Electrical Stability of Large Scale Integration of Micro Generation Into Low Voltage Grids

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Abstract:

With large scale integration of micro generation into low voltage grids, stability becomes an important issue for a MicroGrid. The unique nature of the MicroGrid requires that the MicroGrid is stable in both grid-connected mode and islanded mode. In this paper, the major factors (such as control schemes of the flywheel energy storage system, types of load in the MicroGrid, location of the fault and inertia constants of motor load) influencing the stability of the MicroGrid are investigated. Three possible control strategies (PQ control, Droop control and Frequency/Voltage control) of the MicroGrid are described. Simulation results show how the flywheel uses PQ control only when the MicroGrid is operated in grid-connected mode. During islanded mode, the control scheme of the flywheel has to be switched from PQ control to Droop control or Frequency/Voltage. With fixed PQ load or impedance load in the MicroGrid there is no stability problem. However, motor loads have a significant influence on the transient stability of the MicroGrid. In the MicroGrid, no evidence of small signal instability has been found. Instability of the MicroGrid is likely to result in low voltages. Hence, the stability of the MicroGrid can be improved by using an undervoltage load shedding method on the less important motor loads in the MicroGrid.

Keywords: *Stability, MicroGrid*

1. Introduction

Micro-scale distributed generators (DGs), or micro sources, are being considered increasingly to provide electricity for the expanding energy demands in the network. The development of DGs operated in a MicroGrid also helps to reduce greenhouse gas emissions and increase energy efficiency.

The MicroGrid concept is a cluster of micro sources and loads designed as a single controllable system that provides both power and heat to local area and operates in both grid-connected mode and islanded mode [1]. Figure 1 shows a typical configuration of MicroGrid. In this MicroGrid the electrical system is radial with three feeders A, B and C. The voltages at the loads are 400 volts or less. Feeder A consists of several micro sources (e.g. wind turbine, photovoltaics, fuel cell and micro gas turbine) providing power and heat to local residential consumers and an apartment building. Feeders B and C are similar to feeder A. The MicroGrid is connected to the main distribution system through a tap-changed transformer and a separation circuit breaker CB2. The transformer normally provides steady-state voltage regulation of the MicroGrid under grid-connected mode (when CB2 is closed) and an earth point under islanded mode (when CB2 is open). The MicroGrid is isolated from the main distribution network by tripping CB2. A flywheel energy storage device is installed at the 400volt busbar. The flywheel provides voltage and frequency control of the MicroGrid when the MicroGrid is operated in islanded mode.

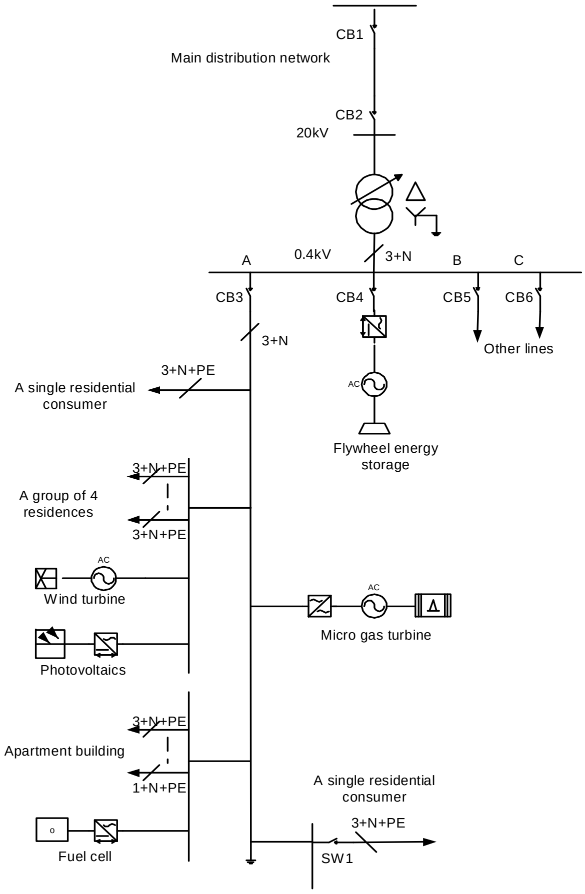

Figure 1 Basic MicroGrid architecture

Many new technologies (e.g. micro gas turbine, fuel cells, photovoltaic system and several kinds of wind turbines) proposed to be used in MicroGrids are not suitable for supplying energy to the network directly. They have to be interfaced with the grid through an inverter stage [2]. The use of power electronic interfaces in the MicroGrid will lead to a series of challenges in the design and operation of the MicroGrid. These major challenges include the safety and stability of the MicroGrid during all operating modes, particularly, islanded mode.

The control of the micro sources and the flywheel is important to maintain the stability of the MicroGrid [3]. For basic operation of the MicroGrid, the controllers use only local information to control the flywheel and micro sources [4]. Hence, fast communication between the micro sources and the flywheel is unnecessary.

For the micro sources, the electricity, generated by the micro sources, may be constant because of the need of the associated thermal load. For the flywheel, the inverter should be able to respond to the change of load in a predetermined manner automatically. Thus, possible control strategies of the MicroGrid are: (a) PQ control (fixed active and reactive power control), (b) Droop control and (c) Frequency/Voltage control.

With PQ control, the micro sources and the flywheel run at constant power output. The power output of the flywheel can be fixed at zero when the MicroGrid is operated in parallel with the main network, grid-connected mode. With Droop control, the output power of the flywheel is regulated according to droop settings. With Frequency/Voltage control, the frequency and voltage of the MicroGrid can be restored to normal values (e.g. f=50Hz and V=1.0p.u).

In this paper, three control strategies (PQ control, Droop control and Frequency/Voltage control) of the MicroGrid are described and implemented in a simple MicroGrid model. In the model the micro sources and flywheel are represented by a STATCOM-BES. Using this model, the impact of characteristics of load, locations of fault and inertia constants of motors on the stability (or critical clearing time, CCT) of the MicroGrid is investigated. Finally, an undervoltage load shedding method is used to improve the stability of the MicroGrid. Simulations are demonstrated and discussed with supporting PSCAD/EMTDC results.

2. Control strategies of a MicroGrid

The unique nature of the MicroGrid determines that the possible control strategies of the MicroGrid can be: (1) PQ control, (2) Droop control and (3) Frequency/Voltage control.

(1) PQ control

Using this control, the outputs of the micro sources and the flywheel are fixed at their constant values (settings). PQ control consists of a P controller and a Q controller.

The P controller adjusts the frequency-droop characteristic of the generator up or down to maintain the active power output of the generator at a constant value ($\boldsymbol{P_{des}}$, desired active power) when the frequency is changed. Figure 2 shows the effect of frequency-droop characteristic adjustment. A typical droop of the frequency characteristic is about 4% [5].

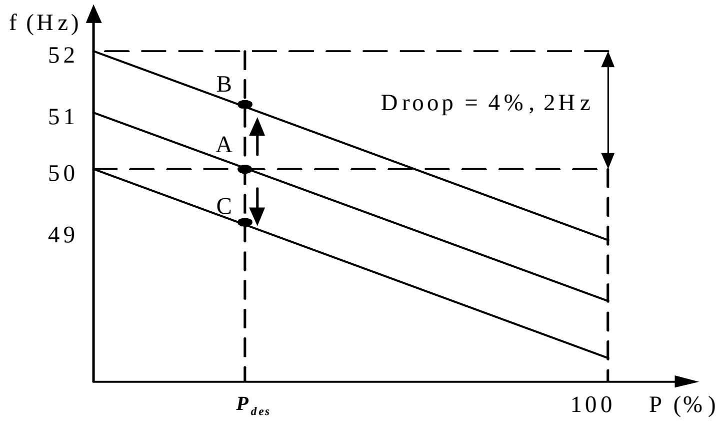

Figure 2 Effect of the frequency-droop characteristic adjustment

At output $\boldsymbol{P_{des}}$, characteristic A corresponds to 50Hz frequency of the grid, characteristic B corresponds to 51Hz frequency of the grid and characteristic C corresponds to 49Hz frequency of the grid. For a frequency change, the power output of the generator can be maintained at the desired value by moving the droop characteristic up or down.

Similarly, the Q controller adjusts the voltage-droop characteristic of the generator by moving the droop lines up or down to maintain the reactive power output of the generator at a constant value ($\boldsymbol{Q_{des}}$, desired reactive power) when the voltage is changed. Figure 3 shows the effect of voltage-droop characteristic adjustment. A typical droop of voltage characteristic is about 10% [5].

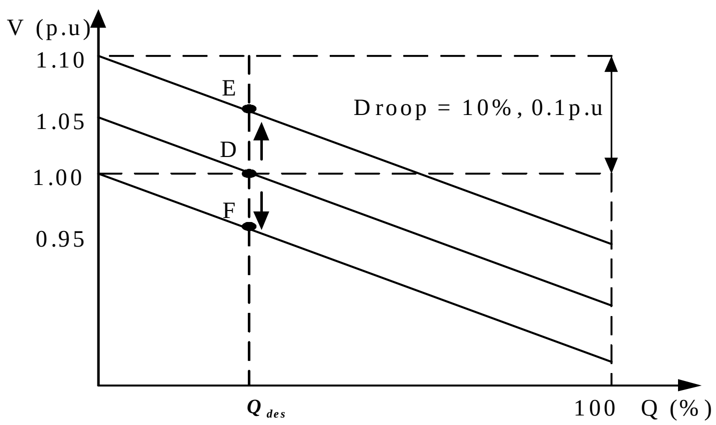

Figure 3 Effect of the voltage-droop characteristic adjustment

At output Q_{des} , characteristic D corresponds to 1.00 voltage of the network, characteristic E corresponds to 1.05 voltage of the grid and characteristic F corresponds to 0.95 voltage of the grid. For a voltage change, the reactive power output of the generator is maintained at the desired value Q_{des} by shifting the voltage-droop characteristic up or down.

(2) Droop control

When the MicroGrid is operated in islanded mode, the control schemes of the micro sources are still PQ control. However, the control scheme of the flywheel should be changed to enable local frequency control. The flywheel then uses Droop control. The power output of the flywheel is regulated according to the predetermined droop characteristics. Droop control consists of a frequency-droop controller and a voltage-droop controller. Figure 4 shows a frequency-droop characteristic, which would be used in the frequency-droop controller.

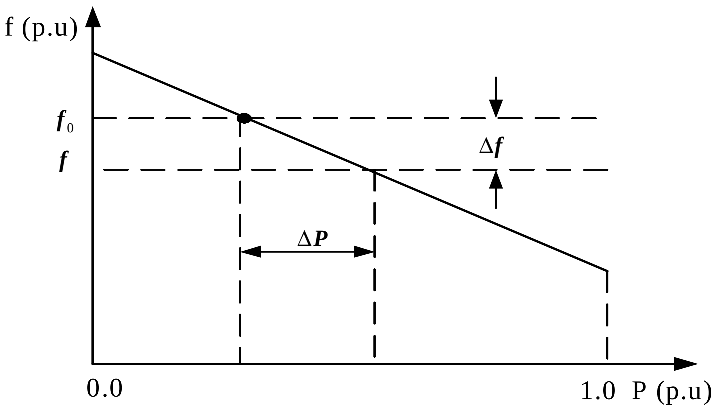

Figure 4 A typical frequency - droop characteristic

The value of droop R_f is a ratio of frequency deviation Δf to change in active power output ΔP. It can be expressed in percentage as equation (1).

$$R_f = \frac{\Delta f(p.u)}{\Delta P(p.u)} \times 100\% \quad (1)$$

Similarly, Figure 5 shows a typical voltage-droop characteristic used in the voltage-droop controller.

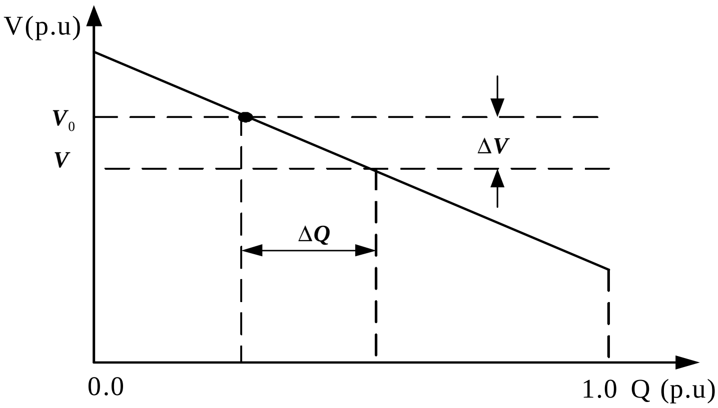

Figure 5 A typical voltage -droop characteristic

The value of droop $\boldsymbol{R_V}$ is a ratio of voltage deviation $\Delta\boldsymbol{V}$ to change in reactive power output $\Delta\boldsymbol{Q}$. It can be expressed in percentage as equation (2).

$$\boldsymbol{R_V} = \frac{\Delta\boldsymbol{V}(\boldsymbol{p.u})}{\Delta\boldsymbol{Q}(\boldsymbol{p.u})}\times 100\% \qquad (2)$$

(3) Frequency/Voltage control

With droop control action, a load change in the MicroGrid will result in steady-state frequency and voltage deviations, depending on the droop characteristics and Frequency/Voltage sensitivity of the load. The flywheel will contribute to the overall change in generation. Restoration of the Frequency/Voltage of the MicroGrid to their normal values requires a supplementary action to adjust the output of the flywheel. The basic means of the local frequency control of the MicroGrid is through regulating the output of the flywheel. As the load of the MicroGrid changes continually, it is necessary to automatically change the output of the flywheel.

The objective of the frequency control is to restore the frequency to its normal value. This is accomplished by moving the frequency-droop characteristic left or right to maintain the frequency at a constant value. The frequency control adjusts the output of the flywheel to restore the frequency of the MicroGrid to normal (e.g. 50Hz). Figure 6 shows the effect of this adjustment.

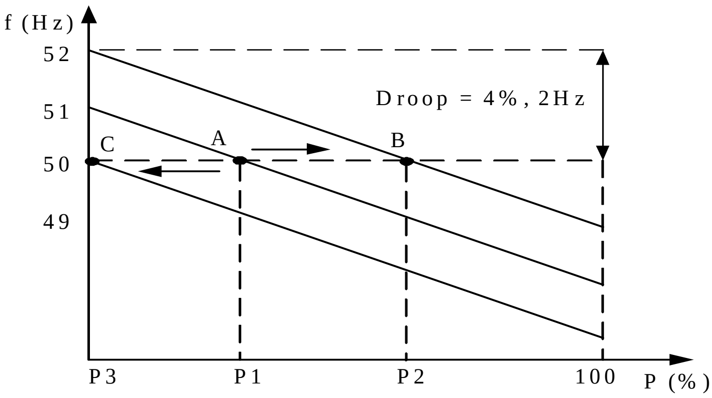

Figure 6 Effect of the adjustment on the frequency - droop characteristic

At 50Hz, characteristic A corresponds to P1 active power output of the flywheel, characteristic B corresponds to P2 active power output and characteristic C corresponds to P3 active power output. The frequency of the MicroGrid is fixed at a constant value (e.g. 50Hz) by moving the frequency-droop characteristic left or right.

Similarly, the voltage control adjusts the voltage-droop characteristic left or right to maintain a constant voltage when the voltage of the MicroGrid is changed. Thus, the voltage of the MicroGrid is fixed at a desired value (e.g. 1.0p.u). The effect of this adjustment is shown in Figure 7.

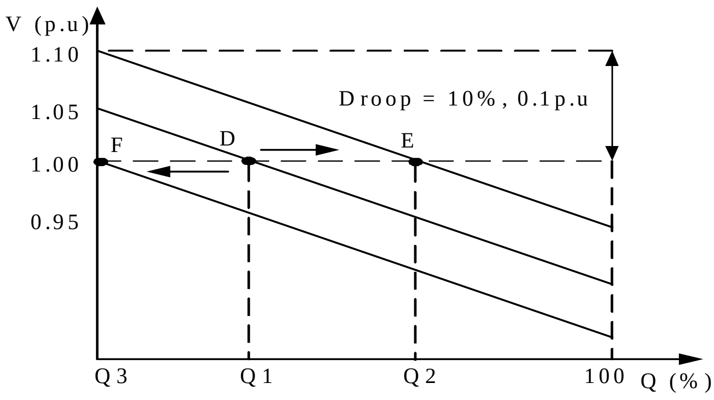

Figure 7 Effect of the adjustment on the voltage - droop characteristic

At 1.0 p.u voltage, characteristic D corresponds to Q1 reactive power output of the flywheel; characteristic E corresponds to Q2 reactive power output; and characteristic F corresponds to Q3 reactive power output. The voltage of the MicroGrid is fixed at a constant value (e.g. 1.0p.u) by moving the voltage-droop characteristic left or right.

3. STATCOM-BES representation of a MicroGrid

In a MicroGrid, the micro sources and flywheel are usually interfaced with the grid through a stage of power electronic devices (inverters). The dynamic performance and characteristic of the micro sources and flywheel is similar to that of a STATCOM-BES. Thus, the micro sources and flywheel can be represented by a STATCOM-BES. Figure 8 shows a simple MicroGrid in which the micro source and flywheel are represented by a STATCOM-BES.

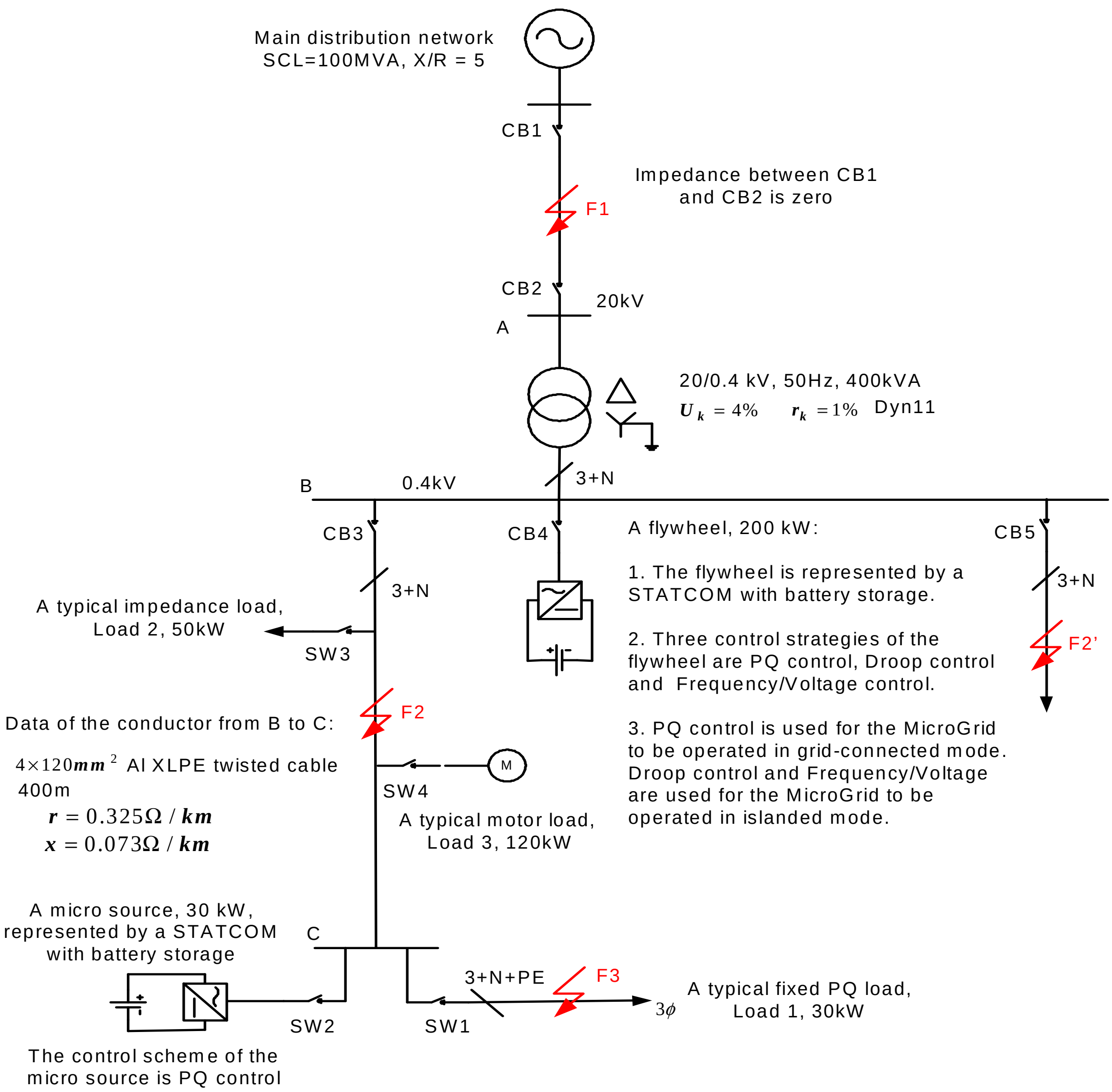

Figure 8 A simple MicroGrid model represented by STATCOM-BES

4. Investigation of the stability of a MicroGrid

The stability of the MicroGrid is defined as a property of the MicroGrid that enables it to remain in a state of operating equilibrium under normal operating condition and to regain an acceptable state of equilibrium after being subjected to a disturbance. Being similar to the stability of the conventional system [5], the stability of the MicroGrid may be divided into two components, namely, small signal stability and transient stability

The MicroGrid is small-signally stable under small disturbances if, following that disturbances, it maintains a steady state operating condition. In the MicroGrid, the micro sources and flywheel are interfaced with the grid through power electronic devices (inverters). They are completely decoupled from the MicroGrid by the inverters. Normally, the length of the MicroGrid is short (less than 500meters) with highly resistive low voltage conductor. During the simulations, the MicroGrid showed no evidences of small signal instability.

The MicroGrid is transiently stable under large disturbances if, following that disturbances, it reaches an acceptable steady state operating condition. The large disturbance usually considered is a severe contingency, causing a large deviation of the operating state of the MicroGrid (e.g. a three-phase fault on the feeder). Instability of the MicroGrid may result in voltage and/or frequency collapse.

The factors influencing the stability of the MicroGrid include the control strategies of the MicroGrid, types of load in the MicroGrid and inertia constants of the motor. The control schemes of the MicroGrid are PQ control, Droop Control and Frequency/Voltage control. The micro sources and the flywheel use PQ control only when the MicroGrid is operated in grid-connected mode. After disconnection of the MicroGrid from the main network, the control of the flywheel is switched from PQ control to Droop control or Frequency/Voltage control. The types of load in the MicroGrid are fixed PQ, impedance and motor. The absorbed power of the fixed PQ load is constant at all time. The power taken by impedance loads is a function of the frequency and voltage of the MicroGrid. The motors are rotating machines with a value of inertia.

To indicate the stability of the MicroGrid, a critical clearing time (CCT) is used in the study. The CCT is defined as a maximum fault clearing time, such that when the fault is cleared before this value the MicroGrid is stable. If the CCT is larger than the actual fault clearing time, the MicroGrid is determined to be stable; otherwise, the MicroGrid is unstable. The difference between these two values is an index of stability of the MicroGrid. The larger the CCT is, the higher the stability of the MicroGrid has. The CCT of the MicroGrid is calculated from the time domain off-line simulations by using electrical power system simulation software, PSCAD/EMTDC.

4.1 Assumptions

In this study, a simple MicroGrid is implemented in PSCAD/EMTDC and used, as shown in Figure 8. It is assumed that the fault level at the 20kV main distribution network is 100MVA, with a X/R ratio of 5. One transformer (400kVA, 20/0.4kV) is installed at the substation between the main network and the MicroGrid. The impedance of the transformer is 0.01+j0.04 p.u. The MicroGrid consists of a flywheel and a feeder. The flywheel is connected to the 0.4kV busbar, which is near to the substation. The capacity of the flywheel is 200kW (assuming the flywheel supplies 4MJ energy for 20 seconds continuously). The feeder is connected to a micro source and three loads (Load 1, Load 2 and Load 3) through 400 meters of ALXLPE twisted cable ($4\times120\text{mm}^2$). The impedance of the cable is 0.325+j0.073 ohms per kilometre [6]. The capacity of the micro source is 30kW. Load 1 is a fixed PQ load with capacity of 30kW. Load 2 is an impedance load with capacity of 50kW. Load 3 is a squirrel induction motor load with capacity of 120kW. The parameters of the motor are as follows [7]:

- Rated capacity: 120 [kW]
- Rated voltage: 0.4 [kV]
- No. of Poles: 4;
- Power factor: 0.8100;
- Stator resistance ($\boldsymbol{R_s}$): 0.0267 [p.u];
- Stator unsaturated leakage reactance ($\boldsymbol{X_s}$): 0.0990 [p.u];
- Mutual unsaturated reactance ($\boldsymbol{X_m}$): 3.7380 [p.u];
- Rotor resistance ($\boldsymbol{R_r}$): 0.0126 [p.u];

- Rotor unsaturated mutual reactance (X_r): 0.0665 [p.u];
- Inertia constant (H): 0.6600 [kW sec./kVA].

4.2 Simulation results

(1) Impact of control strategies of the flywheel

Based on the STATCOM-BES representation of the MicroGrid (shown in Figure 8), the impact of three control strategies (PQ control, Droop control and Frequency/Voltage control) of the flywheel on the stability of the MicroGrid is investigated. The micro source uses PQ control at all times. The flywheel uses PQ control when the MicroGrid is operated in grid-connected mode. During islanded mode of the MicroGrid, the control scheme of the flywheel use PQ control, Droop control and Frequency/Voltage control separately. In all cases, circuit breaker CB2 is tripped at 10 seconds without a fault on the network. Following the trip of CB2, the MicroGrid is disconnected from the main network and operated in islanded mode. The types of Load 1, Load 2 and Load 3 are fixed PQ, with a total capacity of 200kW. The dynamic performances of the MicroGrid are demonstrated in PSCAD/EMTDC and shown in Figures 9, 10 and 11.

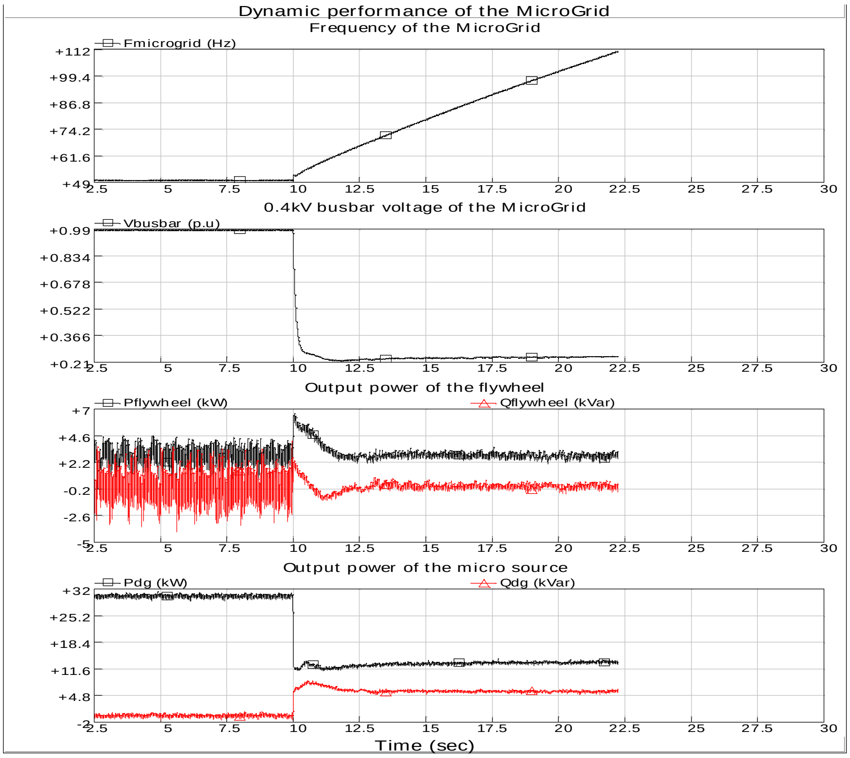

Figure 9 Dynamic performance of the MicroGrid
(During islanded mode, the flywheel uses PQ control)

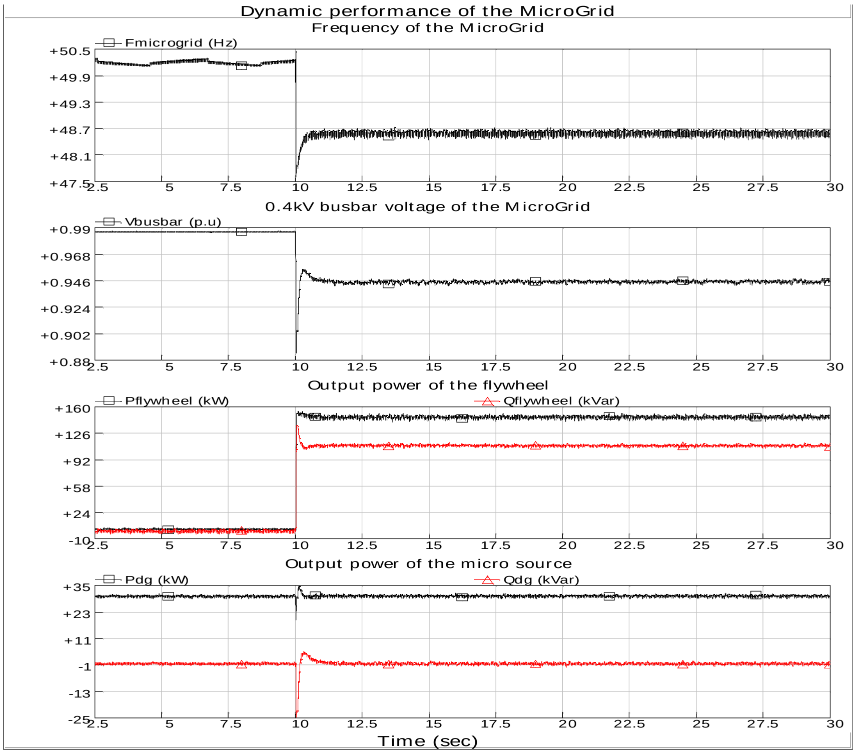

Figure 10 Dynamic performance of the MicroGrid
(During islanded mode, the flywheel uses Droop control)

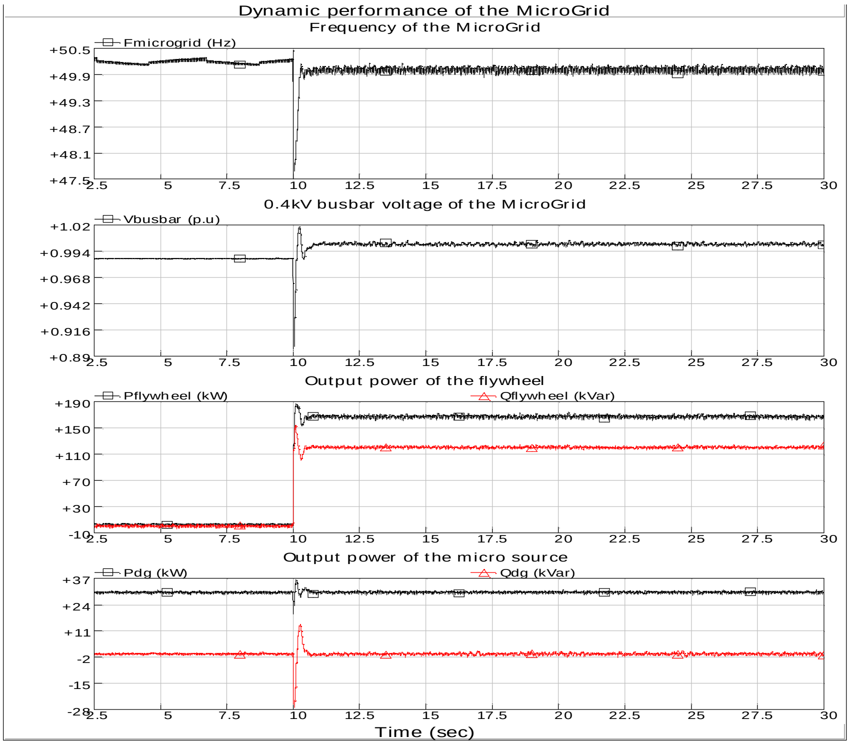

Figure 11 Dynamic performance of the MicroGrid
(During islanded mode, the flywheel uses Frequency/Voltage control)

Figure 9 shows the dynamic performance of the MicroGrid when the flywheel uses PQ control during islanded mode. The control schemes of both the micro source and the flywheel are PQ control. Obviously, the flywheel makes no contribution to the stability of the MicroGrid. The frequency and voltage of the MicroGrid are unstable after disconnection of the MicroGrid from the main network. The frequency rises and the voltage of the MicroGrid collapses so that the MicroGrid can not be operated in islanded mode.

Figure 10 shows the dynamic performance of the MicroGrid when the flywheel uses Droop control during islanded mode. After disconnection of the MicroGrid from the main network, the output of the micro source is still retained at 30kW. However, the output of flywheel is changed from zero to the value of 149kW+j110kVar, according to the droop settings ($\boldsymbol{R}_f = 4\%$ and $\boldsymbol{R}_v = 10\%$) of Droop control. At last, the frequency and voltage of the MicroGrid drop to their steady state values (48.35Hz and 0.946p.u) associated with the droop characteristics. The MicroGrid is stable.

Figure 11 shows the dynamic performance of the MicroGrid when the flywheel uses Frequency/Voltage control during islanded mode. The frequency and voltage of the MicroGrid are both brought back to the normal values (50Hz and 1.0p.u). The power qualities of the MicroGrid using Frequency/Voltage control are better than using Droop control. The MicroGrid is also stable. However, it should be noted that the energy export of the flywheel using Frequency/Voltage control is larger than when using Droop control.

(2) Impact of types of the load

To check the impact of types of load on the stability of the MicroGrid, three types of load (fixed PQ load, impedance load and motor load) in the MicroGrid are tested in PSCAD/EMTDC. A three-phase fault was applied at F1 at 10 seconds. Following the fault, the MicroGrid was disconnected from the main network and operated in islanded mode when the circuit breaker CB2 was open. The control scheme of the micro source is PQ control at all times. The flywheel uses PQ control in grid-connected mode. During islanded mode, the control strategy of the flywheel is switched from PQ control to Frequency/Voltage control.

(a) Fixed PQ load

In this case, the types of loads (Load 1, Load 2 and Load 3) in the MicroGrid are fixed PQ, with a total capacity of 200kW. Figure 12 shows the dynamic performance of the MicroGrid subjected to a three-phase fault at F1 with an extreme duration time (5 seconds). It can be seen that the MicroGrid has no stability problem. During the fault, the voltage of the MicroGrid drops almost to zero. The frequency of the MicroGrid, shown in Figure 12, is measured from the phase angle change of the MicroGrid 400V busbar voltage through a phase-locked-loop (PLL). The frequency of the MicroGrid is a function of the active power balance between generation and demand in the MicroGrid. During the fault, the generation exporting from the micro source and flywheel is larger than the demand absorbed by the fixed PQ load. Thus, the frequency of the MicroGrid increases continuously due to the extra active power in the MicroGrid. Although the frequency of the MicroGrid is high during the fault, it has no influence on the load as the absorbed power of the load is zero during the fault. After the fault, the voltage of the MicroGrid is brought back to normal immediately. The frequency of the MicroGrid decreases and returns to normal slowly. The MicroGrid is stable. It should be noted that the fault duration time of 5 minutes is not realistic.

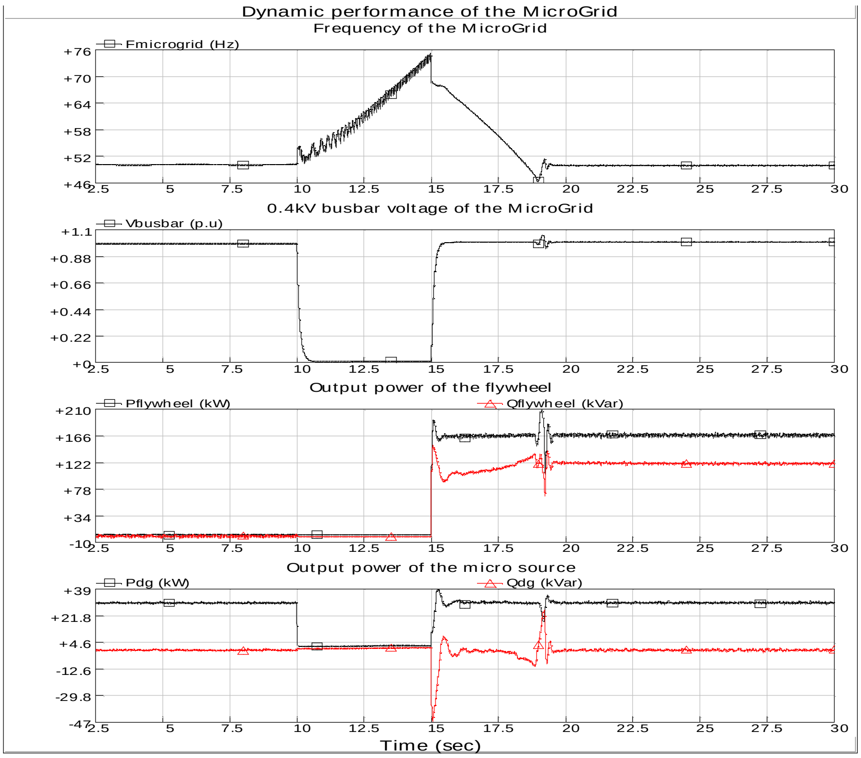

Figure 12 Dynamic performance of the MicroGrid for the type of fixed PQ load

(b) Impedance load

For the impedance loads (Load 1, Load 2 and Load 3, with a total capacity of 200kW) in the MicroGrid, the dynamic performance of the MicroGrid is similar to that shown in Figure 12. The MicroGrid has also no stability problem.

(c) Motor load

In this case, the type of load in the MicroGrid is a squirrel cage induction motor, with a total capacity of 200kW. Figure 13 shows the dynamic performance of the MicroGrid for the fault at F1 with a clearing time of 30ms. During the fault, the speed of the motor decreases. After the fault, it can be seen that the speed of the motor is reduced continuously, and then, the motor stalls. The motor tends to absorb large reactive power from the MicroGrid during stalled operation. The voltage of the MicroGrid collapses while the frequency of the MicroGrid is normal. The MicroGrid is unstable. This is a typical transient voltage instability (voltage collapse) of the MicroGrid.

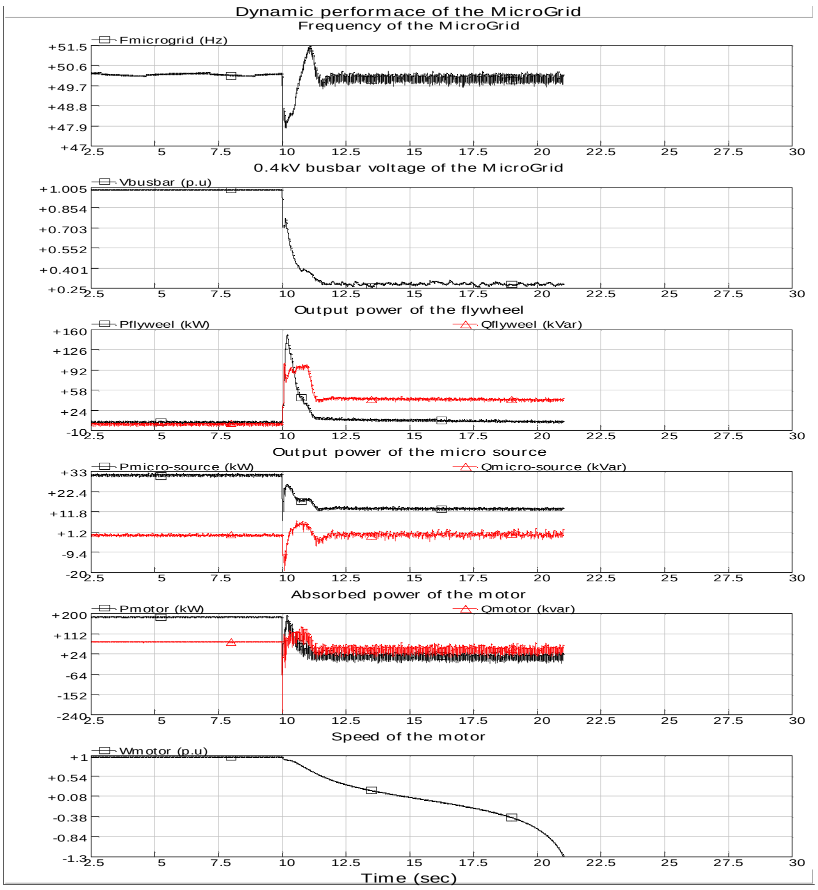

Figure 13 Dynamic performance of the MicroGrid for the type of motor load

Simulation results of the types of fixed PQ load, impedance load and motor load show that the stability of the MicroGrid mainly depends on the motor load in the MicroGrid. The larger the capacity of the motor is in the MicroGrid, the lower the stability of the MicroGrid has. In the motor load case, instability of the MicroGrid is usually due to voltage collapse.

(3) Impact of locations of the fault

In this study, the total capacity of load in the MicroGrid is 200kW. A mixed type loads (Load 1, 30kW fixed PQ load, 15%; Load 2, 50kW impedance load, 25%; and Load 3, 120kW motor load, 60%) in the MicroGrid is used. A three-phase fault is applied at three different places: F1, F2' and F3 separately, as shown in Figure 8.

Figure 14 shows the CCT characteristics of the MicroGrid for three locations of the faults. The capacity of the motor load is changed from 50kW to 120kW.

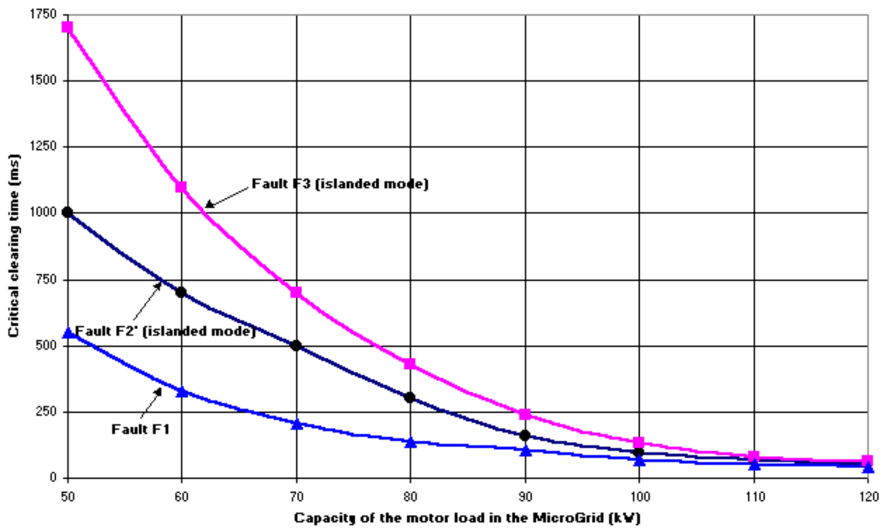

Figure 14 CCT characteristics of the MicroGrid for faults F1, F2' and F3

For fault F1, the MicroGrid is disconnected from the main network after the fault. The MicroGrid is operated in islanded mode when the circuit breaker CB2 is open. The control scheme of the flywheel is switched from PQ control to Frequency/Voltage. The control scheme of the micro source is still PQ control. Simulation results produced in PSCAD/EMTDC indicate the MicroGrid has a stability problem. The CCT of the MicroGrid mainly depends on the characteristic of the motor load in the MicroGrid. The stability of the MicroGrid will decrease when the capacity of the motor load in the MicroGrid increases.

For faults F2' and F3, the circuit breaker CB2 is closed at all times if the MicroGrid is operated in grid-connected mode before the fault. After the fault, the MicroGrid is still operated in grid-connected mode. The control schemes of the micro source and flywheel are still PQ control. Simulation results show that the MicroGrid has no stability problem. In these cases, the main network can supply enough active and reactive power to compensate the MicroGrid. The voltage and frequency of the MicroGrid can be brought back to the normal values. The speed of the motor is also able to restore to normal. However, the MicroGrid may be unstable when the MicroGrid is operated in islanded mode before the fault. The flywheel has to compensate the extra power unbalance between generation and demand in the MicroGrid. The characteristic of the flywheel will strongly influence the stability of the MicroGrid. For a given capacity (200kW) of the flywheel, the CCT characteristics of the MicroGrid are calculated in PSCAD/EMTDC and shown in Figure 14.

Considering the stability of the MicroGrid at three different locations of the faults (F1, F2' and F3), the fault at F1 is the severest case to maintain the stable operation of the MicroGrid after the fault. For fault F1, the MicroGrid will be disconnected from the main network and operated in islanded mode. The control strategy of the flywheel is switched from PQ control to Frequency/Voltage control. The CCT values of the MicroGrid are quite low when a fault happens at F1. Therefore, to maintain the stability of the MicroGrid after the fault, transition to islanded mode, fast protection (e.g. differential protection) is needed for fault F1.

(4) Impact of inertia constants of the motor

In this study, similarly, a mixed type of loads (Load 1, 15% fixed PQ; Load 2, 25% impedance; and Load3, 60% motor) is also used in the MicroGrid. The capacity of the motor load is changed from 50kW to 120kW. A three-phase fault is applied at F1 on the main network (see Figure 8). After the fault, the MicroGrid is operated in islanded mode. The control scheme of the micro source is PQ control. The control strategy of the flywheel is switched from the PQ control to Frequency/Voltage control. Figure 15 shows the CCT characteristics of the MicroGrid for different inertia constants of the motor.

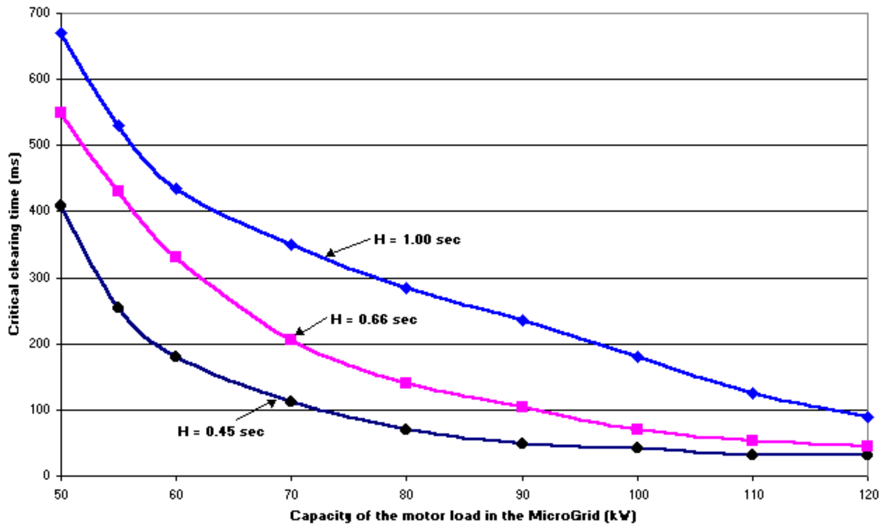

Figure 15 CCT characteristics of the MicroGrid for different inertia constants of the motor in the MicroGrid

In Figure 15, the three curves correspond to the three inertia constants (H = 0.45sec., 0.66se. and 1.00sec.) of the motor. It can be seen that the inertia constant of the motor has a significant influence on the stability of the MicroGrid. The stability of the MicroGrid is high when the inertia constant of the motor is large.

5. Improvement of the stability of the MicroGrid

The investigation of the stability of the MicroGrid indicates the main issues influencing the stable operation of the MicroGrid are the control strategy of the flywheel and the type of load used in the MicroGrid, particularly motor load. The control scheme of the flywheel is PQ control when the MicroGrid is operated in grid-connected mode. During islanded mode, the control of the flywheel needs to be switched from PQ control to Droop control or Frequency/Voltage. The motors will be stalled when their speeds decrease significantly. The motors will be unstable when the operating point of the motor is beyond its pull-out point, corresponding to the maximum electrical torque of the motor. The motors absorb large reactive power from the MicroGrid during stalled operation. Thus, the voltage of the MicroGrid will collapse. However, the stability of the MicroGrid can be improved by using undervoltage load shedding to trip some less important motor loads in the MicroGrid. Undervoltage load shedding method is a traditional approach to improve the stability of conventional power systems. The undervoltage load shedding measure can be easily implemented on the motor loads in the MicroGrid. The motor loads are divided into a number of groups according to their importance to the customers. Then undervoltage load shedding devices, with their setting values (e.g. V< 0.7p.u), are installed on the motor loads in the unimportant group. If the voltage of the MicroGrid is below 0.7 per unit, the undervoltage load shedding devices trip the unimportant motor loads automatically with a time delay of 150ms.

In this study, a simple MicroGrid model (see Figure 8) is used. A three-phase fault was applied at F1. The loads in the MicroGrid comprise Load 1, Load 2 and Load 3. Load 1 is a fixed PQ load, with a capacity of 30kW. Load 2 is an impedance load, with capacity of 50kW. Load 3 is a squirrel motor load. The inertia constant of the motor is 0.66 seconds. The function of undervoltage load shedding is installed on Load 3. Based on three capacities of the motor load (80kW, 100kW and 120kW), the improvement of the stability of the MicroGrid is investigated using the undervoltage load shedding method. The CCT characteristics of the MicroGrid are calculated in PSCAD/EMTDC. Figure 16 shows the stability improvement of the MicroGrid by applying the undervoltage load shedding measure on the motor load.

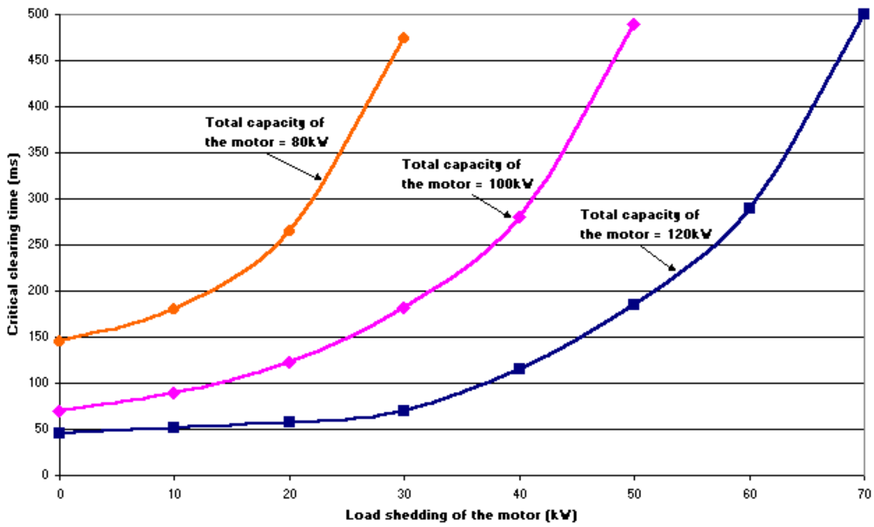

Figure 16 Stability improvement of the MicroGrid through using undervoltage load shedding on the motor load in the MicroGrid

From Figure 16, the results show that the stability of the MicroGrid is improved significantly by using the undervoltage load shedding on the motor load. For a 120kW motor in the MicroGrid, the CCT of the MicroGrid increases from 45ms to 500ms when the capacity of the motor load is shed varies from zero to 70kW. For a 100kW and a 80kW motors, the improvement of stability of the MicroGrid has similar results. Therefore, the larger the capacity of the motor load that is shed in the MicroGrid, the higher the stability of the MicroGrid.

6. Conclusions

With increasing penetration levels of the DGs, a number of MicroGrids will exist in the distribution network system in the future. The safety and stability of the MicroGrid are becoming more and more important. The unique nature of the MicroGrid requires that the MicroGrid is stable operating in both grid-connected mode and islanded mode. The stable operation of the MicroGrid can be maintained through control of the flywheel and using load-shedding measures on the loads in the MicroGrid. The control schemes of the flywheel are PQ control, Droop control or Frequency/Voltage control. The undervoltage load shedding method can be used to improve the stability of the MicroGrid.

Three control schemes (PQ control, Droop control and Frequency/Voltage control) of the MicroGrid are tested in PSCAD/EMTDC. The control scheme of the micro source is PQ control at all times. The control strategy of the flywheel is PQ control only when the MicroGrid is operated in grid-connected mode. During islanded operation of the MicroGrid, the control of the flywheel has to be switched from PQ control to Droop control or Frequency/Voltage. The major factors influencing the stability of the MicroGrid are the control strategies of the flywheel, types of load in the MicroGrid and inertia constants of the motor load.

The flywheel uses PQ control only when the MicroGrid is operating in grid-connected mode. The active and reactive power outputs of the flywheel are then fixed at the constant values (e.g. zero). After disconnection of the MicroGrid from the main network, during islanded mode, the control of the flywheel should be switched from PQ control to Droop control or Frequency/Voltage control. The output powers of the flywheel are regulated automatically according to the predetermined droop characteristics (Droop control) or errors of the frequency and voltage of the MicroGrid (Frequency/Voltage control).

Three types of load (fixed PQ load, impedance load and motor load) in the MicroGrid are investigated. Simulation results show that the fixed PQ and impedance loads have no effect on the stability of the MicroGrid. The motor load introduces instability to the MicroGrid as it absorbs large amounts of reactive power from the MicroGrid during its stalled operation. The instability mechanism of the MicroGrid is likely to be voltage collapse.

Three different locations (F1, F2' and F3) of the fault are also investigated. The fault at F1 is the severest case to maintain the stable operation of the MicroGrid. For fault F1, the MicroGrid is disconnected from the main network and operated in islanded mode after the fault. The control strategy of the flywheel is switched from PQ control to Droop control or Frequency/Voltage control during the islanded operation. The CCTs of the MicroGrid have the lowest values when the fault occurs at F1. To maintain the stability of the MicroGrid during the transition to islanded mode, fast protection (e.g. differential protection) is thus needed.

The inertia constants of the motor load have significant influence on the stability of the MicroGrid. Motors with high inertia constants used in the MicroGrid will enhance the stability of the MicroGrid.

The stability of the MicroGrid can be improved by using undervoltage load shedding on these motors which are less important loads in the MicroGrid. The larger the capacities of motors that are shed in the MicroGrid, the higher the stability of the MicroGrid.

7. Acknowledgement

The author would like to thank the support received from the European Union as a part of project NNE5-2001-00463 "MICROGRIDS", contract ENK5-CT-2002-00610.

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