Implementation of State of Charge based Energy Management System for Enabling Integration of Solar Power Generation

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Abstract—The photovoltaic power generation is a distributed resource whose output changes extremely rapidly, resulting in power quality issues. To overcome the power quality issues, “Battery energy storage systems” are used to integrate solar power for both grid-connected mode and autonomous mode. 1. The battery model with open circuit voltage as a function of State of Charge (SoC). 2. Closed loop feedback control strategies of the battery system are developed for microgrid for both operation modes. At the grid-connected mode, power control is employed while at the autonomous mode voltage and frequency control is employed, this operation is executed through SoC measurement.

Keywords—Energy Management; Solar; Power; Microgrid

I. INTRODUCTION

Microgrid compromise low voltage distribution system with distributed energy resources, such as photovoltaic power systems and wind turbines and other distributed renewable energy resources together with storage devices. These systems are interconnected to the medium voltage distribution network, but they can also be operated isolated from the main grid. A microgrid can either operate at the grid connected or autonomous modes. At autonomous modes, voltage and frequency should be supported by microgrid itself. Battery systems are employed to restore system voltage and frequency quickly. At grid connected modes, VSC of battery systems can work at power control mode. Depending on state of charge (SOC) of battery active power requirements by the microgrid a battery may operate at either charging or discharging conditions[1]-[2].

In reality, a battery has operation limits, the SOC cannot be lower than threshold; the depth of discharge (DOD) may affect the life time of a battery. Therefore, there is a need to model a battery accurately and develop control strategies based on battery status information. A Li-ion battery has been suitable for high power applications. The battery management system (BMS) capable of following active/reactive power order announced by the microgrid central controller shown in fig 1. The BMS is also expected to change its mode to the appropriate one considering the value of SOC and the signal of islanding provided by the central controller.

To improve power quality by supporting voltage and reducing voltage dips and potentially lower costs of energy supply. A battery is used as energy storage unit and is simply represented as a DC voltage source with adequate capacity, capable of meeting the real and reactive power commands within pre-specified limits[8].

Among various distributed generation (DG) technologies, PV systems are becoming very popular and finding more applications particularly in residential networks due to the increasing concern about environmental issues and adopted feed-in tariffs in many developing countries. Currently, most PV generators are designed with maximum power point tracking abilities without any energy storage options to justify their relatively high investment cost. The main task of the PV converter is to extract the maximum possible energy from the sun and deliver it to the power grid to increase the profit.

An islanding mode is a condition in a DG which the energy resource continues to supply to the local load even though the utility grid has been disconnected from the local load. Under this condition, the grid is no longer servicing as a solid voltage and frequency reference. During islanding mode, the utility circuit breaker is opened while the DG is still injecting power to supply the local load (the section between utility circuit breaker and the point of common coupling, PCC). This phenomenon occurs when utility suffers from unpredictable interruption of abnormality, such as voltage shut-down, short-circuit or equipment failure. Battery management system identifies the islanding condition and continuously delivers power flow to the end users simultaneously checks its State Of Charge.

2. BLOCK DIAGRAM FOR SOC BASED ENERGY MANAGEMENT SYSTEM

Fig. 1. Simplified one-line diagram of a BESS in parallel with a Solar PV facility connected to the Microgrid on a common bus.

3. SOC BASED ENERGY MANAGEMENT SYSTEM

The energy management system proposed in this paper is a hierarchical control system containing three modules named SOC computation module, battery mode identification system (BMIS), and closed-loop feedback controller (CLFC). The function of BMIS is to determine the appropriate reference values as well as the mode in which the battery be operated considering SOC.

The BMS receives power order and microgrid connection status from the upper operation center. The BMS also receives measurements from the battery to compute SOC. SOC is passed to BMIS to decide if limits are reached and which action should be taken. The BMIS then passes the decision making to the closed-
loop feedback control system which generates PWM gate signals to the converters.

Fig. 2 Configuration of proposed battery management system.

A. SOC Computation Module

SOC is a measure of the amount of charge stored in a battery, which can be expressed as the percentage of the capacity of the battery and shows energy is left in an energy storage system. The responsibility of SOC computation module is to obtain the SOC based on the battery measurements [7]. This signal is used by BMS to decide accurately about the operation modes and reference signals. BMS also frequently sends the signal of SOC to microgrid control center (MGCC) or in response to its inquiry to inform it how much energy is already stored in the battery, which enables MGCC to use this signal in its optimization procedures which is shown in fig 2. An SOC computation method using coulomb counting technique is employed by the BMS. Since the charge stored in a battery is integration of the current injected to the battery we have:

$$Q(t) = Q(t-1) + \Delta Q(t)$$

$$\Delta Q(t) = I_B(t) \Delta t = [P_B(t)/V_{dc}(t)] \Delta t$$

(1)

SOC can be derived, where sizeB identifies battery size in kWh.

$$SOC(t) = SOC(t-1) + \left[1/3.6 \times \text{Size} \times B\right][P_B(t)/V_{dc}(t)] \Delta t$$

(2)

B. Battery Mode Identification System

Based on SOC and the islanding status of microgrid, BMIS determines the appropriate battery operation mode. Three modes of operation are defined in the BMIS proposed in this paper: a) grid-connected discharging mode or PQ control mode, b) grid-connected charging mode, and c) islanding mode or VF control mode. In case that the microgrid is connected to the main grid, MGCC expects the battery to follow the power orders dictated to BMS. BMS follows the power order as long as the SOC is greater than its minimum limit. Otherwise, the battery must be charged via injecting a predetermined power to the battery and its mode changes to the charging mode until the SOC meets its maximum limit [6]. In order to make sure that SOC never meets 100%, a function is applied to reduce the power injected to the battery when SOC is more than 90% (4); otherwise charging current is equal to its predetermined value.

$$I_{(\text{charging})} = I_{(\text{pre-defined})} - \left[100 - \text{SOC(\%)}\right]/100$$

(3)

As sudden changes in the current injected to the battery likely cause damages to the battery, increasing and decreasing ramp rates are considered to determine the reference values. After the battery gets charged, the battery will go back to discharging mode. On the other hand, when the microgrid is disconnected from the main grid (islanding mode), microgrid management expects the battery to participate in voltage and frequency regulation process. In this case, BMS changes the operation mode of the battery to islanding mode as long as the SOC does not exceed its limits. Fig. 3 also illustrates how BMS works when the microgrid is in islanding mode. As soon as the microgrid connects again to the main grid, BMS changes the battery control mode to discharging or charging mode according to the value of SOC [9].

Fig. 3: Function of battery mode identification system

C. Closed Loop Feedback Controller (CLFC)

The main objective of the closed loop feedback controller is to control VSC in order to achieve the goals defined by BMIS. Two different control systems realize microgrid expectations: power control and voltage-frequency control loops. According to BMIS output, CLFC enables either power control loop or voltage-frequency control loop.

1. Power Control Loop: The power control loop gets enabled when the battery control is in grid-connected or charging mode and its duty is to regulate the active and reactive power output from the battery/converter to the microgrid. The CLFC proposed is also capable to regulate dc- and ac-link voltages. Variables in the abc system in the above circuits can be transformed into a
synchronous reference frame. DC voltage control is based on balance of active power flow the battery and main grid

\[
V_{d1}=-(R_{d1}+L_{d1}(di_{d1}/dt))+w_{s}L_{d1}i_{q1}+V_{d}
\]

\[
V_{q1}=-(R_{q1}+L_{q1}(di_{q1}/dt))+w_{s}L_{q1}i_{d1}
\]  (4)

2. Voltage and Frequency Control Loop: The PCC three-phase voltage is measured and transformed into a reference frame[5]. Three-phase current flowing between the loads and the inverter is measured and transformed to \( I_{d} \) and \( I_{q} \). With the comparisons of the \( d \)q voltages to their respective references, the resulting errors are sent to the PI controllers to generate the required output voltage of the VSC. The frequency of the ac voltage which supplies passive loads is also controlled by the VSC. An internal oscillator is used to generate the angle, which is used as the input of \( dq \) to abc transformation and ensures the frequency of output voltage is kept at 50 Hz if PWM scheme applied. The steady state voltage of the system:

\[
V_{d1}=w_{s}L_{d1}i_{q1}+V_{d}
\]

\[
V_{q1}=-(R_{d1}+L_{d1}(di_{d1}/dt))+w_{s}L_{q1}i_{d1}
\]  (5)

4. CO-ORDINATED CONTROL STRATEGIES

A. Grid-Connected Mode

When the SOC of the battery is 13%, SOC meets its minimum limit (5%) Consequently, BMIS turns the operation mode from discharging mode to charging mode in order to prevent the battery against depth of discharge damages. BMIS also changes the operation mode from discharging mode to charging mode and the active power reference toward predefined charging power respect to operation mode from discharging mode to charging mode and the against depth of discharge damages. BMIS also changes the discharging mode to charging mode in order to prevent the battery limit (5%). Consequently, BMIS turns the operation mode from

The battery contributes in frequency regulation when the microgrid is connected to the main grid. A droop equal to 3% is assumed for the battery system and added to modify the reference. active power. Since the primary frequency regulation requires fast response, the charging and discharging rate limits imposed in the previous case studies are not imposed in this case study.

The main grid is modeled as a voltage source with controllable frequency. The frequency of the microgrid drops to 49.5 Hz jumps to 50.5 Hz, and comes back to 50 Hz after 5 seconds. As soon as the frequency falls, the battery increases its active power delivery by,

\[
\frac{(P_{base})(R).(-\text{change in F})/(F_{base})}{kW}
\]  (6)

The active power output of the battery reduces in response to the frequency increase, and settles back on its original value when frequency gets 50 Hz again. No change occurs in the reactive power output of the battery and PCC voltage of the microgrid.

B. Autonomous Mode

When the microgrid is disconnected from the main grid, BMIS is expected to change the battery operation mode to islanding mode in order for the CLFC to regulate frequency and ac voltage of the microgrid. BMS is also expected to provide a smooth transition from the grid connected mode to the islanding mode shown in fig 4. During the transient period, the battery is expected to provide voltage and frequency support quickly[4].
6. CONCLUSION

In this paper, an SOC-based battery management system (BMS) has been proposed to control the battery at both grid-connected and islanding operation conditions. The simulation results demonstrate the effectiveness of the control strategies through the SOC-based battery management system.

REFERENCES


