태양광-배터리-수퍼캡을 갖는 직류 홈 그리드의 버스 전압 제어

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Bus Voltage Regulation of DC Home Grid with PV-Battery-Ultracap

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ABSTRACT

This paper proposes an improved bus voltage regulation scheme in filter-based reference current generation of power management for DC home grid with photovoltaics (PV), battery, and ultra-capacitor (ultracap) by using feedforward terms instead of the filter output to produce the ultracap reference current. Simulation results have proved the effectiveness of the proposed scheme.

1. Introduction

Recently, there is an increasing interest towards an effective power management system incorporating grid, load, storage, and renewable sources in DC bus based systems [1], [2]. One indicating benchmark to measure the performance of the power management is the regulation of the DC bus voltage.

In this paper, a DC home grid with PV-battery-ultracap is modeled. The modeling is developed using simplified circuits rather than using switching circuits of the converters. Then, an improved bus voltage regulation using feedforward variables is proposed. The validity of the approach is verified by simulation results.

2. Modeling of DC Home Grid

Consider a DC home grid illustrated in Fig. 1, consisting of grid, PV, battery, ultracap, and load connected to a DC bus. Rather than modeling the system using the circuit model of converters (e.g. AC-DC and DC-DC converters), the system is modeled using two levels of abstraction, the system model and the subsystems model, as shown in Fig. 2(a) and Fig. 2(b) respectively.

Fig. 2(a) shows the system model of the DC home grid. The source, storage, and load are modeled as controlled current source with $I_k = P_k / v_{dc}$ as input, where I is current, P is power, v_{dc} is DC bus voltage, and $k \in \{grid, batt, ultracap, PV, load\}$. The load model includes constant power and resistive model. Although the DC bus resistances are not included, they can be added in future studies for practical consideration.

Fig. 2(b) shows the subsystems model of the system. The grid rectifier (i.e. three-phase AC-DC) is modeled with d-axis and q-axis equivalent circuit and controlled voltage source with input V_d^* and V_q^*(i.e. the controller output of the AC current regulator [3]).

The PV, battery, and ultracap in Fig. 2(a) are modeled as shown in Fig. 2(b), where each has an equivalent circuit and a controlled current source with first order low-pass filtered reference as input. The time constant of each low-pass filter (LPF) is specified by the bandwidth of the PI current regulator of each interfacing DC-DC converter.

Fig. 2(c) shows the equivalent circuits used in subsystems seen in Fig. 2(b), which are based on widely accepted model in the literature [3]-[5]. In this figure, V_d^* is d-axis grid current controller output, and V_q^* is q-axis grid current controller output. The grid current I_d is controlled to zero, whereas I_q is controlled to maintain the DC bus voltage. The PV model is based on ref. [4] where a current source I_m, a series resistance R_s, and a parallel resistance R_p are used to model the PV current i_{pv}.

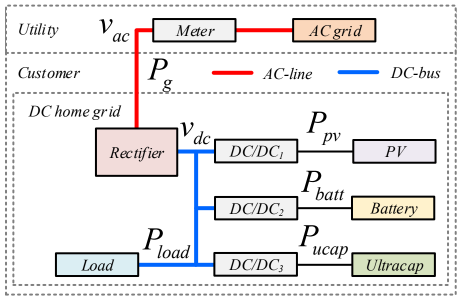

Fig. 1 DC home grid with PV-battery-ultracap diagram.

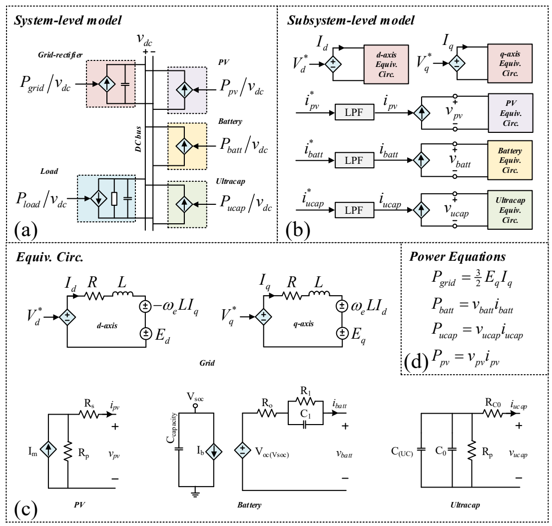

Fig. 2 Modeling of DC home grid with PV-battery-ultracap. (a) System-level. (b) Subsystem-level. (c) Equivalent circuits used in subsystems. (d) Power equations.

The battery terminal voltage v_{batt} is related with battery current I_{batt} according to the equation developed in [5] where v_{oc} is the open-circuit voltage, R_1 and R_2 is the internal resistances of battery, and τ is the time-constant of the battery.

For the ultracap, the model developed in [6] is used, where C_0 is the capacitance at zero voltage, $C_{(UC)}$ is the voltage-dependent capacitance, R_p is the equivalent parallel resistance, and R_{C0} is the equivalent series resistance.

Fig. 2(d) shows the power equations that relates the system with its subsystems. At steady-state, the power equation is related as

$$P_{load} = P_{grid} + P_{batt} + P_{ucap} + P_{pv} \qquad (1)$$

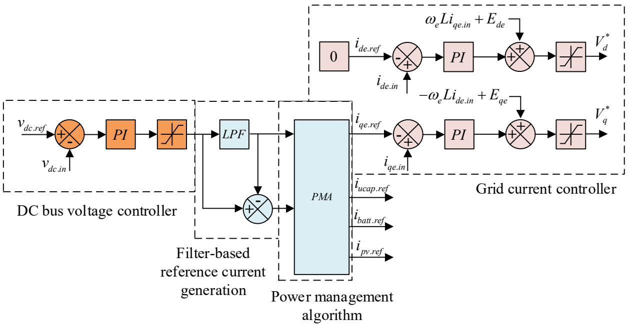

Fig. 3 Control structure of DC home grid with PV-battery-ultracap.

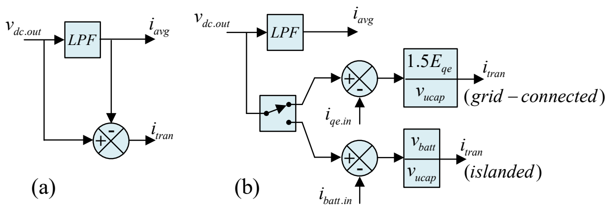

Fig. 4 Filter-based reference current generation for power management. (a) Conventional. (b) Proposed.

3. Control of DC Home Grid

In this paper, a centralized control scheme is considered. Fig. 3 shows the control structure of the DC home grid. The DC bus voltage controller is based on PI controller. The output of the DC bus voltage controller $v_{dc.out}$ is used to generate the reference current for the current controller of q-axis grid, ultracap and battery using a first order LPF. The first order LPF produces an averaged current reference for q-axis grid current controller during grid-connected operation, or for battery current controller during islanded operation. The cut-off frequency is selected as 5 Hz so that the battery/grid reference current responds to a load step with settling time 0.2 s [1]. The PV current reference is the output of an MPPT controller, not discussed in this paper.

Fig. 4 shows the filter-based current reference generation for power management of system with ultracap. Fig. 4(a) shows the conventional control structure [1], where the transient power reference is simply obtained from a subtraction of the LPF output from the LPF input expressed as

$$i_{ucap.ref} = i_{tran} = v_{dc.out} - i_{avg} \quad (2)$$

Fig. 4(b) shows the proposed control structure to improve the regulation of the DC bus voltage, where the transient power reference is obtained depending on the system operation such as either grid-connected operation or islanded operation. The q-axis current is subtracted from the LPF input during grid-connected operation so that

$$i_{ucap.ref} = i_{tran} = (v_{dc.out} - i_{qe.in}) \times 1.5E_{qe}/v_{ucap} \quad (3)$$

Meanwhile, the battery current is subtracted from the LPF input during islanded operation to generate the ultracap current reference, as

$$i_{ucap.ref} = i_{tran} = (v_{dc.out} - i_{batt.in}) \times v_{batt}/v_{ucap} \quad (4)$$

4. Simulation Results

Simulations have been performed in PLECS software to test the model with a specified power management scheme. Fig. 5 shows the DC bus voltage, where Fig. 5(a) shows the performance under the conventional filter-based scheme, whereas Fig. 5(b) shows the performance under the proposed scheme. It can be seen that under the proposed scheme, the DC bus voltage overshoot during transient is reduced. The maximum deviation of the DC bus voltage during transient load change with the conventional scheme is 4.7 V and with the proposed scheme is 3 V. Fig. 6 shows the power of the grid, PV, battery, ultra-capacitor, and load. Fig. 6(a) and (b) show the performance under the conventional and proposed scheme, respectively.

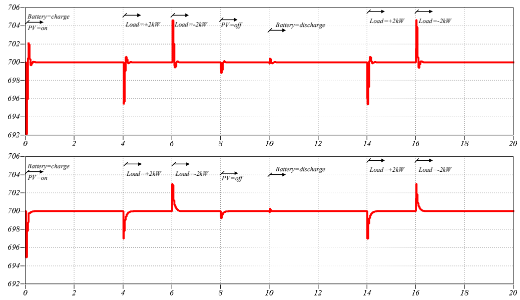
Fig. 5 DC bus voltage (v_{dc}). (a) Conventional. (b) Proposed.

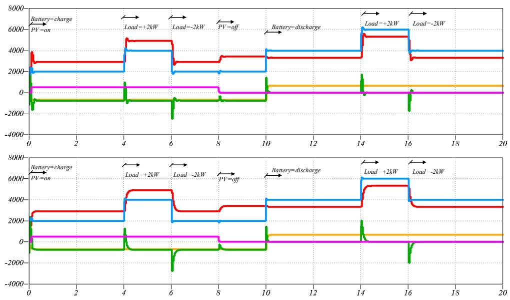
Fig. 6 Power flow. (a) Conventional. (b) Proposed.

5. Conclusions

This paper has proposed an improved reference current generation for bus voltage regulation in DC home grid with PV-battery-ultracap. Simulation results have shown that the proposed approach have reduced the maximum deviation of the DC bus voltage up to ±1.7 V for ±2 kW step change of load.

This research was supported by Korea Electric Power Corporation. (Grant number : R18XA06-35).

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