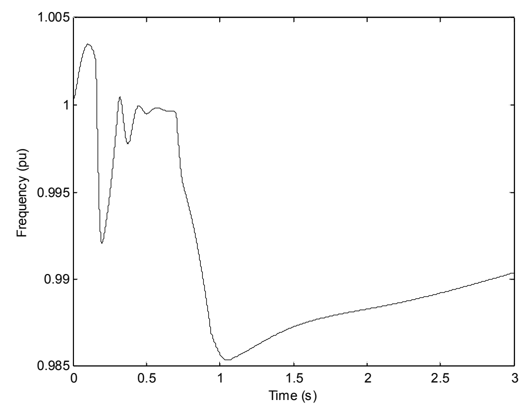
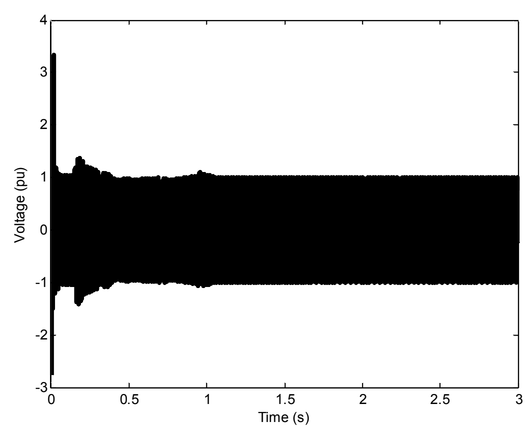


Fig. 10: Ferequency of MG before load shedding



(a)



(b)

Fig. 11: The results of simulation after load shedding (a) frequency of MG, (b) voltage

VI. Conclusion

The use of a controller is expressed to stabilize MG in both modes of operation. As a result, after disconnecting from main grid a stable islanded MG is obtained. But keeping MG following tripping of a DG is impossible for controller. In this case, some loads based on frequency, ROCOF and voltage are shed. Because of both parameters effect on load shedding, the answers could be more reliable by using them.

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