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# Load Shedding in Microgrids

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***Abstract:*** *Similar to conventional systems, having acceptable voltage and frequency is necessary in a microgrid (MG). This issue is realized by grid in grid-connected mode. But in islanded mode, it depends on proper controllers in primary, secondary and emergency levels. Security in MG following a severe disturbance can be established through emergency control like shutdown of a unit, demand side management, islanding and load shedding. In this paper, 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.

## 1. Introduction

Microgrid concept as a quasi-power system is introduced because of various reasons like environmental pollution, economical issues, depletion of fossil fuel resources, 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 as 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 usually absorb power from grid, in the grid-connected mode. As a result, unbalancing power is created in islanded mode [12]. For this purpose in the present paper, a controller is presented to stabilize isolated MG.

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].

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].

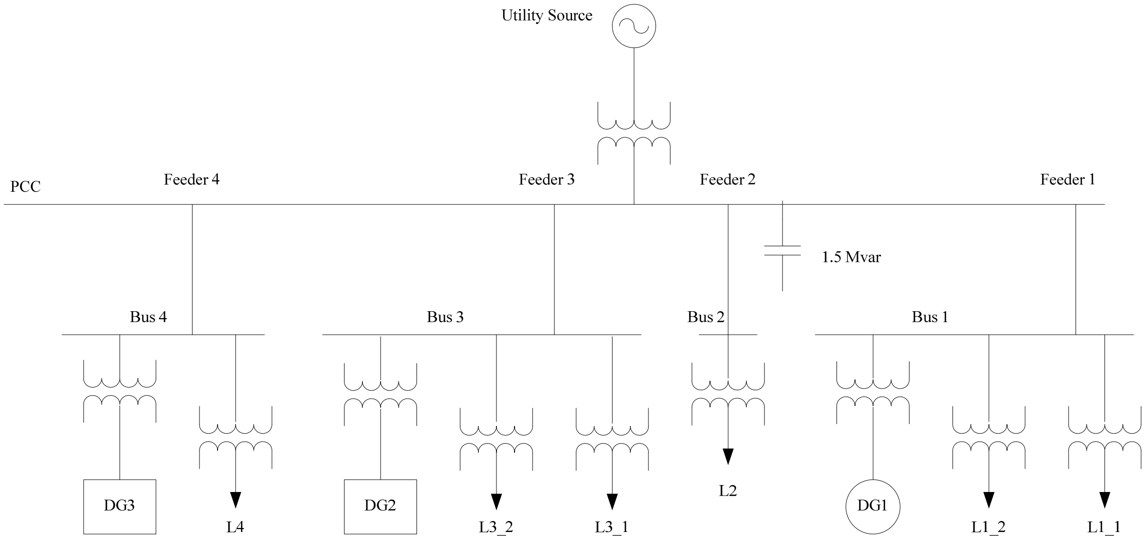


Fig. 1: Model of MG [22]

This paper organized as follow: system of MG is introduced in section 2. Proper controller to stabilize system in islanded mode is studied in section 3. Load shedding plan following large disturbances and when controllers cannot response is proposed in section 4. Conclusions are represented in section 5.

## 2. System Model

MG system in medium voltage (MV) level with its elements is shown in Fig. 1 [22]. MV system with base voltage of 13.8-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.

## 3. The Control Strategy of Microgrid

Reality, a MG has two operation modes, i.e., 1) grid-connected, 2) islanded. Also, there is a transient state between these 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 the 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 no 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 [23]. But conventional units have slow response for this mode change and contribution in transient control [24].

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. 2.

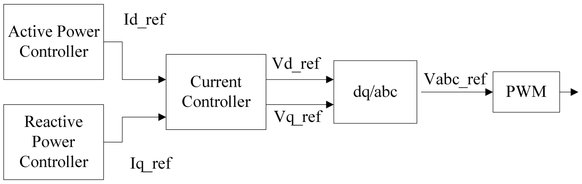


Fig. 2: Control Structure

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. 3 and 4.

In this work, the rotor speed of synchronous machine is used as the grid frequency. The use of rotor speed as one of the states of system can be more reliable for frequency.

### 3.1 Grid-connected Mode

In the 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 grid connected mode, DGs generate constant power and MG is importing power from the grid. The results are shown in Figs. 5-7.

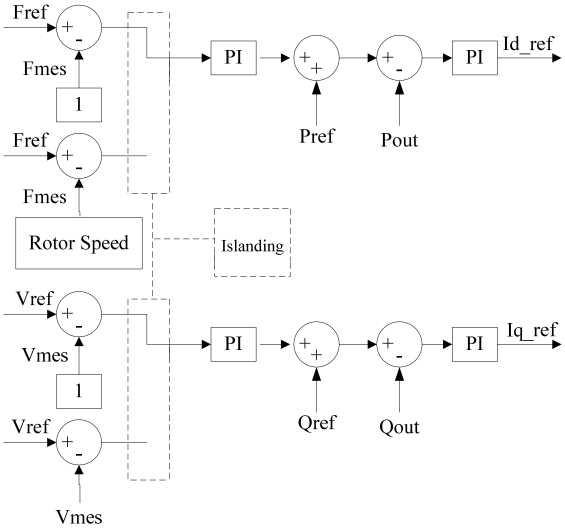


Fig. 3: Active and Reactive Controller

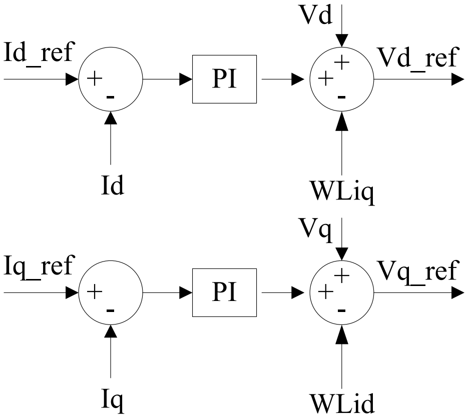


Fig. 4: Current Controller

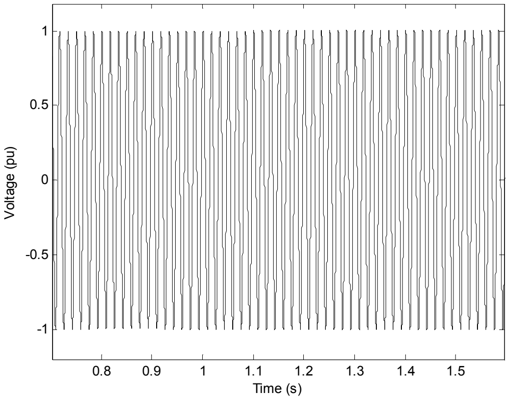
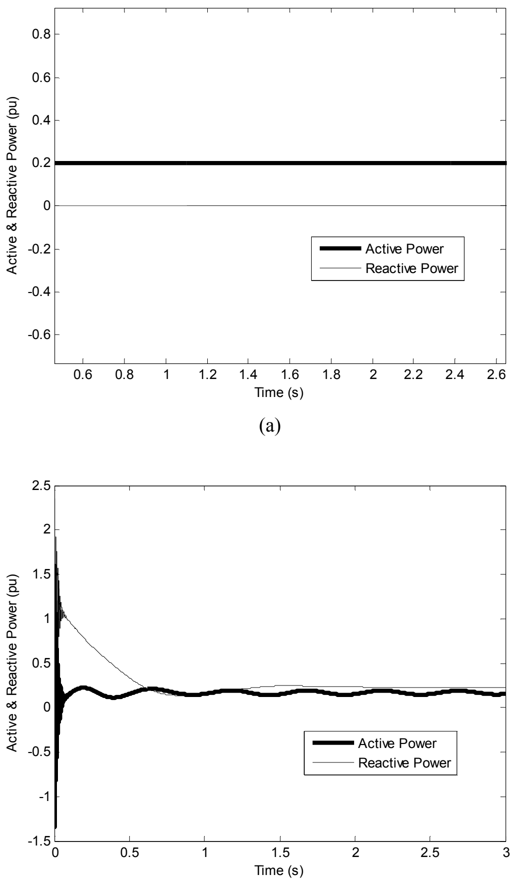


Fig. 5: Zoomed view of voltage during grid-connected mode



(a)

(b)

Fig. 6: Active and reactive power of generetor units during grid-connected mode (a) electronically interfaced DG, (b) conventional unit.

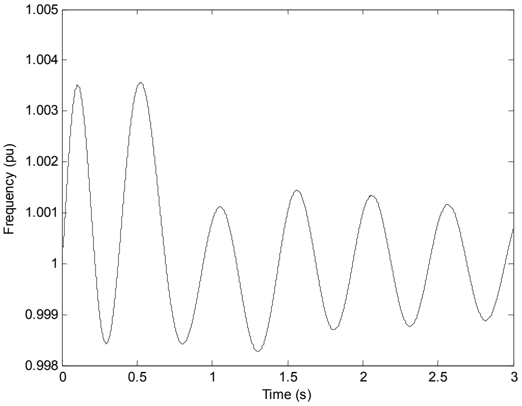


Fig. 7: Frequency of MG during grid-connected mode

For a while, the rotor speed fluctuates in an acceptable range. But finally, it converges to its nominal value. It is shown in Fig. 8.

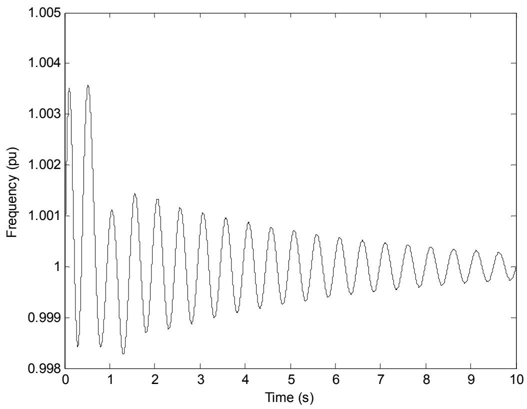


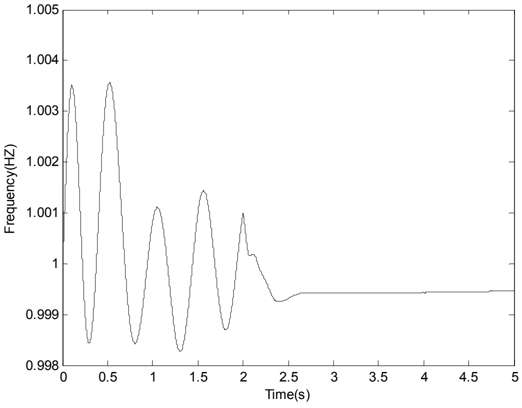
Fig. 8: Rotor speed (frequency)

### 3.2 Islanded Mode

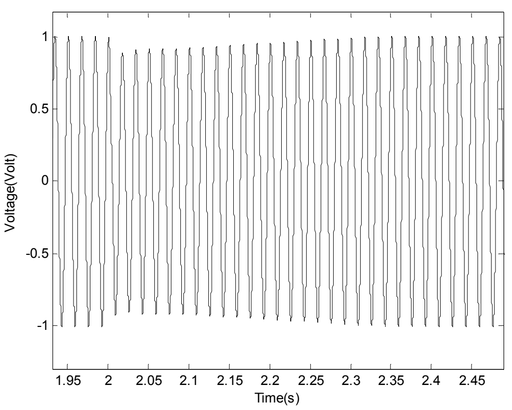
In islanded mode, measured voltage and rotor speed of synchronous generator, which is in role of measured frequency, are compared with their references. These differences cause DGs to change their generations to remain stable voltage and frequency similar to the grid-connected mode.

The performance of controller during islanding at t=2s is studied. The results are presented in Fig. 9. In islanded mode, MG increases power to supply its loads. But, DGs have limitations and cannot generate infinite power.

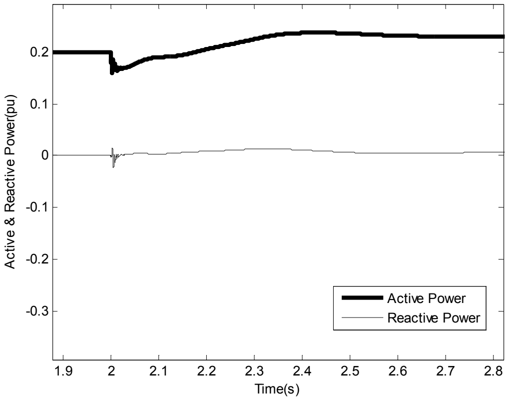
This controller could stabilize system following islanding. In the other word, it establishes a stable islanded MG. But, it cannot always suitable for all events. Because various controller loops in different levels have a certain ability to compensate disturbance. Islanding and tripping generator or 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)

Fig. 9: Evaluation of controller performance after islanding (a) frequency of MG, (b) zoomed view of voltage, (c) zoomed view of active and reactive power of DGs.

## 4. Load Shedding

The proposed flowchart of load shedding scheme is shown in Fig. 10. The plan is based on frequency and rate of change of frequency (ROCOF) and the effect of each load is considered, separately. In the other word, the ROCOF of each load is calculated by simulation of an isolated system with the deficiency of that load. Loads are ranked based on their ROCOF. The load that has the least ROCOF value shed first and the load that has the most ROCOF value shed last. Related ranking is available in Table 1.

This algorithm includes two phases. In the phase 1, frequency and ROCOF are measured at each instant and then compared with their thresholds. If both parameters are out of normal range the load in the first rank will be shed. After that, the phase 2 of load shedding is initiated. In Phase 2, only frequency is used. When it goes down below its acceptable amount for T=0.05s times, the loads in the other ranks are shed, respectively until frequency is restored.

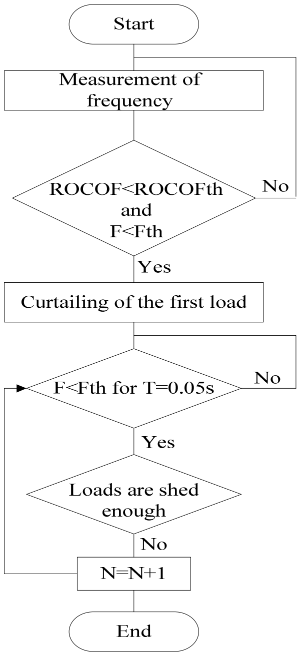


Fig. 10: Flowchart of the proposed load shedding algorithm

After islanding of MG at t=0.2s, MG was stabilized by previous section controller. But the event of tripping DG at t=0.7s causes MG to go to destruction. In this situation, load shedding plan is activated and prevent destruction of the system. Two loads are shed in t=0.93s and t=0.98s. Figs. 11 and 12 show the results before and after of load shedding.

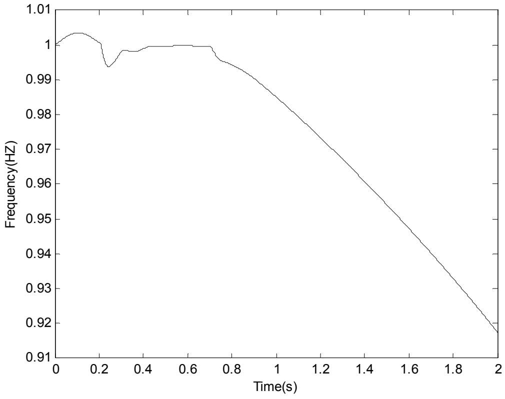
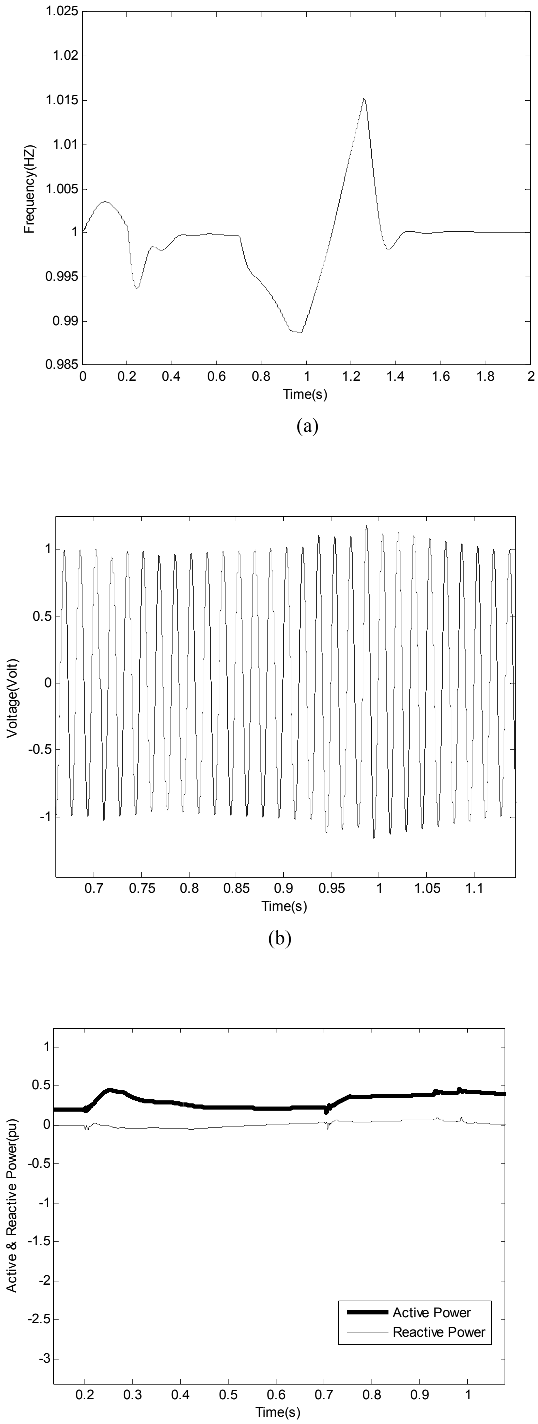


Fig. 11: Frequency of MG before load shedding



(c)

Fig. 12: Results of load shedding plan (a) frequency of MG, (b) zoomed view of voltage, (c) zoomed view of active and reactive powers of DG

## 5. Conclusion

The use of a controller is expressed to stabilize MG in both modes 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 and ROCOF are shed. The results show correct performance of plan.

TABLE 1: Ranking of loads based on the ROCOF

| Load | ROCOF |
|---|---|
| L3-2 | -0.252 |
| L1-2 | -0.246 |
| L3-1 | -0.24 |
| L1-1 | -0.204 |
| L4 | -0.192 |
| L2 | -0.18 |

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