

Microgrid Control Strategies

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List of Symbols

DGs	Distributed Generators
PV	Solar Photovoltaic
MPPT	Maximum Power Point Tracking
VSDs	Voltage Source Converters
PC	Point of Connection

1. Introduction

A microgrid can be considered as a small grid based on distributed generators (DGs). Generally, the microgrid consists of renewable energy based DGs and combined heat and power plants. It can supply power to small/medium sized urban housing communities or to large rural areas. It can be an economical, environment friendly and reliable way to supply power at distribution levels. The sources in a microgrid can be mainly classified as dispatchable or nondispatchable in terms of power flow control [1][2]. The output power of dispatchable sources such as microturbines, fuel cells and bio-diesel generators can be controlled to maintain the desired system frequency and voltage in an isolated microgrid. However, nondispatchable sources such as wind and PV, in which the output power depends on the environmental conditions, are expected to be mainly controlled on the basis of maximum power point tracking (MPPT).

The sources in a microgrid can also be classified as inertial and non-inertial depending on the way they are connected to the system. For example, a diesel generator and a hydro generator are inertial sources since they include synchronous generators with their rotating inertial masses. On the other hand, the sources connected through converters such as PV, fuel cell and batteries are non-inertial since power output through these DGs can be changed instantaneously.

A microgrid can operate either in grid connected or islanded mode. The available power of all DG units should meet the total load demand for islanded operation; otherwise load shedding need to be implemented. The control of real and reactive power output of the sources is essential to maintain a stable operation in a microgrid, especially when it operates in the islanded mode. The frequency

and voltage in an islanded (autonomous) microgrid should be maintained within predefined limits. The frequency variations are very small in strong grids; however, large variations can occur in autonomous grids [3]. Thus power management strategies are vital for an autonomous microgrid in the presence of few small DG units, where no single dominant energy source is present to supply the energy requirement [4]. Also, fast and flexible power control strategies are necessary to damp out transient power oscillations in an autonomous microgrid where no infinite source available [5].

2. Microgrid islanding control

2.1 Peer-to-Peer Strategy

Peer-to-peer strategy means every DS (separation device) has the same status in microgrid. It enables microgrid to “plug and play”. “Plug and play” means that microsources can be added to the microgrid without changes to the control and protection of units that are already part of the system. Peer-to-peer strategy results that each microsource controller must be able to respond effectively to system changes without requiring data from other sources or locations. This improves microgrid reliability and reduces system cost.

Peer-to-peer strategy can be implemented by droop control which requires all microsources exhibit basically identical external characteristic to coordinated control the entire microgrid system. There are two control methods based on the droop control, f-P/Q-V droop control and P-f/V-Q droop control. f-P/Q-V droop control produces reference active power and reactive power by measured system frequency and DG output voltage amplitude, while P-f/V-Q droop control produces output frequency and voltage amplitude by measured output active power and

reactive power. And P-f/V-Q control is more wide application than f-P/Q-V in peer-to-peer strategy [6]

2.2 Master-Slave Strategy

Master-slave strategy refers to that there is a master controller in microgrid while others are slave controllers which obey the regulation of master controller with communication connection. When connected with the bulk grid system which could stable system frequency, microgrid needs no frequency regulation. It permits PQ control on all DGs in microgrid to insure microsources' high efficiency and economy. When isolated from the bulk grid system, the master controller in microgrid should take the responsibility of maintain system frequency, voltage and also power balance separately by V/f control and regulation its own output.

If the master controller uses V/f control in mater-slave strategy, it could be classified as single master control and multi-master control. Single master control has only one large-capacity microsource as master controller microsource to avoid multiple V/f controlled microsource confusion. When there's a reasonable step control scheme which next step master control microsource takes V/f control continuously while the previous step master control microsource's output gets the upper limit and transfers to PQ control, multimaster control could have multiple master controllers.

As master DG in the master-slave strategy is equivalent to infinite bus satisfying changing load demand of entire microgrid, it absorbs rest power when load demand is less than generation, and provides more power when load demand

is more than generation. Only enough large-capacity storage equipment or DG with enough storage equipment can be the master controller because DG of this control strategy must satisfies the changing demand of load. In addition, especially for multi-master control mode, it requires high on the communication connection of master unit and slave unit [6].

3. Control Methods for Microgrid

From the view of the bulk grid system, microgrid is an aggregation unit as a generation or load. On the other hand, microgrid is a power system operates autonomously, supplying reliable and high quality electric power from the view of customer side. Therefore, a good performance microgrid control and management system is needed. The purposes of microgrid control are as follows [6]:

- New microsources can be added to the system without modification of existing equipment.
- The microgrid can choose operation point autonomously.
- The microgrid can connect to or isolate itself from the grid in a rapid and seamless fashion.
- Reactive and active power can be independently controlled.
- Voltage sag and system imbalances can be corrected.
- The microgrid can meet the grid's load dynamics requirements.

3.1 DG interface inverter system

There are two basic classes of microsources: DC sources, such as fuel cells, photovoltaic cells and battery storage; and AC sources such as microturbines, which need to be rectified. In both cases, the DC voltage that is produced is converted using a voltage source inverter. Figure 4.1 is the DC DG interface inverter system, and Figure 4.2 is the AC DG interface back-to-back inverter system.

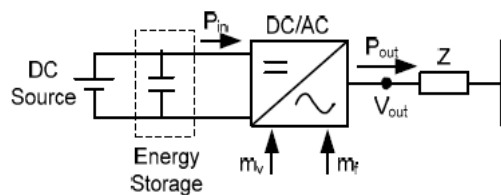


Figure 1 DC DG interface inverter system

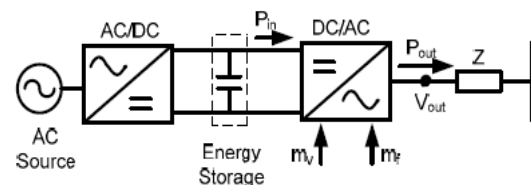


Figure 2 AC DG interface inverter system

Different from the generation connecting directly with the grid, the output voltage and current frequency of DG interface inverter system is determined by inverter control strategy, and the voltage amplitude is joint determined by capacitor voltage amplitude of DC side and inverter control strategy. Another important difference is that the storage energy of capacitor is far less than the rotation storage energy of rotate shaft. It means there should be storage equipment in microgrid as little inertia. Therefore, choosing the reasonable control strategy is of great importance to the normal operation of DG with inverter interface [6].

3.2 DG interface inverter control

3.2.1 V/f Control

V/f control is similar to secondary frequency regulation of traditional power system. The purpose of V/f control is to insure the constant of both DG output

voltage amplitude and frequency. The theory of V/f control is to transversely adjust the droop curve itself, as in Figure 4.3 [6].

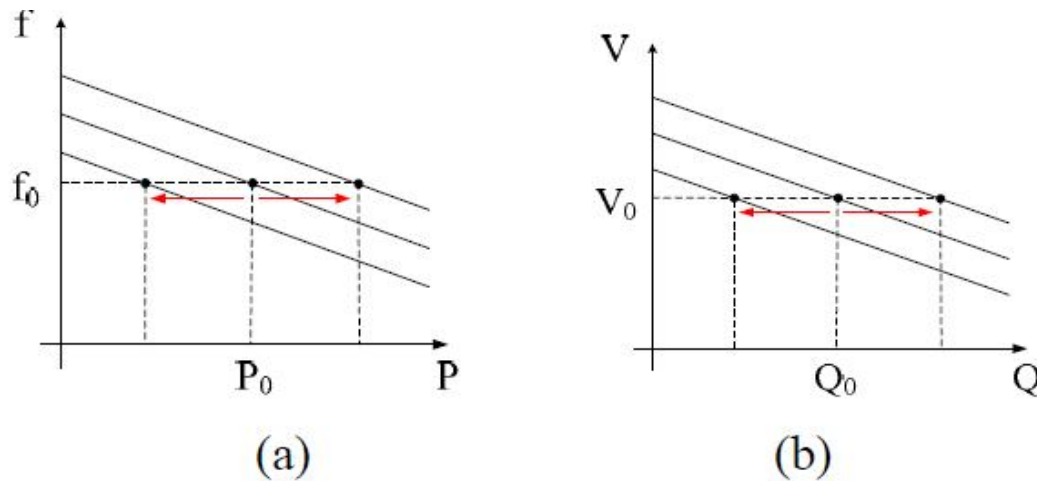


Figure 3. The theory of V/f control: (a) frequency droop characteristic and (b) voltage droop characteristic

3.2.2 Real and Reactive Power Sharing in a Microgrid

As mentioned before, both inertial and non-inertial sources can be present in a hybrid microgrid. These different types of sources can connect or disconnect to the network at any time. However, the dynamic behavior of inertial and non-inertial sources is different. Micro-sources such as solar photovoltaic (PV) and fuel cell produce power at dc voltage. Therefore, voltage source converters (VSCs) are required to convert dc voltage into ac voltage. These DGs connected through converters can respond very quickly to changes in real and reactive power demands. On the other hand, the response of a synchronous machine based DGs will be much slower.

Non-dispatchable sources such as solar and wind may not be available all the time. However, when they are available, it is better to harness as much power

as possible by controlling them through MPPT. However at the same time, dispatchable sources may also be connected to an autonomous microgrid. Therefore, the power management and dynamic interaction must be investigated.

3.2.3 Droop Control

In a conventional frequency droop control method, each DG in the system uses its real power output to set the frequency at its point of connection (PC). Thus, the system frequency will act as the communication signal amongst the DGs to share the real power appropriately. The conventional frequency droop characteristic can be expressed as [7][8][9],

$$f^* = f_r + m *(0.5 P_r - P^*) \quad (\text{eq.1})$$

Where:

f^* : the instantaneous frequency setting for the DG considered,

f_r : the rated frequency of the system,

P_r : the rated real power output of the DG,

P^* : the measured actual real power output of the DG,

And m : the droop coefficient.

The frequency droop characteristic in (eq.1) is shown in Figure 4. In this figure, isochronous frequency range is denoted using the allowable minimum and maximum system frequency (i.e., f_{min} and f_{max} respectively). When a DG operates in frequency droop control mode, the system frequency can change between f_{min} and f_{max} depending on the value of real power output. A slower

outer control loop can be used to shift the droop line vertically by changing the rated frequency to restore the steady state frequency to the nominal value (i.e., load frequency control).

The droop coefficient m can be calculated using defined values of minimum and maximum frequency and the rated real power output of the DG. When few DGs with different capacities are operating in the frequency droop control, each generator may have a unique value for the droop coefficient, m . The different droop coefficients allow sharing the total load power requirement among the DGs according to a predefined ratio. For example, the total load power requirement of a microgrid can be shared proportional to rated real power output of each DG.

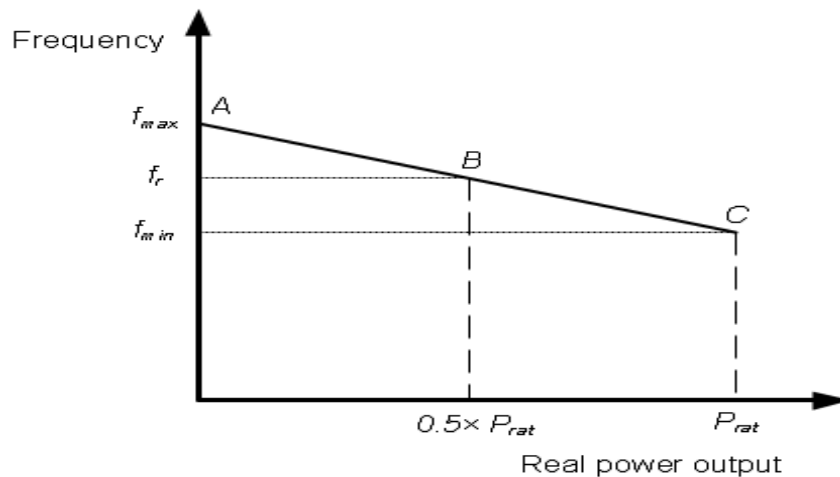


Figure 4 Frequency droop characteristic of a generator.

The output voltage magnitude of a DG can be controlled to change the reactive power supplied to a system. However, in the presence of a number of DGs, maintaining a voltage to a pre-defined value can cause the reactive power circulation amongst these DGs. This becomes more prevalent when the microgrid

has short line segments. This problem can be minimized by implementing voltage droop control in all the DGs. Also, the voltage droop control results in reactive load power sharing in the microgrid. The conventional voltage droop control characteristic can be given by [7][8],

$$V^* = V_r + n \cdot (0.5 Q_r - Q^*) \tag{eq.2}$$

Where

V^* : the instantaneous voltage magnitude setting for the DG,

V_r : the rated voltage of the microgrid system,

Q_r : the rated reactive power output of the DG,

Q^* : the measured actual reactive power output,

And n : the voltage droop coefficient.

The voltage droop characteristic given in (eq.2) is shown in Figure 5. In this figure, the minimum and maximum allowable voltages in the system are represented by V_{min} and V_{max} respectively. The voltage droop coefficient can be calculated using the rated reactive power output of the DG and the minimum and maximum voltage levels.

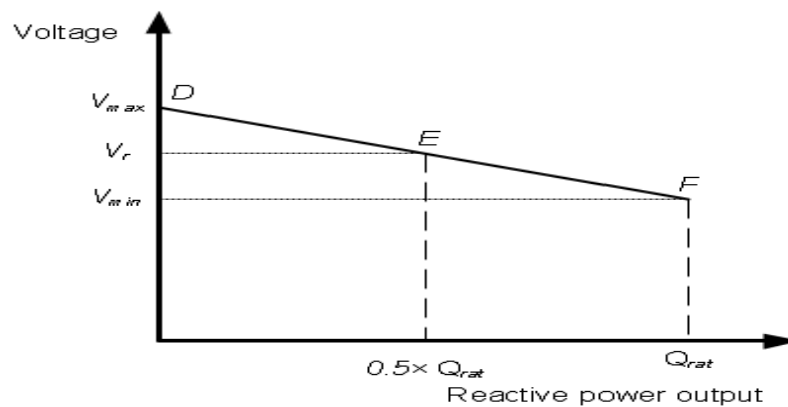


Figure 5 Voltage droop characteristic of a generator.

The frequency and voltage droop controls in (eq.1) and (eq.2) are employed in each dispatchable DG to maintain the microgrid frequency and voltage within the specified standards. It also results in proper power sharing in the microgrid. Moreover, as mentioned earlier, the non-dispatchable DGs in the microgrid are operated in MPPT mode. In this report, the interaction between different types of DGs is investigated considering transient response and dynamic load power sharing in an autonomous microgrid. It is assumed that the microgrid can consist of only inertial sources or only non-inertial sources or both. The synchronization of DGs into the microgrid is also considered in the analysis.

4. Integral to Droop Line Control

To improve the real power sharing amongst these DGs further, a modified droop control characteristic is proposed for a microgrid containing both inertial and non-inertial DGs. This ensures that the change of load is proportionally picked up by all the DGs. The proposed droop control is called as the *integral to droop line* and is only implemented on the converter interfaced DGs in the microgrid. It has been shown in [10] that a high gain droop control is preferable for accurate power sharing, but it can cause the system to be unstable, especially during transients. In the proposed droop control, the steady state and transient gains are set independently using an integral controller. Thus, system can respond with a medium gain during a transient event but reach a steady state point corresponding to a high gain. Once an appropriate time constant is selected for the integrator, converter interfaced DGs can respond in a similar manner as inertial DGs. This results in a smooth transition to steady state. To implement the proposed droop, the frequency droop is modified by introducing an integration process to reach the steady state frequency droop point in the system. The error between calculated

droop frequency in (eq.1) and frequency at the PC is passed through an integrator to force the operating frequency of DG to reach the steady state droop point within a defined time period. The proposed method not only has the ability to minimize transient instability but also ensures proper power sharing amongst DGs. The integral to droop line control is given by

$$fd = f^* + \int (f^* - f_{pc}) dt \quad (\text{eq.3})$$

Where

fd : the modified droop frequency setting for the DG,

f^* : droop given in (eq.1),

and f_{pc} : the measured frequency at PC (point of connection) [6].

5. Microgrid connecting control

From the prospective of microgrid, when connecting with the grid, microsource maintaining high level of output can make high efficiency. Therefore, microsources can be all set PQ control strategy when connecting with the grid. When microgrid isolated from the grid, master microsource transfers from PQ control to V/f control to provide frequency and voltage support to microgrid, while other microsources are still PQ controlled. The regulation of this control strategy can only involve microsource's output power, but not the transfer power between microgrid and the bulk grid. It leaves the grid to undertake the unbalance power in microgrid while connection. From the prospective of the grid, microgrid would be better acting as a constant load to reduce the difficulty of control. Constant transfer power control can be adopted at this situation. The purpose of constant transfer power control is to make the absorption power P and Q from the grid to microgrid

(feeder flow) constant. When there's unplanned islanding, all microsources in microgrid turns to droop control, sharing load based on their droop characteristic and providing voltage and frequency support for microgrid [6].

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