ANALYSIS OF ISLANDING MICROGRID STABILITY DURING FAULT CONDITION

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ABSTRACT

Microgrids can play an important role in decentralized control of electric distribution network. In autonomous mode of operation, maintaining the service to the local loads when a fault or disturbance is occurred has the major importance. Therefore, evaluation of microgrid operation in standalone mode due to its large flexibility and limited power source of distributed generators (DGs) should be investigated. During fault condition, microgrid controllers should have the capability of maintaining system stability. In this paper droop control based islanding microgrid will be evaluated in different fault conditions and the main causes of the grid instability will be discussed.

INTRODUCTION

The interconnection of small sized generation systems such as solar PVs, micro turbines, fuel cells, wind turbines and energy storage devices to low voltage distribution grid will lead to a new energy network named microgrid. Aforementioned power sources give the capabilities of decentralized generation and are known as distributed generators (DGs) [1-2].
A microgrid is flexible with two different modes of operation. In interconnected mode it is connected to the main upstream grid, injecting power into it or being either supplied from it. Other mode of operating is known as islanding or standalone mode and the microgrid operates autonomously, disconnected from the distribution network [3-4].
DG utilization will improve the service reliability and decrease the need for future generation expansion planning. On the other hand, in concept of standalone microgrid it extends up the feasibility of making DGs responsible for local power quality factors in a way that is not conceivable with conventional centralized power generators [5-7].
Unlike conventional generators which almost exclusively produce 50 or 60 hertz electricity, the majority of distributed generators are connected to the grid with dc to ac converters (inverters) [8-9].
The basic control objective for generators in a microgrid is to achieve proper power sharing while regulating of the microgrid voltage and frequency. Centralized control strategy of a microgrid based on communication infrastructure is proposed in [10]. However, in areas with long distance between DGs, it is impractical and costly to determine accurate dynamic power sharing. To overcome these limitations, decentralized controllers are investigated. Droop controllers are hence utilized as power sharing controllers of microgrid generators.
In [11] and [12], static droop compensator is proposed for power sharing. Droop control is modified featuring the transient response performance in [13]. To reduce the active and reactive power dependency, droop controllers with virtual frequency-voltage frame and virtual output impedance are also discussed in [14-15]. Considering nonlinear loads, harmonic based droop controllers are also proposed in [16-18].
Due to great penetration of distributed power generation systems to supply the demand power, application of microgrid for industrial purposes should be noticed. Evaluation of droop controller in presence of induction motors as the most important industrial load is less discussed in previous studies.
In this paper, induction motor characteristics are evaluated in fault conditions in an islanding microgrid with droop control. Different fault scenarios are applied to a sample microgrid and Matlab simulation results are shown for verifications.

DROOP CONTROL METHOD

Droop controllers, emulating droop characteristic of synchronous generators, are utilized as power sharing controllers for microgrid inverter based generators. To connect several parallel inverters without communication infrastructures, the droop control method is investigated. Droop control method is based on the principle that the frequency and voltage amplitude of inverter can be used to control active and reactive powers generated by each DG.
By presuming simplified output impedance of each generator, basic equations can be derived as droop characteristics. In these equations droop gains determine assigned active and reactive power of each source. Due to the global feature of frequency in an electric grid, the active power is shared ideally with the respect of droop gain ratios. In this paper a droop control based sample microgrid will be examined in fault condition to investigate the capability of control scheme to converge the system frequency in such disturbance.
Droop control for a sample microgrid is considered in dq0 reference frame which facilitates control process by transforming time variant quantities of voltage and current in three phase reference frame (a-b-c) to DC quantities (d-q-0).
Reference voltage for PWM of inverters is generated by three back to back power, voltage and current controllers. Figure 1 shows a DG unit connected to the microgrid by inverter. It is assumed that the input source of inverter is an ideal dc link. Inner controllers are further discussed.

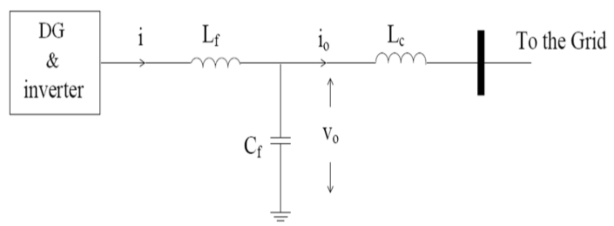

Figure 1. VSC based DG connected to the microgrid.

Power controller

Droop control scheme mimics the operation of governor and exciter in synchronous generators and determines output frequency and voltage of DGs according to the active and reactive powers derived from their terminals. In order to determine frequency and voltage by droop equations, instantaneous powers should be calculated in dq0 coordinate system from generator output voltage and current (v_o and i_o) as they are shown in figure 1.

$$p = v_{od} i_{od} + v_{oq} i_{oq} \tag{1}$$

$$q = v_{od} i_{oq} - v_{oq} i_{od} \tag{2}$$

According to (3) and (4) to derive P and Q, above quantities should be passed through low pass filter in which ω_f is the cut-out frequency. Reference voltage and frequency of power controller can be obtained by (5) and (6).

$$P = \frac{\omega_f}{s + \omega_f} p \tag{3}$$

$$Q = \frac{\omega_f}{s + \omega_f} q \tag{4}$$

$$\omega = \omega_n - k_1 P \tag{5}$$

$$v_{od}^* = V_n - k_2 Q \tag{6}$$

In above equations ω_n and V_n are nominal frequency and voltage of microgrid. k_1 and k_2 are droop gains; these gains relate to economic and technical features of each DG. Droop gains are kept the same for all generators in this paper for simplicity. Reference voltage of q-axis is set to be zero.

According to droop characteristic, frequency of each DG changes continuously by variation in its active power. When a disturbance occurs, frequency will reach the steady state amount after transition time. DGs have different frequencies in compare to each other during transient time because they face different impedances. As one frequency is possible for generators of a microgrid, active power is divided between DGs in a way that produce same frequency for them. Therefore DGs produce same P in same k_1.

Voltage and current controllers

Reference voltage and frequency generated by power controller are fed to back to back voltage and current controllers (figure 2). Both controllers are designed to reject high frequency disturbances and provide adequate damping for the output filter.

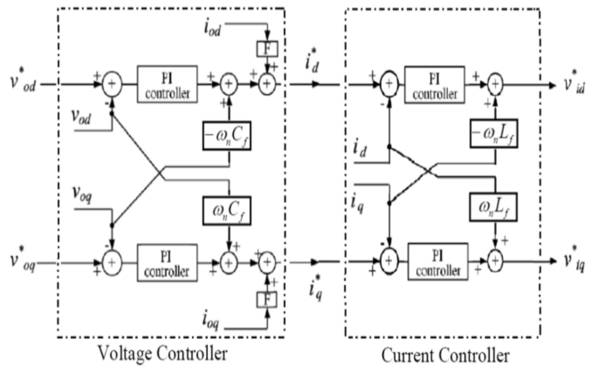

Figure 2. Voltage and current controllers.

Inner PI controllers guarantee zero steady state error and improve system transient response. Also feed-forward loops isolate DGs from load disturbances.

RESULTS

In this part an islanded microgrid with droop control is evaluated in fault condition in presence of induction motor.

Figure 3 shows the microgrid that is simulated in Matlab Simulink. It contains three buses with a DG in each bus. Network and controller parameters like resistance and reactance of lines, inverter output filter, switching frequency and droop gains are given in table 1. Coefficients of inner PI controllers are tuned in each section by try and error method.

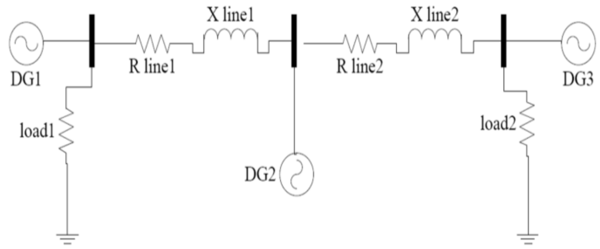

Figure 3. Single phase schematic of simulated microgrid.

In order to study dynamic loads in a microgrid with droop control, induction motor as the most common industrial load is chosen to be simulated. Motor characteristics like stator and rotor current and rotor speed are observed in fault conditions. Single phase schematic of the circuit is shown in figure 4. Motor parameters are also given in table 2.

Table 1. Network and controller parameters of microgrid.

L_f	1.3 mH	C_f	50 µF
F	0.75	L_c	0.35 mH
f_s	8 kHz	ω_f	31
k_2	1.5×10^{-3}	k_1	9.5×10^{-5}
x_{line1}	0.1Ω	r_{line1}	0.2 Ω
x_{line2}	0.6 Ω	r_{line2}	0.3 Ω

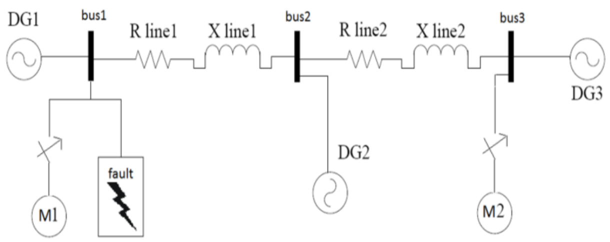

Figure 4. Simulation of induction motor.

Table 2. Induction motor parameters.

Equivalent Circuit Parameters		Nominal Values	
r_s	0.7384 Ω	rms Voltage	400 v
L_s	0.003045 H	Frequency	50 Hz
r_r'	0.7402 Ω	Speed	1440 rpm
L_r'	0.003045 H	Active Power	7.5 kw
L_m	0.1241 H	Torque	50 N.m

After 0.6 seconds of the motor starting a two phases to ground fault is occurred in bus1. After 3 cycles the fault is cleared. Figures 5 to 7 show motor1 characteristics. It can be seen that voltage and frequency controllers have the capability of maintaining system stability after fault clearance.

By increasing fault extremity, 3 phases to ground fault is applied to the microgrid. All the other conditions are kept the same as the previous fault. As it can be seen after fault clearance, controllers are failed to maintain system stability.

The main cause for instability is due to the extreme demand of current and power. According to the droop characteristic, DGs frequency will fail to converge because they generate large amount of P and their generation difference is remarkable. Reference frequencies determined by power controllers for each three DGs are shown in figures 11 to 13.

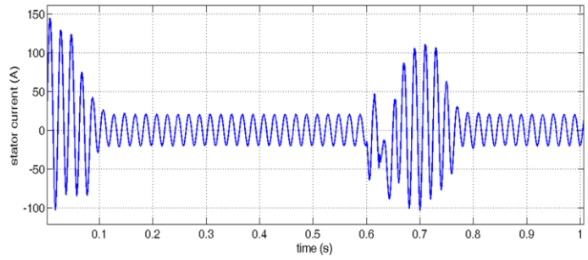

Figure 5. Stator current in two phases to ground fault.

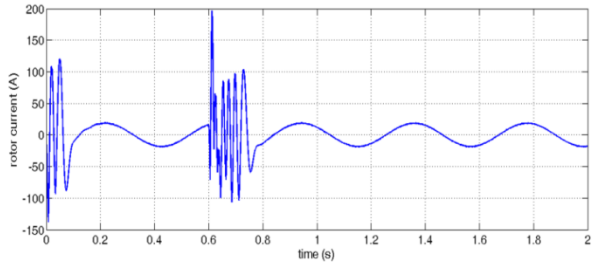

Figure 6. Rotor current in two phases to ground fault.

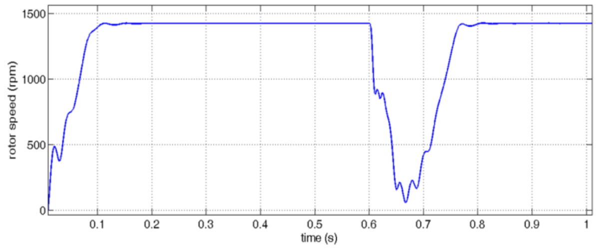

Figure 7. Rotor speed in two phases to ground fault.

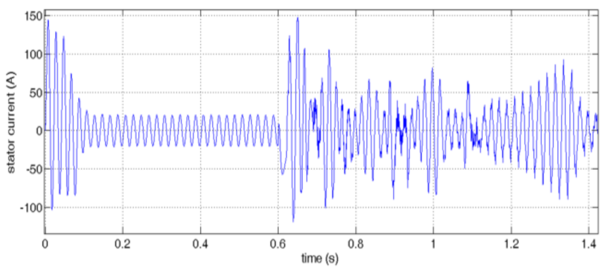

Figure 8. Stator current in three phases to ground fault.

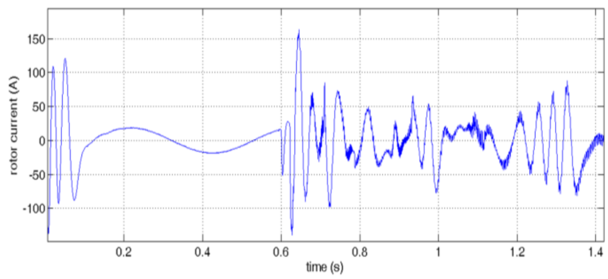

Figure 9. Rotor current in three phases to ground fault.

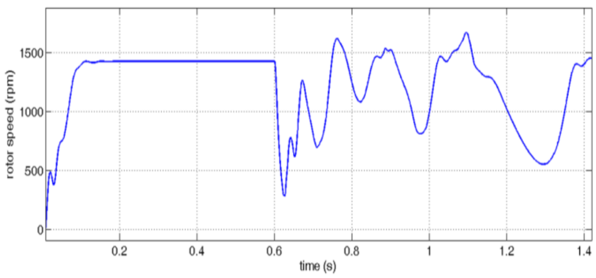

Figure 10. Rotor speed in three phases to ground fault.

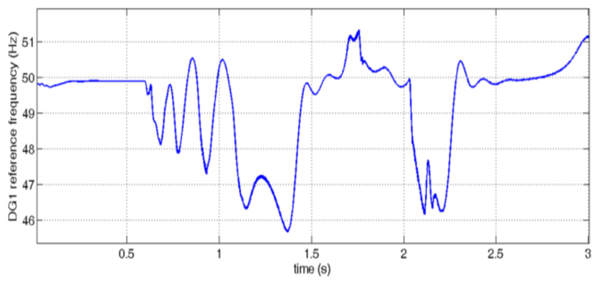

Figure 11. DG1 reference frequency in three phases to ground fault.

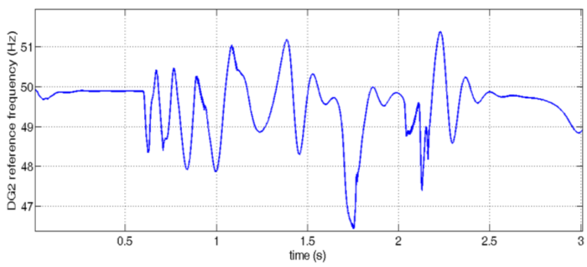

Figure 12. DG2 reference frequency in three phases to ground fault.

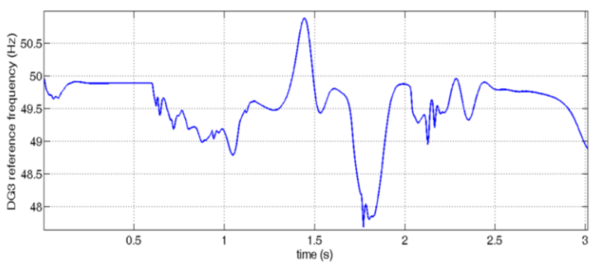

Figure 13. DG3 reference frequency in three phases to ground fault.

CONCLUSION

In this paper frequency stability of standalone microgrid was analyzed in detail. By demonstrating droop control method as the main solution for power sharing in microgrids, its capability to frequency convergence was discussed in fault conditions. To evaluate frequency stability of the microgrid, different fault scenarios were applied. Characteristics of an induction motor as a sample load was observed by Matlab simulation results. It was concluded that both the duration and intensity of the fault can determine how the frequencies of different DGs in the microgrid will be stabilized.

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