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# Research on Simulation Model for Integration of Controller and Inverter

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***Abstract***

*The simulation models of controller and inverter provided by micro-grid simulation software are separate ones. Fewer models develop in monotonous form and are complicated itself, physical meaning of each variable in the model is not clear. Simulation members are connected by a combination of series and parallel way, interaction between elements is not reflected or ignored, so the simulation results are distortion and less credibility which seriously hinder the application of Matlab/Simulink in micro-grid simulation. Considered various operating mode, used different coordinate transformation and the redefined voltage coordinates, an integrated simulation model of controller and inverter is designed which remove the influence of the electromagnetic coupling among the components. Simulation model is simplified so as to accelerate simulation speed. The model can be flexibly set in different operating modes and different modules in Matlab/Simulink which makes the operating mode of each micro-power be designed easier and more clearly. Results of micro-grid composed with integrated model can accurately reflect the variation of voltage, frequency, active power, reactive power etc. according to various disturbances in the various operating modes. Integrated model is demonstrated the effectiveness by results of the simulation ,which can also meet the requirements of micro-grid simulation*

***Keywords****: phasor control; micro power supply; interface; coordinate transformation; simulation model*

## 1. Introduction

Most of micro sources in a micro-grid are interfaced by power electronic inverters, the different types of micro sources use different interface [1-2]. Therefore, in the Matlab simulation software, different interfaces simulation models are needed to be builded. Even if the same connected point in different operating modes, the interface simulation model is different [3-4]. In order to maintain the micro-grid stability under the different modes, different control strategies are applied. The main strategies include constant power control (P/Q control), droop control (Droop control) and constant voltage/frequency control (V/f control) or a combination of the strategies or a improvement strategy [5-8]. Voltage and current information of the connection point measured by power electronics interface unit will be transferred to the central controller, then, the central controller in accordance with the selected strategy calculates how many power should be delivered in order to maintain voltage, frequency stability, therefore power electronic inverters need to be taken into account so as to combine interface controller and power electronic inverters, which facilitate the user design and simulation of the control strategy.

Currently, the simulation models of controller and inverter provided by micro-grid simulation software are separated ones. fewer models develop in monotonous form and are complicated itself, physical meaning of each variable in the model is not clear, systematic simulation member is connected by a combination of series and parallel way, interaction between elements is not reflected or ignored, so the simulation results are

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distortion and less credibility which seriously hinder the application of Matlab/Simulink in micro-grid simulation. Hence, a high-credibility integrated simulation model of controller and inverter to be needed. Furthermore, phasor control technology is mostly used among the interface control [9-10], so the paper summarily introduces phasor control technology, then designed integrated simulation model based on phasor control technology adapted to different operating modes which facilitate users modeling and simulation for power system and micro grid under the Matlab/Simulink.

## 2. Establish Phasor Control Microgrid Interfaces Model

With the development of power electronics, Phasor control is a new technology. Originally, it intended to meet the dynamic requirements of high modern AC speed control system. By using of rotating coordinate transformation and field-oriented control technology, The motor stator current is decomposed into excitation current and torque current, which simplify the dynamic mathematical model of AC motor, so controlling AC motor becomes as easy as DC ones. Its core technology is the use of reasonable coordinate transformation. Borrowing the spirit of phasor control, using different coordinate transformation and voltage oriented control technology, three kinds of interface models are designed which can apply in different modes of micro power and power system. According to different voltage oriented coordinate system where interface model will be divided into different kinds of models respectively based on dq0, aβ, rotating abc coordinate system. All interface models are conducted by using equivalent principle of coordinate transformation, namely: the synthetic phasor such as voltage, current, flux *etc*. of same interface model in different coordinate systems is constant, the transmission of power is also constant.

### 2.1. Micro-Grid Interfaces

Figure 1 shows a typical micro-power interface – voltage-based inverter [11]. In the figure: $u_{ca}$, $u_{cb}$, $u_{cc}$ and $u_{sa}$, $u_{sb}$, $u_{sc}$ respectively for threephase voltage of converter and three phase voltage of microgrid; $i_a$, $i_b$, $i_c$ for the current from inverter to network; C for inverter side capacitor; $i_{dl}$ for direct current provided from micro-power; $i_{dc}$ for the direct current from inverter to microgrids.

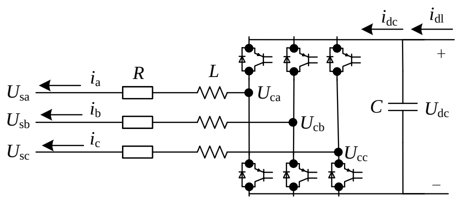



**Figure 1. Converter Structure**

Its equation of state:

$$L\frac{\mathrm{d}}{\mathrm{d}t}\begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} = \begin{bmatrix} u_{ca} \\ u_{cb} \\ u_{cc} \end{bmatrix} - R\begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} - \begin{bmatrix} u_{sa} \\ u_{sb} \\ u_{sc} \end{bmatrix} \quad (1)$$

$$C\frac{\mathrm{d}u_{dc}}{\mathrm{d}t} = i_{dl} - i_{dc} \quad (2)$$

In this paper, as an example, the establishment of micro-grid interface mode respectively in dq0, αβ, rotating abc coordinate system is based on Figure1.

## 2.2. Micro-Grid Interface Model in Dq0 Coordinate System

Firstly, dq0 coordinate system should be established. It is divided into three steps: the first step: the abc stationary coordinate system is converted to a stationary aβ0 coordinate system, the second step: the aβ0 coordinate system into a rotating coordinate system dq0. The third step: re-directed dq0 coordinate system the selected coordinate system for abc system converting to aβ0 system is shown in Figure 2(a). Coordinate transformation relationship is below：

$$\begin{bmatrix} u_\alpha \\ u_\beta \\ u_0 \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \end{bmatrix} \begin{bmatrix} u_a \\ u_b \\ u_c \end{bmatrix} \tag{3}$$

The selected coordinate system for aβ0 coordinate system converting to dq0 system is shown in Figure 2(b), d, q axis and the synthesized phasor F are rotating at the grid angular speed, component $u_d$, $u_q$ are of the same length. a, b axis is stationary, the angle φ between the a-axis and the d-axis varies over time, therefore, the length of component of F in a, b axis is also varies over time, it corresponds to the instantaneous value of the AC voltage. Obviously, the relationship between $u_\alpha$, $u_\beta$, $u_0$ and $u_d$, $u_q$, $u_0$ is equation (4):

$$\begin{bmatrix} u_d \\ u_q \\ u_0 \end{bmatrix} = \begin{bmatrix} \cos\varphi & \sin\varphi & 0 \\ -\sin\varphi & \cos\varphi & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} u_\alpha \\ u_\beta \\ u_0 \end{bmatrix} \tag{4}$$

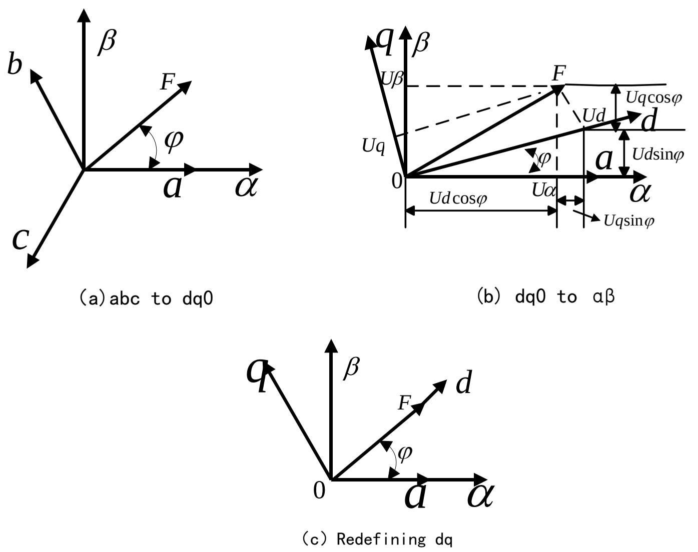



**Figure 2. Coordinate Transformation**

In order to realizing de-coupled control of active and reactive power transferred between the grid and micro-power, grid voltage oriented phasor control scheme is often used in interface of micro-power and power system. The direction of the grid voltage synthesis vector is the same as d axis of dq0 coordinate system, so in the Figure 2(b) phasor F direction is defined as a new d-axis, counterclockwise direction ahead of the d-axis by 90° for the q axis. Thus completes the build dq0 coordinate system.

According to equation (3) and (4) , formula (1) $i_{abc}$, $u_{cabc}$, $u_{sabc}$ can be transformed into the following Figure2(b) coordinate system, equation of state of the interface can be changed to the equation(5):

$$\begin{cases} pi_{\mathrm{d}} = \dfrac{1}{L}\left(u_{\mathrm{cd}} - Ri_{\mathrm{d}} - \omega Li_{\mathrm{q}} - u_{\mathrm{sd}}\right) \\ pi_{\mathrm{q}} = \dfrac{1}{L}\left(u_{\mathrm{cq}} - Ri_{\mathrm{q}} + \omega Li_{\mathrm{d}} - u_{\mathrm{sq}}\right) \end{cases} \tag{5}$$

Obviously, during the aβ0 system to dq0 system conversion process, more measured or calculated the value of φ is required by using converted matrix (4), phase locked technology is also required, which make more trouble in the use of it to design or simulate. The model need to be further simplified, the second model following in this paper can be used.

### 2.3. Micro-Grid Interface Model in Aβ Coordinate System

Firstly, aβ coordinate system should be established. It is divided into two steps: the first step: the stationary abc coordinate system is converted into a stationary aβ coordinate system, then phasor synthesized; the second step: Orientation dq coordinates.

The selected coordinate system for aβ0 coordinate system converting to dq0 system is shown in Figure 2(a). In accordance with equivalent principle of coordinate transformation, the conversion matrix is the equation (6):

$$\begin{bmatrix} u_{\alpha} \\ u_{\beta} \end{bmatrix} = \frac{2}{3}\begin{bmatrix} 1 & -\dfrac{1}{2} & -\dfrac{1}{2} \\ 0 & \dfrac{\sqrt{3}}{2} & -\dfrac{\sqrt{3}}{2} \end{bmatrix}\begin{bmatrix} u_{\mathrm{a}} \\ u_{\mathrm{b}} \\ u_{\mathrm{c}} \end{bmatrix} \tag{6}$$

The resultant of synthesized phasor is calculated as follows:

$$|F| = \sqrt{u_{\alpha}^2 + u_{\beta}^2}$$
$$\tan\varphi = \frac{u_{\beta}}{u_{\alpha}} \tag{7}$$

The design of micro-power system interface models is based on the grid voltage oriented phasor control scheme, which selecting synthesized phasor F is d-axis direction, a counterclockwise direction 90° ahead of the d-axis is the q-axis. as fig 2(c) shows. Then coordinate $u_{\alpha\beta}$ in dq coordinate system is:

$$u_{\mathrm{dq}} = u_{\alpha\beta}\mathrm{e}^{-\mathrm{j}\varphi} \tag{8}$$

According to equation (6) and (8), the formula (1) $i_{\mathrm{abc}}$, $u_{\mathrm{cabc}}$, $u_{\mathrm{sabc}}$ are transformed into a Figure 2(c) coordinate system, its equation below:

$$\begin{cases} pi_{\mathrm{d}} = \dfrac{1}{L}\left(u_{\mathrm{cd}} - Ri_{\mathrm{d}} - \omega Li_{\mathrm{q}} - u_{\mathrm{sd}}\right) \\ pi_{\mathrm{q}} = \dfrac{1}{L}\left(u_{\mathrm{cq}} - Ri_{\mathrm{q}} + \omega Li_{\mathrm{d}} - u_{\mathrm{sq}}\right) \end{cases} \tag{9}$$

Current offered from Micro power to the grid is:

$$\begin{bmatrix} i_{\mathrm{a}} \\ i_{\mathrm{b}} \\ i_{\mathrm{c}} \end{bmatrix} = \frac{2}{3}\mathrm{e}^{\mathrm{j}\varphi}\begin{bmatrix} 1 & 0 \\ -\dfrac{1}{2} & \dfrac{\sqrt{3}}{2} \\ -\dfrac{1}{2} & -\dfrac{\sqrt{3}}{2} \end{bmatrix}\begin{bmatrix} i_{\mathrm{d}} \\ i_{\mathrm{q}} \end{bmatrix} \tag{10}$$

Formula (9) and (10) form the equation of state of the interface circuit. In the dq coordinate system, micro power through an inverter to the micro-grid can be expressed as：

$$\begin{cases} P = \frac{3}{2} u_{sd} i_d \\ Q = -\frac{3}{2} u_{sd} i_q \end{cases} \tag{11}$$

By the formula (11), active micro power from convert to microgrid can be adjusted by setting the id; reactive power from convert to micro-grid can be adjusted by setting iq when the grid voltage is constant, which realize de-coupled control of active and reactive power transferred between the grid and micro-power. By the formula (6) to (10) can establish flexible interface model in different modes.

### 2.4. Micro-Grid Interface Model in ABC Coordinate System

The abc coordinate system can be established in two steps, the first step: the ABC stationary coordinate system is converted to abc rotating coordinate system, then phasor synthesized; The second step: orientation dq coordinates.

The selected coordinate system for ABC coordinate system converting to abc system is shown in Figure3(a). The reference starting position of a-axis in abc rotating coordinate system is same as A-axis in ABC stationary coordinate system.

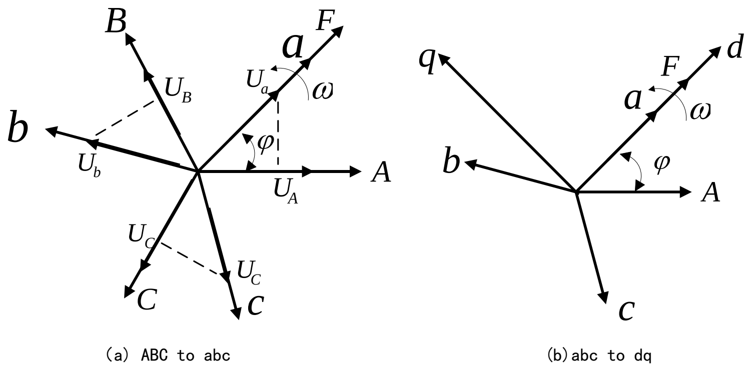



**Figure 3. Coordinate Transformation**

a, b, c axis and the synthesized phasor F are rotating at the grid angular speed, length of component $u_a$, $u_b$, $u_c$ unchanged. A, B, C axis is stationary; the angle φ between the a-axis and the A-axis varies over time. Obviously, the following relationship exists between $u_a$, $u_b$, $u_c$,and $u_A$, $u_B$, $u_C$

$$u_{ABC} = u_{abc} e^{j\varphi} \tag{12}$$

The synthesized phasor is calculated as follows:

$$F = u_a + u_b e^{j120^0} + u_c e^{j240^0} \tag{13}$$

The design of micro-power system interface models is based on the grid voltage oriented phasor control scheme, which selecting synthesized phasor F is d-axis direction, a counterclockwise direction 90° ahead of the d-axis is the q-axis. as Figure 2 (c) shows. Then coordinate $u_{dq}$ in dq coordinate system is:

$$u_{dq} = F e^{-j\varphi} \tag{14}$$

Because in Matlab measuring module has completed the first step of the formula (12), According to equation (13) and (14), the formula (1) $i_{abc}$, $u_{cabc}$, $u_{sabc}$ are transformed into a Figure 3(b) coordinate system, its equation is:

$$\begin{cases} pi_d = \frac{1}{L}\left(u_{cd} - Ri_d - \omega Li_q - u_{sd}\right) \\ pi_q = \frac{1}{L}\left(u_{cq} - Ri_q + \omega Li_d - u_{sq}\right) \end{cases} \tag{15}$$

Current offered from Micro power to the grid is:

$$\begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} = \left[i_d + ji_q\right]\left[1 \quad e^{-j120°} \quad e^{j120°}\right] \tag{16}$$

Since the coordinate transformation using a grid voltage oriented phasor control scheme, the same decoupling control can be achieved between active and reactive power. Power supplied from micro-power to grid can expressed by formula(11). Interface model can be implemented using formula (11) to (16).

## 3. Mainstream Control Mode in Micro Grid

### 3.1. P/Q, V/f Control Mode

Mainstream microgrid control modes are shown in Figure4[12-13]. f_ref, V_ref, P_ref, Q_ref are given reference value of grid frequency, voltage, active and reactive power; id_ref, iq_ref straight, cross-axis current reference value; Vd*, Vq* are as straight, cross-axis voltage reference value; the rest of symbols are measured values of the system. Two left half of dotted box in the Figure 4 are two different control strategies. P/Q control is based on setting the reference value of active and reactive current that control the inverter active and reactive power, micro power seem as a controlled current source. Normally, the micro grid operates in the grid-connecting mode, reference value of voltage and frequency is provided by the grid, so all the micro-power run by P/Q mode. To minimize the use of renewable green energy and to achieve maximum micro power power output, wind power, solar power and other intermittent power resource usually run in P/Q control mode.

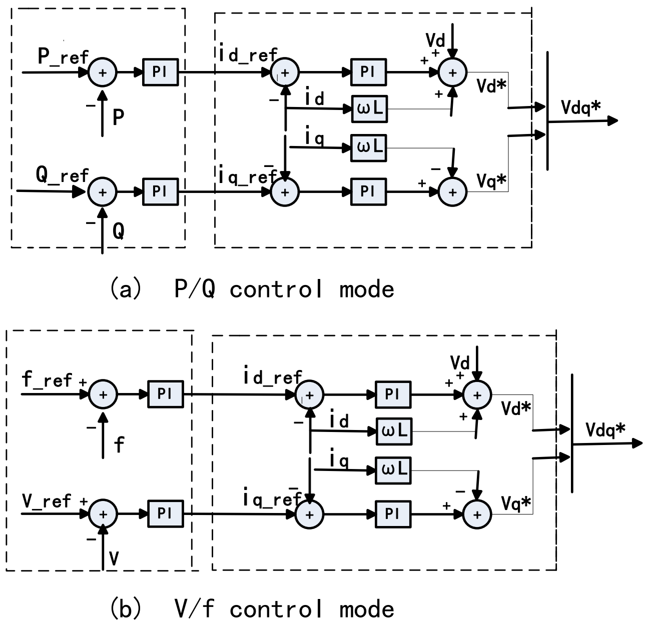



**Figure 4. Control Mode of Microgrid**

Microturbine, fuel cells, batteries, other controllable power energy and energy storage device can use V/f control in off-grid mode; this method is similar to task of the voltage and frequency modulator in the synchronous generator. V/f control usually adopt double closed-loop control which consists of outer voltage loop and inner current loop, comparing reference values of voltage with the measured values, the deviation through proportional-integral (PI) regulator, the various regulator output adjust the inverter output so as to maintain voltage and frequency stability. The control strategy can balance power and demand. At the same time, you can also improve the dynamic response of the inverter to strengthen anti-disturbance capacity. It can provide voltage and frequency support for the micro-grid when the distribution network failure or power quality does not meet the load requirements lead to micro-grid in off-grid mode. The energy storage, some micro power resource can run in the V/f control mode, on the one hand it can control the connection micro-power output, on the other hand provide the frequency reference to the other micro-power run in P/Q control mode, and thus frequency and voltage fluctuations are suppressed.

### 3.2. Droop Control

Droop control characteristics are similar with the reactive power-voltage and active power-frequency droop characteristics of the traditional power system. According to the different ratio of resistance and reactance (R/X) of distribution network transmission line, there are two droop control characteristics: P-f , Q-V and P-V, Q-f. Because of large LCL filter inductor and short low-voltage transmission line, impedance between micro-grid and load is mainly reactance. The selection of droop control is P-f , Q-V similar to traditional power systems. Active power mainly depends on the voltage angle difference between the load and micro grid; reactive power depends mainly on the amplitude of the voltage difference between the two ends. Thus, by adjusting the angle and amplitude of the inverter voltage, respectively, will be able to achieve active and reactive power control. In practice, frequency is often instead of the power angle, droop control equations is:

$$\begin{cases} f = f_0 - \delta P \\ U = U_0 - \sigma Q \end{cases} \tag{17}$$

where $f$, $V$, $P$, $Q$ of the same meaning as equations (1); $f_0$ is the maximum frequency of the grid permitted by national standard (GB/T 15945-2008); $\delta$ is frequency adjustment ratio; $\sigma$ is voltage adjustment ratio. This method is simple and reliable, it can maintain power balance within the micro grid in island mode, active power and reactive power can be reasonable allocation between each unit without communication.

### 3.3. Master-Slave Control Mode and Multi-Agent Technology Control

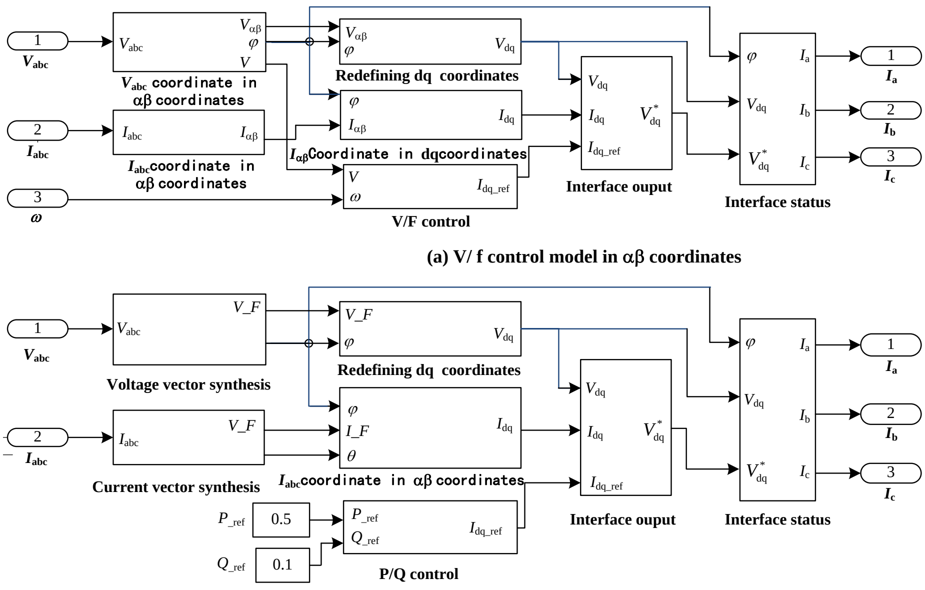
Master-slave control is a hierarchical control mode. Master unit get measured signals from slave unit, and then output instruction fed back to the slave unit. Master unit often use V/f control, providing frequency and voltage reference for micro-grid, slave unit use P/Q control, master-slave control can effectively coordinate the various units and has ability to maintain the system voltage and frequency stability. Its control mode belongs to the first control mode in Figure 4.

A multi-agent system is a combination of several agents working in collaboration in pursuit of accomplishing their assigned tasks resulting in the achievement of overall goal of the system. Multi-agent system enables real-time energy management of a micro-grid. These include the management and control [14]. Such control output instruction include reference of frequency ,voltage, current, active power, reactive power *etc.*, which can also be attributed to the pattern control mode in Figure 4, but its reference value is dynamic.

## 4. The Controller and Inverter Integrated Simulation Model

In order to simplify the simulation model, two kinds of representative and universal integration simulation models based on the logical relationship of controller and inverter, are set up, namely, V/f, P/Q control interface models which are shown in Figure 5.



(a) V/ f control model in αβ coordinates

(b) P/ Q control model in abc coordinates

**Figure 5. Integrated Simulation Model**

## 5. Simulation Analysis

Figure 6 is a simulation diagram of the micro grid. Micro power grid is composed of power distribution network, microturbine[15-16], photovoltaic power generation[17-18], transformer, transmission line and the general load, specific parameters are shown in Figure 6. The simulation process using per unit, the benchmark S=100kVA, reference voltage V = 400V, the reference frequency f = 50Hz. In the Matlab/Simulink, powersystem module set is divided into three operating modes: continuous operation mode, discrete operation mode, phasor mode. The cases were run in discrete mode and phasor mode.

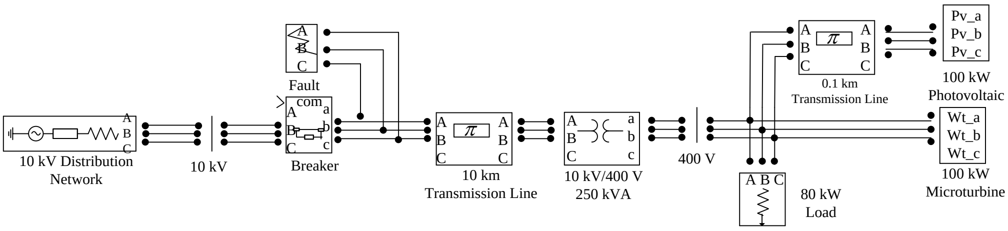



**Figure 6. Microgrid Simulation System Diagram**

### 5.1. Simulation in Discrete Mode

Interface models used in this mode are based on dq0 or aβ coordinates. One simulation is in grid mode, the other is transformation between grid and off-grid, while microturbine use P/Q control in grid mode, V/f control is used in off-grid mode.

Firstly, micro grid run in grid mode during 0.0~3.0s, then during 3.0~5.0s in island mode. active power of microturbine rise from the initial 0.1 to 0.5 at 0.5s, reactive power given from 0 to 0.2; light intensity from the initial 500W/m$^2$ becomes 800W/m$^2$ at 1.5s, the initial photovoltaic reactive power is 0; microgrid transformation from grid to off-grid at t=3s when the circuit breaker is disconnected. Simulation results of active power, reactive power shown in Figure 7(a); the changes of bus voltage amplitude and frequency of the micro-grid during transformation is shown in Figure 7(b) below:

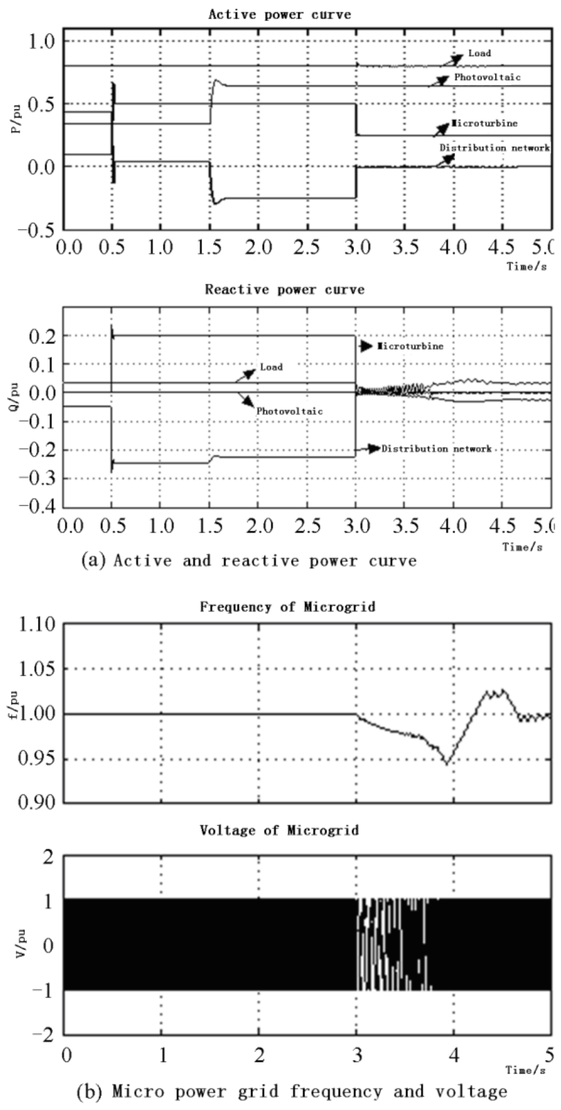



**Figure 7. Simulation of the Discrete Mode**

### 5.2. Simulation Phasor Mode

Interface models used in this mode are based on abc rotating coordinate. One simulation is parallel operation in grid mode, the other is distribution transmission line fault. Simulation parameters and process is the same as discrete operating mode.

Simulation results OF the active power, reactive power are shown in Figure 8(a). At t =3s, transmission line phase-to-phase short-circuit fault occurs, the duration is 0.3 s, the simulation results are shown in Figure 8(b).

As can be seen from the simulation results, the simulation results in both operating modes are same; the simulation results show the whole process of the micro-grid to maintain frequency and voltage stability; the simulation results also reflect the micro-grid voltage, current changes when the line fails.

Although this simulation contain only solar energy and microturbine, but its interface model can also be used to connect power grid with wind turbine, fuel cells, batteries, energy storage, capacitors. Therefore, the simulation used this interface model based on phasor control can accurately reflect changes of voltage, frequency, active, reactive power at various disturbances. Interface model based on vector control can meet the requirements of micro grid simulation.

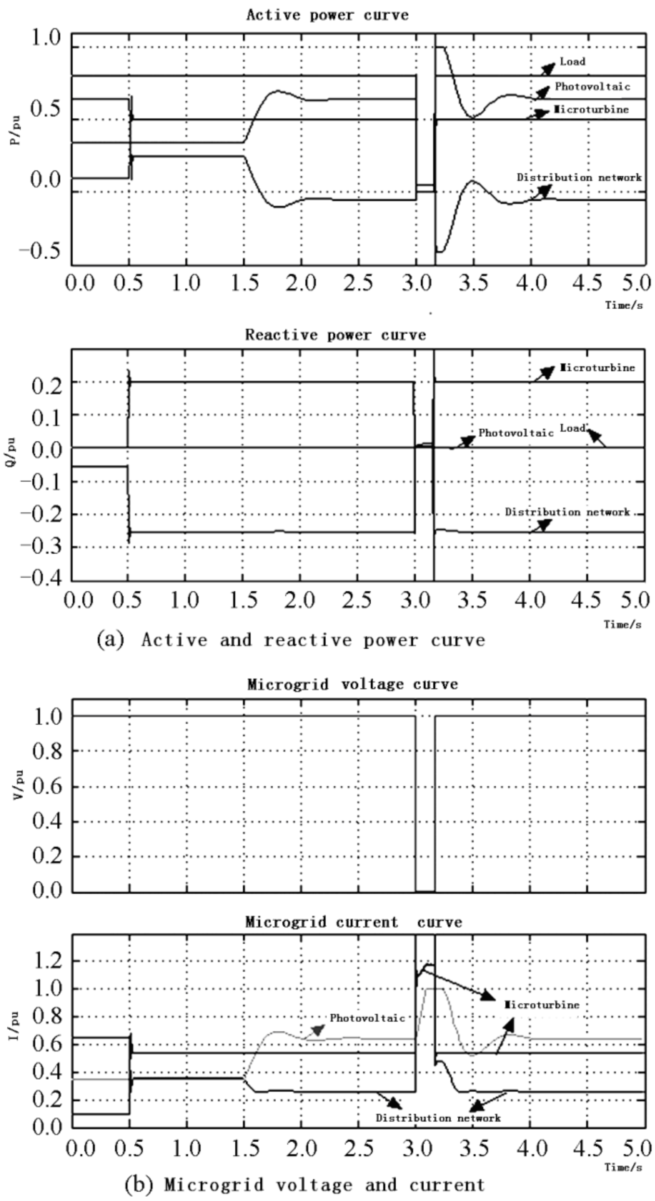



**Figure 8. Simulation of the Phasor Mode**

## 6. Conclusion

1) An integrated simulation model of controller and inverter remove the influence of the electromagnetic coupling among the components. The model can be flexibly set in different operating modes and different modules in Matlab/Simulink.

2) Q-axis component of the voltage phasor in the dq coordinate is zero because of using reasonable coordinate transformation. Phasor control technology simplifies interface model and realize de-coupled control of active and reactive power transferred between the grid and micro power, So that the physical meaning of control variable in the model is very clear.

3) The model omits the transient process of switch, only reflects the conversion relationship of interfaces at both ends, which greatly accelerates the simulation speed.

4) Phasor control technology is widely used, integrated interface model based on phasor control technology not only enrich the Matlab component library, but make it easy for users to carry out other simulation in Matlab/Simulink.

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