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Control Strategy for Micro-grid system in islanded mode

***Abstract**. This paper focuses on the control strategies for islanded mode micro-grid system, which consists of wind turbines, photovoltaic panels, batteries and super-capacitors. When micro-grid is connected to the utility grid, DC-bus voltage is regulated by the inverter. And the magnitude and frequency of AC bus are the same with the grid. However when the microgrid works in island mode, DC-bus voltage must be regulated by microsouces and storages. The magnitude and frequency of AC bus are controlled by droop character of parallel inverters. Because of the fluctuation of renewable energy such as wind turbine and photovoltaic, a fast-dynamic storage system (such as super-capacity) is needed. In order to keep supplying power to the local loads in island operation, a long-term storage system (such as lead-acid battery) is needed. All of microsouces and storages are connected to DC bus by different converters. The converters must be controlled well to keep the bus voltage stable and the power flow balance.*

***Streszczenie.** W artykule przedstawiono analizę algorytmów sterowania dla mikro-sieci odnawialnych źródeł energii (turbiny wiatrowe, panele fotowoltaiczne, superkondensatory), przy pracy wyspowej. Każdy z elementów sieci podłączony jest poprzez oddzielny przekształtnik i każdy z nich wymaga odpowiedniego sterowania w celu utrzymania stabilnego napięcia szyny DC oraz mocy. (**Strategia sterowania mikro-siecią w pracy wyspowej**).*

Keywords: AC-and DC- bus; micro-grid; islanded; fuzzy control; droop control
Słowa kluczowe: szyna AC i DC, mikro-sieć, wyspowość, sterowanie rozmyte, kontrola zapadu.

Introduction

It is preferred to integrate renewable energies instead of fossoil ones in the microgrid to reduce the CO_2 emission. The benefits of micro-grid systems are seen to achieve higher reliability of service, better quality of power supply, and greater economical efficiency of energy. In addition, the ability to use renewable energy with little or no pollution is becoming increasingly attractive for environmental protection considerations and attracts increasingly important interests. Micro-grid can benefit the electric utility by reducing congestion on the utility grid, reducing the need for new generation and transmission capacity, and offering ancillary services such as voltage support and demand response. But the renewable energy sources are usually very intermittent and fluctuant, which make the renewable energy production and the consumption very difficult. In order to accelerate the development of renewable energy generators in the electrical network, methods should be taken to get new renewable energy generators more flexible and more controllable [1,2,3].

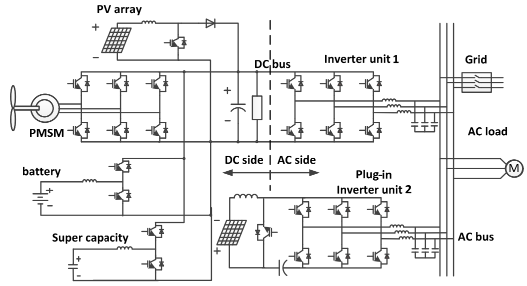

Fig.1. topology of AC-and DC-bus micro-grid system

Topology and power flow of typical micro-grid

One typical Micro-grid system is established in the lab as shown in Fig. 1. It consists of a wind turbine, photovoltaic panels, batteries and super-capacitor. Three bi-direction boost converters are used to connect DC micro-sources to DC bus,one two-level inverter has been used to exchange energy between DC and AC bus. When the Microgrid works in islanded operation, DC-bus voltage must be regulated by renewable energy generations and storage devices, and the voltage and frequency of AC bus are controlled with voltage-frequency or droop control strategy of parallel inverters.

Storage fuzzy controller and DC-bus controller

When working in the islanded operation, energy storage system should be controlled to supply the energy gap between renewable energy generations and loads to reduce the influence of fluctuation. The power flow of this system is shown in Equ.1 and also in Fig. 2

$$P_{storage} = P_{batt} + P_{sc} = P_{wind} + P_{solar} - P_{load} \tag{1}$$

where: $P_{storage}$ is the total power of storage system including batteries and super-capacitor. P_{batt} and P_{sc} is power released from battery and super-capacitor respectively, P_{wind} is power generated by wind turbine. P_{solar} is power generated by photovoltaic panels and P_{load} is power absorbed by DC and AC loads.

If the storage discharges deeply in island operation, and the micro-sources also can't supply enough power to all the loads, energy management system will cut off the less sensitive loads. If the storage charges deeply, and then micro-sources supply more power than loads' need, the wind turbine and photovoltaic must be controlled to match the load instead of Max Power Point Tracking(MPPT).

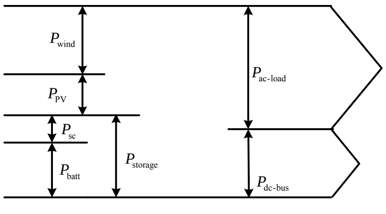

Fig.2. Power flow of the system

PI controller has been used to determine the current reference of the storage system as shown in Fig 3.

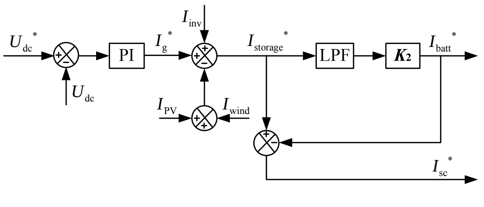

Fig.3. PI controller of DC-bus using storage

Because of the fluctuation of renewable energy such as wind turbine and photovoltaic, a fast-dynamic storage system such as super-capacity is needed. In order to keep supplying power to the local loads in island operation, a long-term storage system such as lead-acid battery is needed. Current reference for battery is given by current reference for storage pass through a low pass filter while super-capacity release the remain.

$$\begin{cases} I_{\mathrm{batt}}{}^{*} = K_2 \cdot \mathrm{LPF}(I_{\mathrm{storage}}{}^{*}) \\ I_{\mathrm{sc}}{}^{*} = I_{\mathrm{storage}}{}^{*} - K_2 \cdot \mathrm{LPF}(I_{\mathrm{storage}}{}^{*}) \end{cases} \tag{2}$$

K_2 is a papameter detemines the proportion of current distribution which the depends on State of Charge (SOC) of batteries and super-capacitor. Fuzzy controller can supply a solution of how to get the value of K_2. Batteries nomallly store more energy than super-capacitor, so EMS makes K_2=0.7 ～ 0.9 when SOC of them are both in normal condition. However when SOC of storage is high or low, EMS will regulate K_2. For example, if SOC of batteries is normal but SOC of super-capacitor is low, EMS makes K_2>1 where batteries will release more power and super-capacitor will absorb power from DC bus in order to make SOC normal. Fig 4 shows the degree of membership of K_2, BH means the SOC of battery is above 80% while CN means the SOC of super-capacity is normal, defination of others are in a similar way. When SOC of two storage part is similar (for example: both above 80% or both below 30%), there is no need for us to adjust K_2 and normal part of membership degree has been chosen.

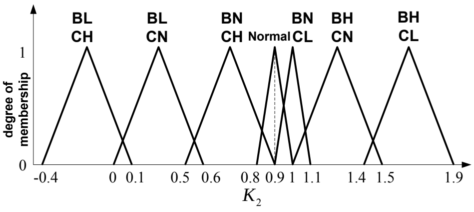

Fig.4 Power flow of the system

Fig 5 is a example of K_2 Value when storage is releasing energy.

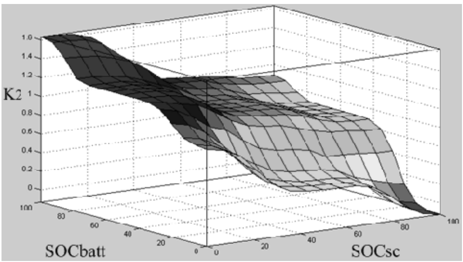

Fig.5 Value of K_2 when storage is releasing energy

PV array may release energy more than the need of local load that make storage absorb the remaim power, this situation is dual to the releasing part and Fig 6 gives the corresponding results..

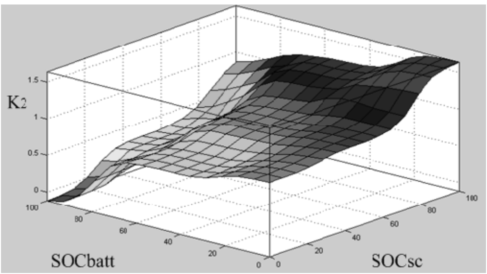

Fig.6 Value of K_2 when storage is absorbing energy

AC-bus controller

In islanded operation, voltage and frequency of AC bus should be controlled by parallel inverters. Energy management system controls one of inverters as a voltage source with Voltage-Frequency control strategy and others as current sources with P-Q control. In d-q frame,

$$\begin{cases} C_g \dfrac{du_d}{dt} = i_{dL} + \omega C_g u_q - i_{dl} \\ C_g \dfrac{du_q}{dt} = i_{qL} + \omega C_g u_d - i_{ql} \end{cases} \tag{3}$$

From Equation (3), we can get V-F control strategy as shown in Fig. 7. In islanded operation, references of voltage and frequency should be determined by local system not utility grid. P-Q control strategy uses P_{ref} and Q_{ref} to get i_{dLref} and i_{qLref} instead of voltage loop. So power of loads should be divided into several parts given to inverters according to ability of renewable energy generations and storage system in different Microgrid units.

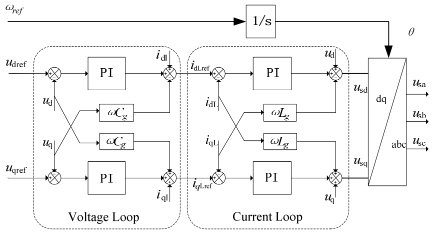

Fig.7 Value of K_2 when storage is absorbing energy

Droop controller

The equations 4 provide relationships between P and Q and the inverter output voltage magnitude and phase angle:

$$\begin{cases} P_i = \dfrac{3V_i E}{2\omega L} \sin\delta_i \\ Q_i = \dfrac{3V_i}{2\omega L}\left(V_i - E\cos\delta_i\right) \end{cases} \tag{4}$$

E is the voltage magnitude at the point of common coupling. If the coupling inductance phase is less than 5°, then P is proportional to angle gap and Q is proportional to voltage gap. Given the values of P and Q, voltage magnitude and phase angle are determined from the power versus frequency and the voltage versus reactive power droops of the microsource[4,5]. Consider a grid-connected microgrid which includes two microsources. Each microsource has a constant negative slope droop on the P-w plane. The power set points of microsources are P_{01} and P_{02} which represent the amounts of power injected by the microsources at the grid frequency . The frequency drops by a given amount as the power spans from zero to $P_{\max}$, as shown in Fig.8.

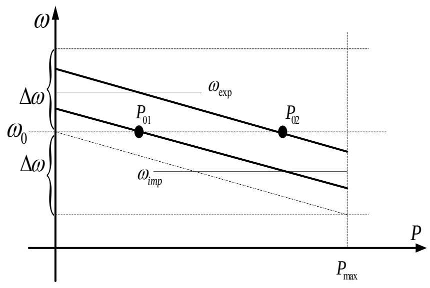

Fig.8 Demonstration of negative slope droop on the P-w plane

Unlike a large power system, the impedance between different units in a microgrid is small. Small errors will cause circulating currents. This can be prevented by a voltage versus reactive power droop control [6,7].

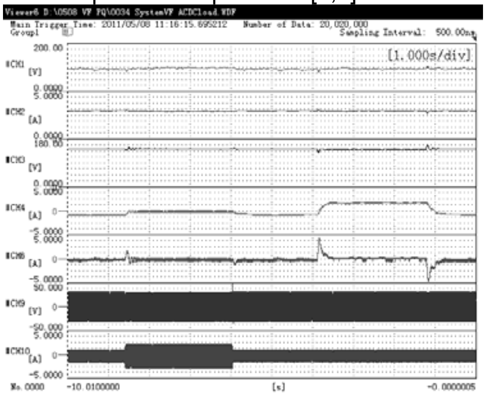
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Fig.9. Transient result of micro-grid system while DC and AC load changed

Experiment Results

Hardware of Microgrid system is established using low capacity IGBT and IPM in lab with the parameters shown in Table I.

U_a

Table 1. The experiment parameters of the system

DC side	PV array	1kW
	Wind Turbine	2kW
	Batteries	12V,65Ah
	Super Capacitor	72V,70F
	DC-bus voltage	150V
	DC inductors	5mh
	DC-bus capacity	3700μF, 400V
AC side	AC filtering capacity	20μF
	AC filtering inductor	5mh
	AC-bus frequency	50Hz
	AC-bus voltage	30V
	AC load	25Ω

In islanded operation, one inverter is voltage source with voltage-frequency control strategy and others with P-Q control strategy. Voltage and frequency of AC bus can be regulated well while local loads changed, Fig. 9 shows some of the results in islanded operation, and local loads changes as follows:

t_1: AC load change from 25Ω to 12.5Ω
t_2: AC load change back from 12.5Ω to 25Ω
t_3: DC load change from 200Ω to 66Ω
t_4: AC load change back from 66Ω to 200Ω

Conclusion

This paper presents the control strategies of Microgrid system in islanded mode with hybrid DC and AC buses. With these strategies, hybrid storage systems release or absorb power difference according to their SOC and response characters. Voltage of DC bus could be kept steadily even though power of local loads and renewable energy generations changed. In islanded operation EMS controls storage to regulate voltage of DC bus and one of inverters as a voltage source to keep voltage and frequency of AC bus stable. experimental results verify that voltage of DC and AC bus could be regulated well with the control strategies.

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