The Operation of Microgrid Containing Electric Vehicles

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***Abstract*-- Microgrid is an effective form of the DGs (distributed generation) integration on distributed network. Through the coordination by energy storage and control devices, microgrid can restrain the negative influence by the DG output fluctuation on the distributed network and buffer the impact of EV charging load effetely. The harmful effect which EV Chargers bring on the microgrid is their nonlinearity will lead to harmonic pollution to the microgrid. Meanwhile EV batteries fully charged can serve as micro-sources which support the operation of the microgrid in island mode. The harmonic distortion caused by EV chargers in the microgrid is studied in this paper and the operation characteristics of the microgrid in island mode supported by EV batteries is presented.**

Keywords- electric vehicles; microgrid; EV battery charger

I. INTRODUCTION

Smart grid consists of transmission network, distribution network and microgrid [1]. Many forms of distributed generation such as fuel-cells, photovoltaic and micro-turbines are interfaced to the microgrid through power electronic converters. Large numbers of loads are also packed into the microgrid, so are electric vehicles which become increasingly popular as their eco-friendly features. EV (electric vehicle) charging load is a type of non-linear load with large power. They cause harmonic distortion to the microgrid[2].Unlike other loads, by means of an applicable commercial mode and microgrid energy management system (MEMS) EV batteries can serve as micro-sources which support the operation of the microgrid especially working in stand-alone mode[3]. So it's necessary to analyze the operation of microgrid containing electric vehicles.

In this paper, EV charging properties are studied and the EV charger model is set up with the tool of SIMULINK on the basis of electric buses parameters in section II. Section III presents the modeling of the microgrid with the P-f & Q-V control method which is based on the PQ droop method. Section IV analyzes the impact brought by EV charging load on the power quality including the overload problem and the harmonic distortion. Finally the operation characteristics of EV-battery-based microgrid switching from grid-connected mode to stand-alone mode are shown.

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II. EV CHARGING PROPERTIES AND MODELING

EV battery chargers can be categorized as on-board chargers and off-board chargers depending on whether the installation of the charger is within the vehicle or outside the vehicle. Generally off-board chargers have higher charging rate and higher charging capacity. But according to some studies, no matter which type of battery charger is selected, it will surely bring harmonic pollution to power grid as a result of its nonlinear characteristics.

At present high-frequency electric vehicle chargers are generally used. The typical charging strategy adopted in power batteries charging control is the two-stages charging (Constant Current/Constant Voltage) [4]. Charging power curve of CC/CV charging method is shown in Fig. 1. When it is in the first stage of constant current, voltage and charging power will go up with time until the voltage reaches the maximum. After that, the current goes down quickly with the output power falling down as a result.

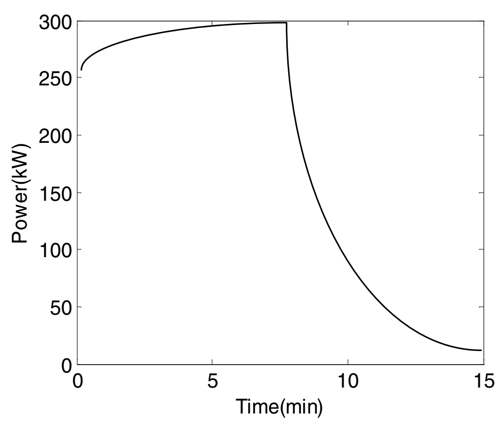

Figure 1. Charging power curve of CC/CV charging method

The equivalent circuit of EV Chargers is shown in fig. 2 Three-phase AC is rectified through three-phase bridge uncontrolled circuit. Then it is filtered and transformed by high-frequency DC-DC power conversion circuit to provide for EV batteries charging. Power converter and EV battery can be made equivalent to nonlinear resistance R_C [4].

$$R_C = \frac{U_B}{I_I} = \frac{U_B^2}{P_I} = \frac{\eta U_B^2}{P_O} = \frac{\eta U_B^2}{U_O I_O} \qquad (1)$$

where η is the charging efficiency.

On the basis of (1), the characteristic curve shown in Fig. 3 of nonlinear resistance R_C.

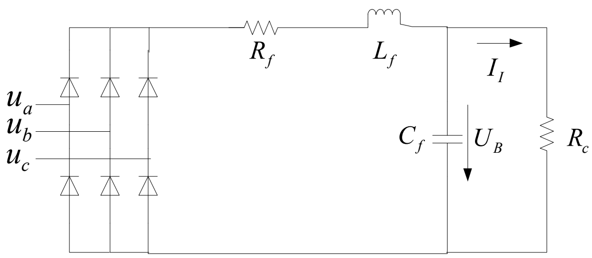

Figure 2. Equivalent circuit of EV Chargers

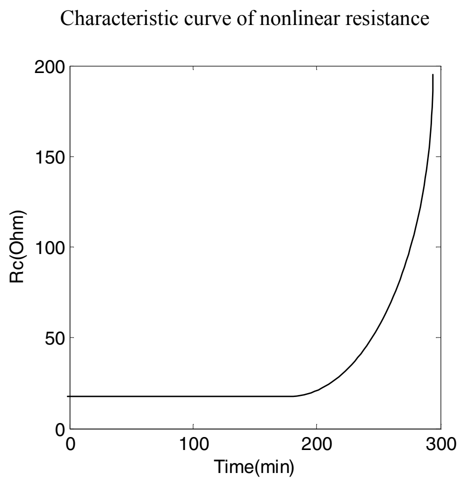

Figure 3. Characteristic curve of nonlinear resistance R_C

III. MODELING OF THE MICROGRID

Microgrid is a distribution subsystem, which consists of DG, energy storage system, loads and relay protection system. Packing DGs and loads, microgrid which is connected to the utility grid controls the output of DGs by use of electronic interface. On one hand, important loads are protected. When some fault occurs on the utility grid, relay protection will take action and the static switch will be open, so important loads will operate in the stand-alone mode, which reduce losses greatly. On the other hand, advanced control methods are used to control the power flow between microgrid and the utility grid, avoiding the shock to the utility grid as the result of DGs' (wind power or photovoltaic system) output intermittence.

Control strategies of microgrid can be divided into two ways: master-slave control mode and distributed control mode [5]. In master-slave control mode related information of DGs are collected to the control center and then the control signal on the basis of analyzing and calculating will be sent out to lower layer which consists of all the DGs. This mode relies on corresponding communication devices to transmit information. Distributed control mode refers to controlling every DG independently according to the local information. In this paper, a typical method in distributed control strategy — droop control is adopted in the microgrid simulation platform. Droop characteristics of DGs are shown in Fig .4. Controller designed based on this method is shown in Fig. 5.

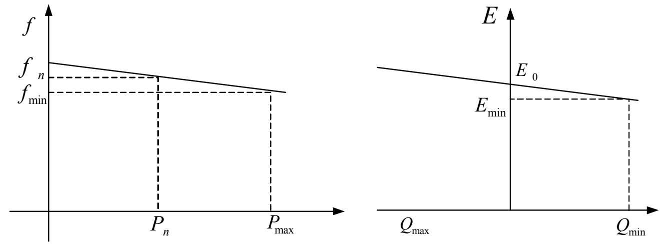

Figure 4. PQ droop control schema

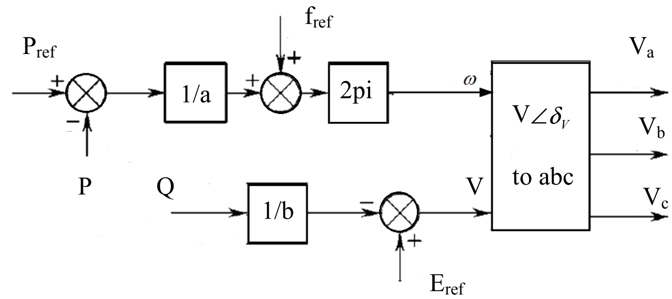

Figure 5. P-f & Q-V controller

IV. ANALYSIS OF IMPACT

When operating in stand-alone mode, microgrid only supports important loads, while EV chargers are not important loads. Also high charging power is a source of harmonic, which can worsen the power quality of stand-alone microgrid. So EV chargers should be cut as soon as microgrid comes into the stand-alone mode. In this paper, the impacts of EV chargers on microgrid power quality are studied only in grid-connected mode, including harmonic pollution and voltage level falling because of overload.

A. *Overload*

The overload problem is closely associated with the penetration of EV and the charging power. Relevant researches show that in the coming ten years the penetration of EV will not exceed 0.1. Also because of different charging speed, charging power of EVs differs greatly. For example, the power of common battery chargers is 3-20 KW while the power of high power battery chargers is over 70KW. So there is a critical overload problem for several high power battery chargers working at the same time to the microgrid. So at present only common battery chargers (under 20kW) are permitted to be connected to microgrid.

According to some statistics the average maximum load per household of city high residential buildings is 1KW. Now let the penetration of EV be 0.1, in other words, only 1 EV is used in 10 families. In the extreme circumstance, i.e. EVs are charged during the peak load, the load per household rises by 0.5KW on average. If the capacities of distribution network lines and transformers are not designed sufficient, these facilities tend to aging and damage. Besides overload problem can drop the voltage level and worsen the power quality.

This problem is brought by the time randomness of charging EVs. In fact, with penetration of 0.1, if all EVs are charged during the wee hours, the behavior of EV charging is helpful for peak load shifting and the operation of microgrid due to the large peak-valley difference in residential districts. However that brings poorer EV using experience, and makes electric vehicles not seem convenient.

B. Harmonic

The harmonic impact produced by EV chargers is studied in MATLAB/Simulink. The structure of the microgrid tested is shown in Fig .6.

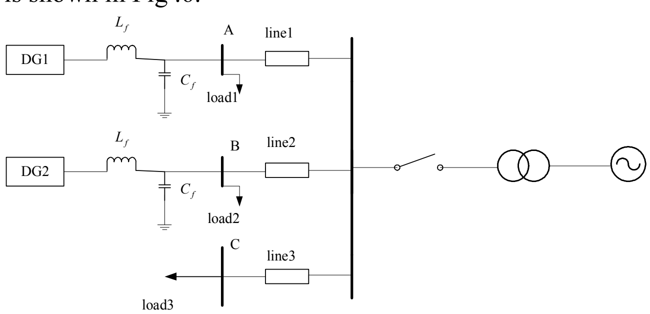

Figure 6. Structure of the microgrid tested

DG1 and DG2 are distributed generators with P-f & Q-V control method. The reference values of the output active power are both 70kW. The filter consists of a filter capacitor C_f (1500μF) and a filter inductance L_f (0.6mH). There are three loads: load1 (150kW, 93kvar) in bus A, load2 (150kW, 93kvar) in bus B and EV charger loads (12 EV chargers, 15kW each one) in bus C. The AC source (10kV) stands for the distribution network and the ratio of the transformer is 0.38/10.5. The parameter of line1, line2 and line3 is the same value: 0.13Ohm, 0.64mH.

The FFT analysis of the voltage wave of bus C from powergui toolbox is shown in Fig. 7 and the voltage THD value with time of bus A and bus C is shown in Fig .8. Change the reference value of DG1's output active power in bus A, the local voltage THD changes is shown in Fig. 9.

The voltage THD has the following features from these figures:

- The harmonic order is mainly $6k\pm1$, k=1, 2, 3… , namely 5, 7, 11, 13.
- During the whole process of charging, as the EV charging power decreases, the equivalent resistance value increases and the load voltage THD will decrease gradually. In other words, the harmonic impact on the power quality of microgrid drops with the charging time. As is shown in Fig.8, EV charging load has more harmonic impact on power quality of microgrid at initial stage of charging. So it should be avoided that quantities of EV batteries are charged synchronously (namely with consistent state of charge) by means of MEMS. Or harmonic filter should be installed to limit the harmonic current.
- The voltage THD of bus A is influenced by the active power of the local DG. As the reference value of DG1 increase, the distorted voltage produced by the harmonic current form bus A will be improved and The THD value of the local voltage will be smaller. It is implied that the more power the DG at the local feeder provides for the loads, the less distorted current from other feeders the loads will draw and the less harmonic impact EV chargers at other feeders will bring on local loads. In other words, Increasing DGs' output contributes to the promotion in the power quality of microgrid if DGs provide sufficient power quality.

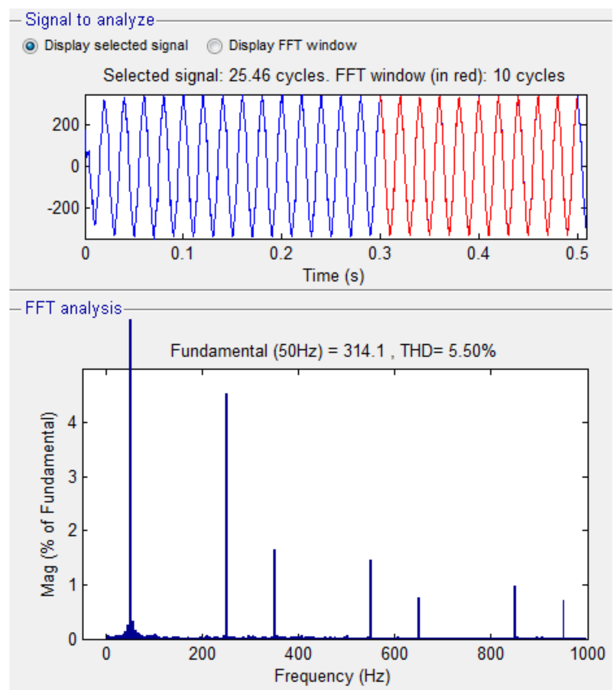

Figure 7. FFT analysis of the voltage wave in bus C (10min)

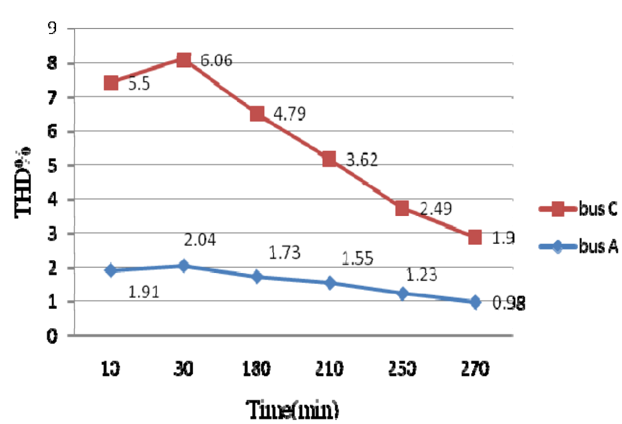

Figure 8. THD value with time in bus A and bus C

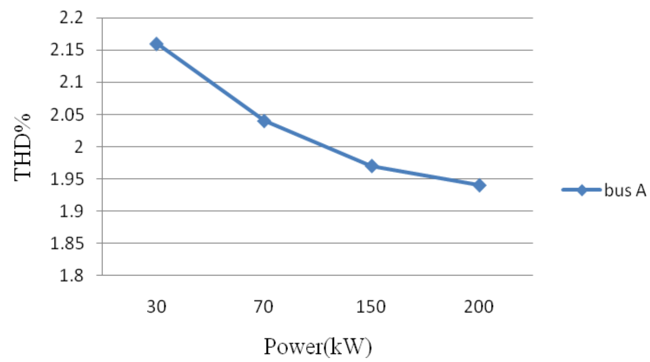

Figure 9. THD value in bus A with the varying active power of DG1

V. OPERATION OF EV-BATTERY-BASED MICROGRID IN THE STAND-ALONE MODE

Customers are supplied by the distributed generators in microgrid. The usual DG including wind power generators and solar cells can't change output power in time to follow the load fluctuation as their intermittent nature of the energy source. So the two types of distributed power can only be controlled with the so-called PQ control method. Although the micro-gas turbine can be controlled with Vf control method as its output flexibility, because of rotational inertia, the adjustment time and the dynamic response is not satisfied. Batteries having good output power regulation performance can maintain the power quality when there are rapid changes in the load. Through P-f & Q-V control, it plays an important role in regulating and buffering.

The simulation is also achieved with the microgrid structure shown in Fig. 6. DG1 and DG2 are EV batteries controlled by MEMS. EV batteries are modeled as constant dc voltage source in the simulation as the voltage of batteries changed wondrously slowly. The reference values of output active power are both 130kW with other parameters unchanged. The utility grid fails at 0.6s when the static switch breaks off and the non-critical load3 is cut off at the same time. The variation of voltage, frequency, active power output and reactive power output and in bus A is shown in Fig. 10, Fig. 11, Fig. 12, and Fig. 13.

The microgrid operates in the stand-alone mode without the voltage support from the utility grid. Due to EV batteries' regulation controlled by the drop controller bus voltage and system frequency quickly returned to normal levels after a short period of adjustment. The steady-state value deviates from the nominal value a little due to the principle of drop control method.

As is shown in above figures, EV batteries controlled by MEMS can stable the microgrid operation, support bus voltage and maintain the system frequency. But owning to the economic limitation, it is mainly applied in stand-alone mode when the utility grid fails. When in grid-connected mode, The

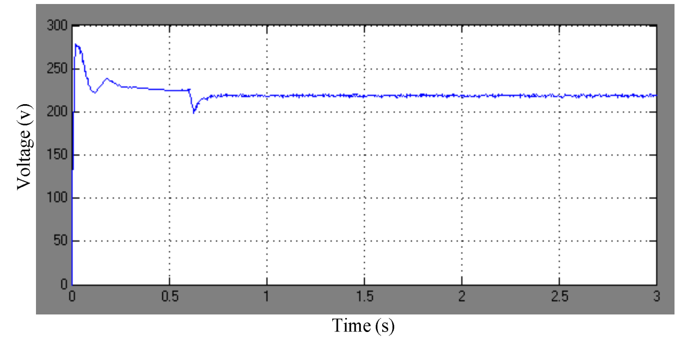

Figure 10. Voltage variation

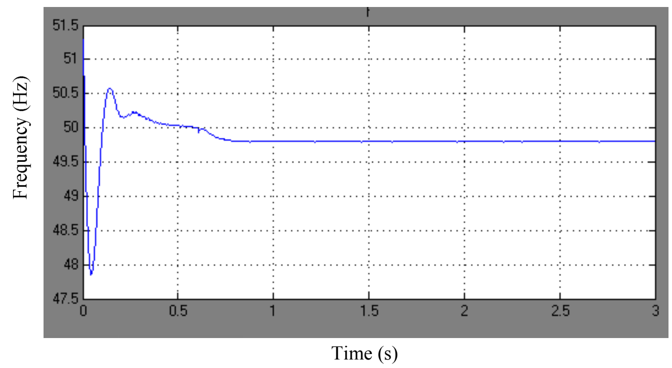

Figure 11. Frequency variation

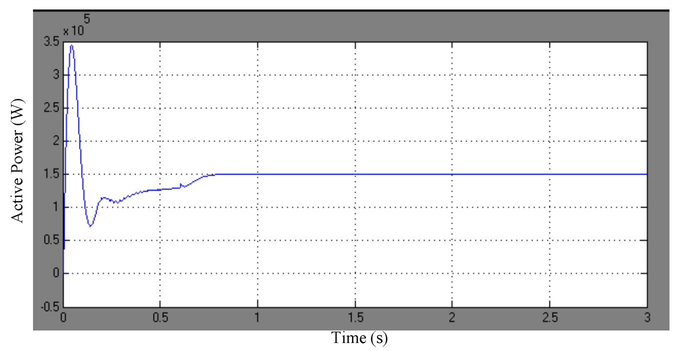

Figure 12. Active power variation

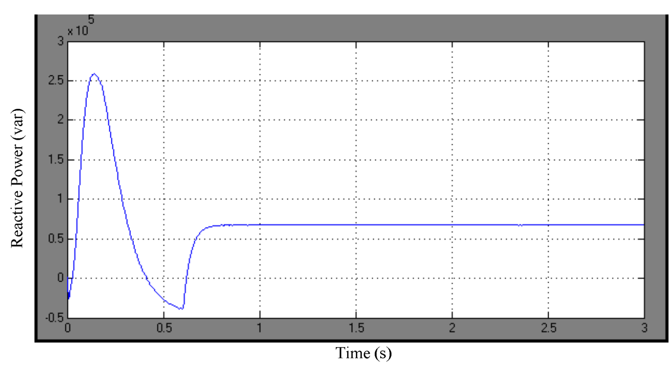

Figure 13. Reactive power variation

MEMS make more use of other micro-sources such as fuel-cells, photovoltaic and micro-turbines. Application range of EV batteries as micro-sources will expand with the development of storage technologies.

VI. CONCLUSION

Electric vehicles are important loads to future microgrid. The paper models the microgrid and EV battery chargers, analyze the harmonic distortion brought by EV battery chargers to the microgrid and present some countermeasures. Idle EV batteries controlled by MEMS can serve as micro-sources to microgrid. The simulation results show that when voltage sag occurs in the utility grid, it will be confirmed that power supply is continued to the loads in the microgrid with little influence.

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