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Controlling SCIG-based Wind Turbine to Satisfy the Power System Operator's Requirement

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Abstract

In this paper, the integration of a battery system into a SCIG-wind farm is investigated so that this wind farm satisfies the grid code's two requirements including active power control and ride through fault ability. A control scheme coordinating between the battery system and the wind turbine's pitch control system is proposed. The coordinating principle, the storage system's control diagram and the pitch controller are described in detail. Simulation results indicated that the wind farm's active power output satisfies the power system operator's demand no matter of the full charge state of the battery and it can ride through after a fault on the grid.

Keywords: *SCIG, battery, control coordination, pitch control, generation schedule*

1. Introduction

Renewable energy resources such as wind, solar, wave…have been prioritizing to exploit in order to replace conventional resources like gas, coal… Until now, many wind farms installed and exploited effectively in the word. In many countries, the total capacity of wind farms goes up to several GW and they play an essential role in meeting the electric demand in there. Among the prediction of European Wind Energy Association, 11.6%-14.3% of the total electric demand in EU in 2020 is supplied by wind resource [1]. However, the integration of wind farms brings many negative effects on the connected power system such as voltage fluctuations, frequency variation due to the difficulty in maintaining active power balance and so on especially for a squirrel-cage induction generator (SCIG)-based wind farm [2-5]. The main reason is that its power output heavily depends on wind velocity which varieties second by second.

To reduce above-mentioned impacts, the grid code has required that wind farms must possess a good power, frequency and voltage control ability. Moreover, wind farms must have a good fault-ride-through (FRT) capability after a fault on the connected grid [6]. For wind farms using SCIG, they are hardly to meet these requirements due to its uncontrollable power.

Many publications, [7-17], pointed out methods that help wind farms to reach to these requirements. Authors in [7-9] recommended that reactive power compensation equipments such as STATCOM, SVC and so on should be installed at SCIG-based wind farms to improve their FRT ability. Moreover, a battery system was also offered as an effective method for wind farms so that their power output becomes smoother or constant [10-15]. In addition, in references [16-17], authors also gave methods so that a wind farm can operate as a conventional power plant. However, in these references, authors only focus on variable speed wind farms using PMSG or DFIG.

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This paper will research the use of battery storage to improve SCIG-based wind farm's power control ability. A control method based on coordination between storage's control system and turbine pitch controller is proposed in order that the wind farm can generate among a generation schedule of the power system operator (PSO). Moreover, in this paper, the battery storage system is used as a STATCOM to support the voltage at the point of common coupling (PCC) and the wind farm's FRT ability. Controller systems are described in detail and they are tested under Matlab/Simulink environment. Simulation results will be analyzed and compared to the case of no battery.

2. Configuration of Wind Farm

Two fundamental components of a wind turbine are a turbine consisting of blades and a generator. These parts are connected together via a shaft system and a gearbox. The main task of the turbine is to convert the kinetic energy of wind into mechanical one rotating its shaft. The generator converts mechanical energy to electrical energy supplying to the connected grid. Type of generator using in this turbine is SCIG. With this generator, its stator winding can be connected directly to the grid. However, the connected grid must supply reactive power to the stator winding to produce the flux in SCIG. Consequently, to reduce reactive power on the grid, a reactive power compensator like capacitor bank, SVC, STATCOM and so on is normally installed at the terminal of SCIG.

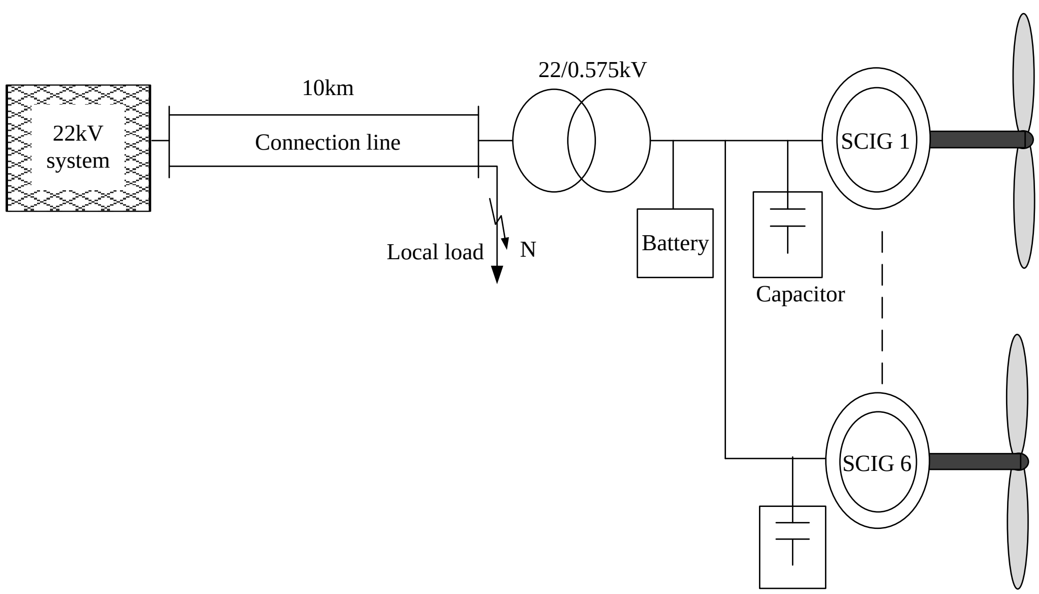


Figure 1. Configuration of SCIG Wind Farm Connecting to the Grid

Naturally, SCIG-based wind turbine can hardly control its active power output. To remain active power output of SCIG-wind farm among a foreseen generation schedule, a storage system like battery bank is required to install at the wind farm. With this configuration, the storage system can accumulate surplus electric energy (active power) in or release it to the grid as needing Therefore, power output of whole wind farm can be adjusted.

In this research, the wind farm consists of 6 SCIG –wind turbines, 1.5MW for each. The wind farm is connected to a 22kV power system via 0,575/22kV transformer and 10km overhead line as shown in Figure 1. During operation, the SCIG-based wind farm must absorb reactive power from the grid [7-8]. A capacitor is installed at each generator to lessen the amount of reactive power supplied from the connected grid. Moreover, in this wind farm, a battery storage system is installed to improve its power control ability. This storage is connected to the wind farm via an AC/DC converter, a filter and a step up transformer, as Figure 2a.

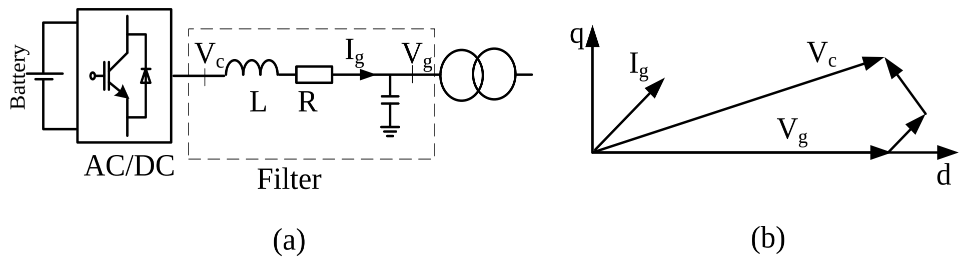


Figure 2. Battery System (a) and Phase Diagram (b)

3. Control System

3.1. Overall of Coordination Control

In this suggested configuration, the battery's task is to charge or discharge electric energy so that the wind farm's power output is satisfied the order quantity of PSO (P_{ord}). It is so important to ensure that during operation, the state of charge of storage (SOC) is maintained in a normal operation range, from 10% to 90% [18]. When the SOC value reaches to 90%, the storage is not allowed to charge more energy. On the other hand, it is not allowed to discharge if the SOC value becomes below 10%. Therefore, when the SOC value is over 90%, the pitch controller will shoulder maintaining the generators' power output at the grid code's request as possible. The principle of coordination is indicated in Figure 3a. The active power reference values applying to the battery system's controller and the pitch control system are designated as Figure 3b and Figure 3c, respectively

As can be seen from the Figure 3b, the reference power value applied to i^{th} turbine P_{scig_ref} is equal to its rating power ($P_{scig\_ref}=1/n$) if the SOC value is below 90%. Otherwise, it is designated based on wind speed at i^{th} turbine W^i, operation state α^i and order quantity P_{ord}. If W^i is between cut-in speed and cut-out speed and the i^{th} turbine is operating, α^i will be equal to 1. Otherwise, it is zero. Because the generators cannot be allowed to generate over the rating power so the value of W^i and P_{scig_ref} must be limited by their rated value, W^i_{rated} and $1/n$, respectively. Note that power measurements are referred to the rating power of the wind farm and n is the number of turbines in the wind farm.

In Figure 3c, if the SOC value is smaller than 10% the reference power value of the storage system $P_{b\text{-}ref}$ only receive negative values. It means that the battery system is only allowed to store the electric energy. When the SOC value is over 10%, $P_{b\text{-}ref}$ is difference between total power output of generators $P_{scig\sum}$ and P_{ord}. From Figure 3b, when the SOC value reaches to 90% the pitch controller will adjust so that the maximum power output of wind farm is equal to P_{ord}. When the SOC value, consequently, is over 90%, $P_{b\text{-}ref}$ will be equal to zero because $P_{scig\sum}$ is equal to P_{ord}.

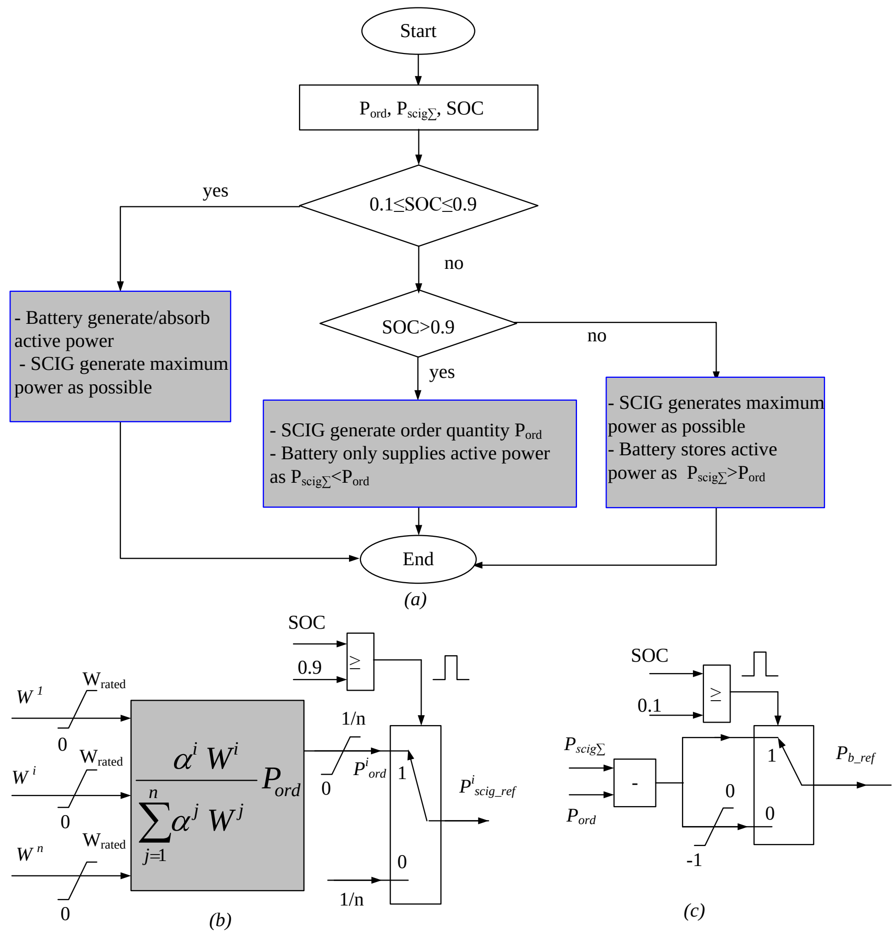


Figure 3. Principle of coordination between turbine and battery (a), pitch controller's active power reference (b) and battery's reference power (c)

3.2. Controller Applied to Battery Storage System

The main objective of controller applied to the battery's AC/DC converter is to adjust the active power output of the storage system to its reference value P_{b_ref}. The second objective is to maintain a constant voltage at the point of common coupling (PCC). It means that the battery system plays the role of a STATCOM to support reactive power for the wind farm.

In *dq* frame, which *d*-axis is oriented in the direction of V_g vector and *q*-axis is 90^o head of *d*-axis Figure *2b*, the power output of the AC/DC converter can expressed in equation (1).

$$\begin{cases} P_b = V_g I_{gd} \\ Q_b = -V_g I_{gq} \end{cases} \qquad (1)$$

From this equation, to control the active power output of the storage system, I_{gd} component needs to be adjusted while I_{gq} is used to regulate the reactive power or the voltage at PCC.

The relationship between current and voltage in the AC side of the AC/DC converter in *dq* frame is described in equation (2). From this equation, PI controllers can be employed to accommodate I_{gd} and I_{gq} components to reference values, $I_{gd\ ref}$ and I_{gq_ref}, respectively. The control diagram applied to the AC/DC converter is demonstrated in Figure 4. In this figurer, P, I, V, ω, θ correspondingly represent for active power, current, voltage, angle speed and phase angle of V_g vector. Subscripts *ref, g, PCC, d* and *q* stand for reference value, grid side, the point of common coupling, d-axis and q-axis, respectively.

$$\begin{cases} \frac{di_{gd}}{dt} = \frac{1}{L}(V_{cd} - V_g) - (\frac{R}{L}i_{gd} - \omega i_{gq}) \\ \frac{di_{gq}}{dt} = \frac{1}{L}V_{cq} - (\frac{R}{L}i_{gq} + \omega i_{gd}) \end{cases} \tag{2}$$

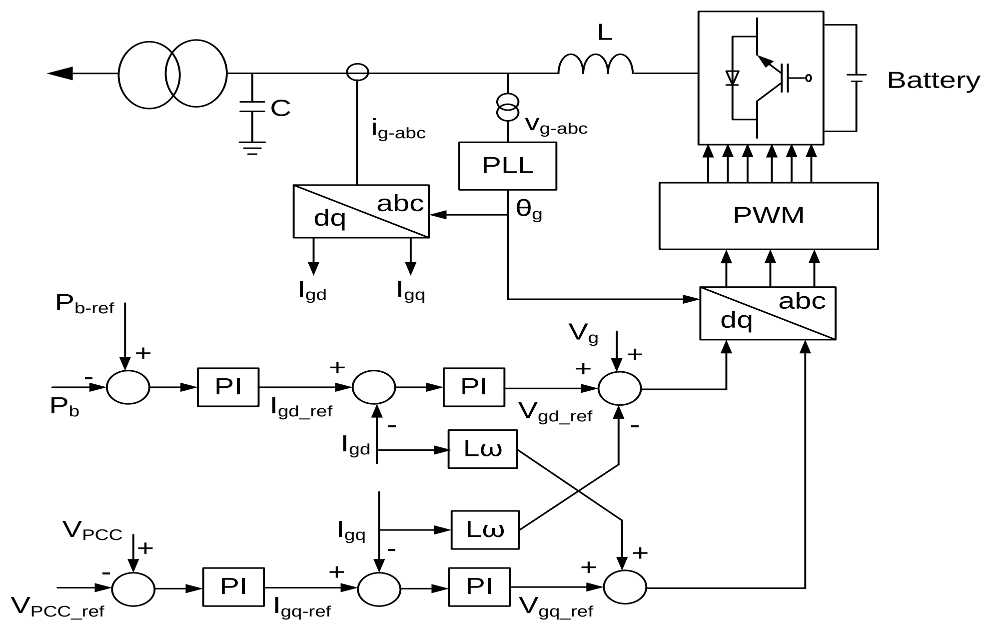


Figure 4. Control Diagram Applied to the AC/DC Converter

Figure 4 indicates that the reference active power of the storage system $P_{b\text{-}ref}$ is difference between the total power output of generators and the power system's order quantity ($P_{b\_ref} = P_{scig\sum} - P_{ord}$). Active power error (between P_{b_ref} and the battery's actual power output P_b) and voltage error (between V_{PCC_ref} and V_{PCC}) designate reference currents, I_{gd_ref} và I_{gq_ref}, via PI controllers. Likely, reference voltages, V_{gd_ref} và V_{gq_ref} is decided by the current errors, which the corresponding values for I_{gd_ref} and I_{gq_ref} are respectively I_{gd} and I_{gq}, via PI controllers. V_{cdq_ref} components for the AC/DC converter can be calculated from V_{gdq_ref} components and voltage drop on the filter. The *dq/abc* block will convert V_{cdq_ref} into three-phase voltage V_{cabc_ref} based on the phase angle of V_{gabc}. The PWM block will generate pluses to supply to the valves of the AC/DC converter.

3.3. Pitch Control System

The objective of the pitch control system is to adjust the angle of blades so that the maximum power output of SCIG is equal to P_{s_ref}. Control diagram is shown in Figure 5.

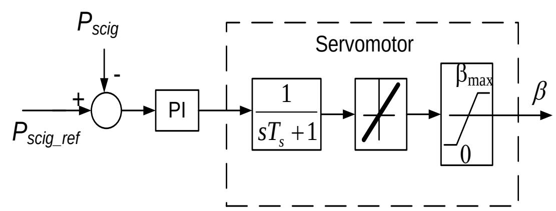


Figure 5. Pitch Control Diagram

4. Simulation Results

4.1. Steady State Operation

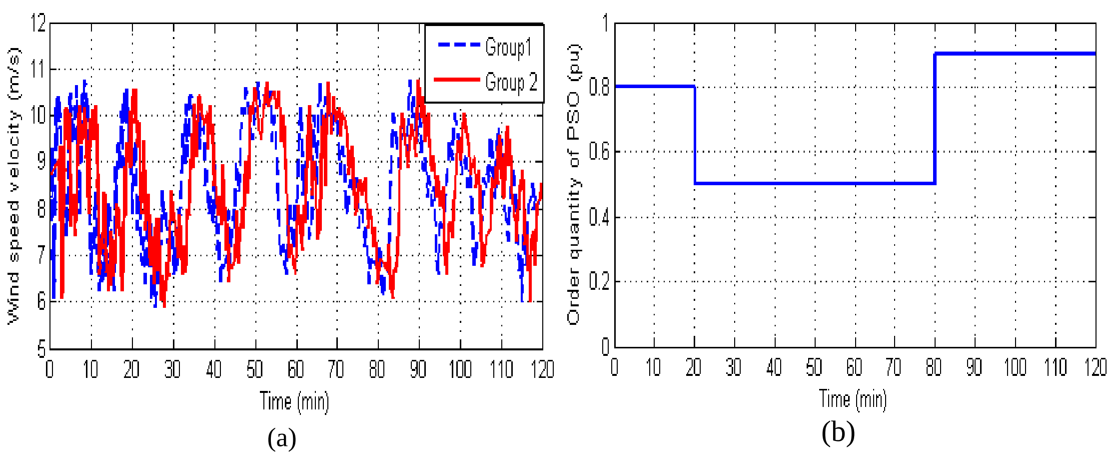
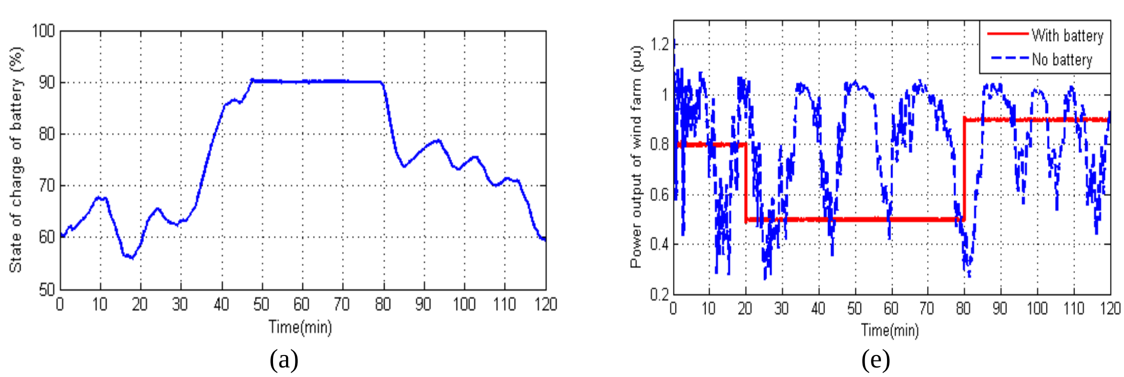
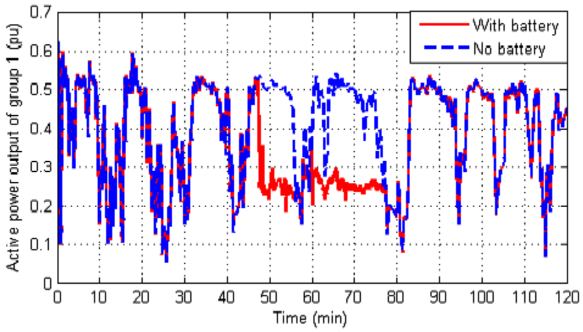


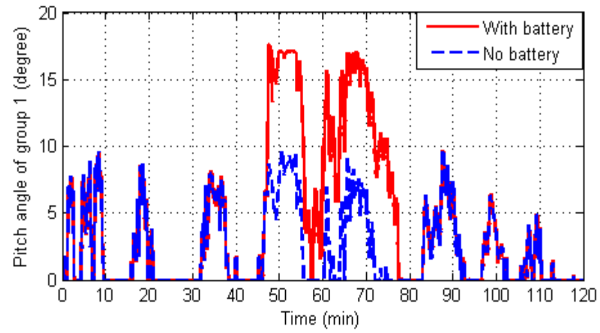
Figure 6. Wind Speed (a) and Generation Schedule (b)

In this research, to test the effectiveness of control system, the storage system installed in this wind farm has a capacity of 8000Ah and a rating voltage of 228V. To increase simulating speed, this wind farm is modeled by two SCIG-turbines, 4,5MW for each, and wind speed attacking to them is indicated in Figure 6a. It is assumed that PSO requires this wind farm to generate among a generation schedule as shown in Figure 6b. In this research, the initial value of SOC is set at 60%. Simulation results are demonstrated in Figure 7.

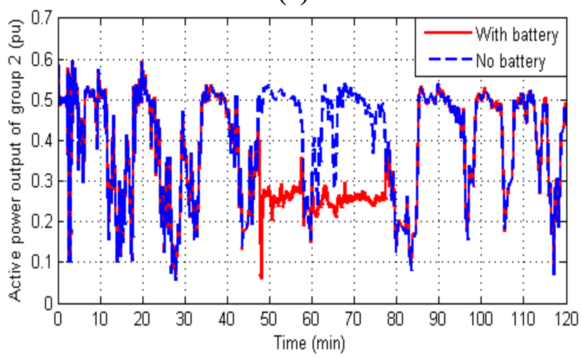




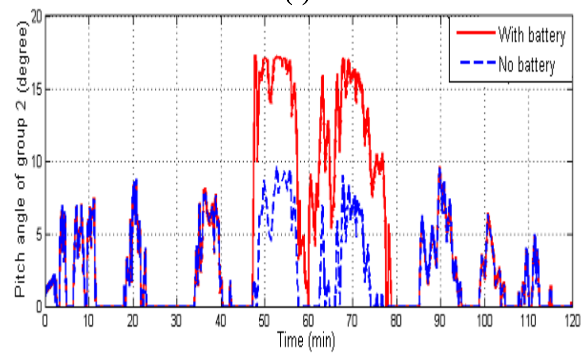
(b)



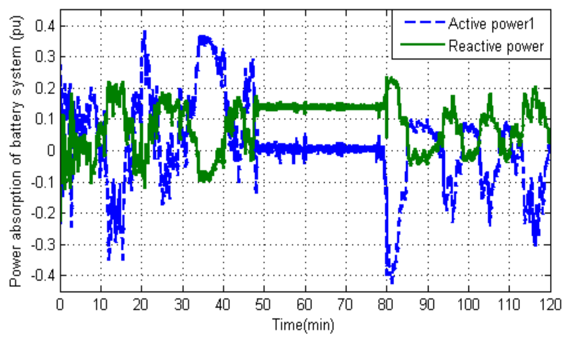
(f)



(c)



(g)



(d)

Figure 7. Simulation Results: the SOC Value of Battery (a), Active Power Output of group1 (b), Active Power Output of Group2 (C), Battery's Power Absorption (D), Active Power Output At PCC (E), Pitch angle of Group1 (f), Pitch Angle of Group2 (g)

As can be seen from Figure 7, before minute 48, because the order quantity is smaller than the power output of SCIGs, a part of this power is stored in the battery system. The SOC value, consequently, increases but it is still below 90%, Figure 7a. Therefore, the SCIG-turbines generate maximum power output as possible. In other words, they operate the same as the case of no battery, Figure 7b and Figure 7c. Thank to the storage system, which can generate or absorb active power, Figure 7d, the active power delivering to the connected grid completely satisfies the order quantity of PSO, Figure 7e.

However, after minute 48, the SOC value reaches to 90%, the pitch controller starts adjusting the power output of generators to meet the demand of PSO. It is clear that the pitch angle of these turbines is higher than that in the case of no battery, Figure 7f and

Figure 7g. As a result, the power output of generators is lower compared to the case of no battery. Note that due to the difference in wind speed between the two turbines their power output is a little different, Figure 7b and Figure 7c. From minute 48 to 79, the battery almost does not exchange the active power for the grid because the total power output of generators is already in balance to the order quantity.

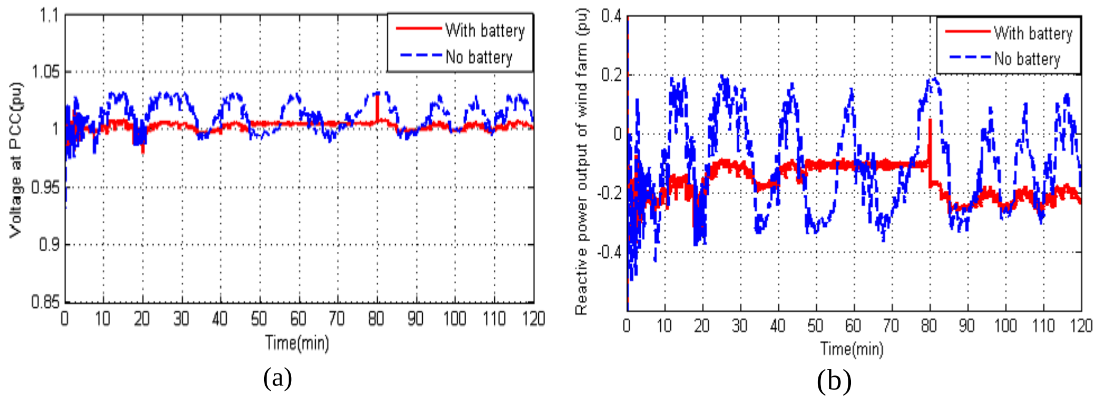


Figure 8. Simulation Results: PCC Voltage (a), Reactive Power Output of Wind Farm (b)

The final period of simulation, due to the high demand of PSO the storage system must supply the active power to the grid so the SOC value is declined. Consequently, wind turbine-generators operate the same as the case of no battery and the power output of the wind farm still keeps the demand of PSO.

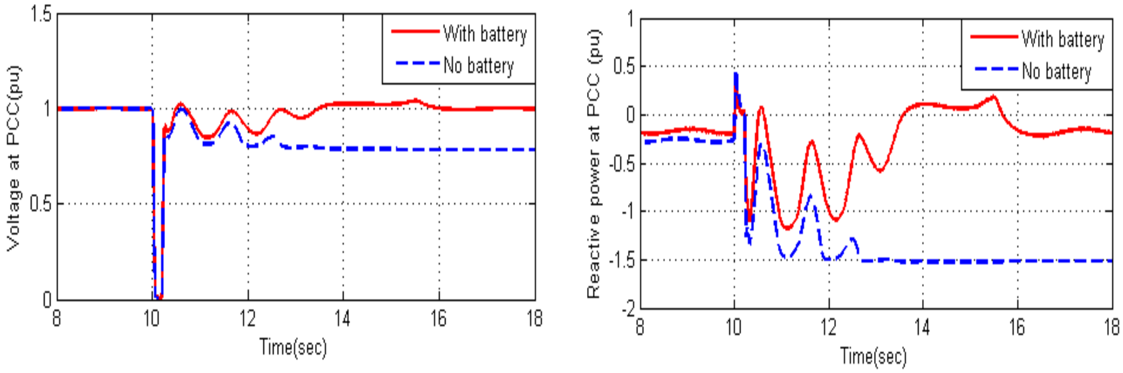
Concerning to the PCC voltage, during the simulation period, the PCC voltage is smoother than that in the case of no battery and it is around the rated value, Figure 8a. The main reason is that the battery system supports the reactive power to the wind farm as shown in Figure 7d. As a result, the reactive power, which the connected grid must supply to the wind farm, is smaller and smoother comparing to the case of no battery, Figure 8b.

It is clear that with the battery system and the recommended control plan, the power output of the wind farm completely meet the generation schedule of PSO. Moreover, the battery system also supports the maintaining of the PCC voltage at the rated value.

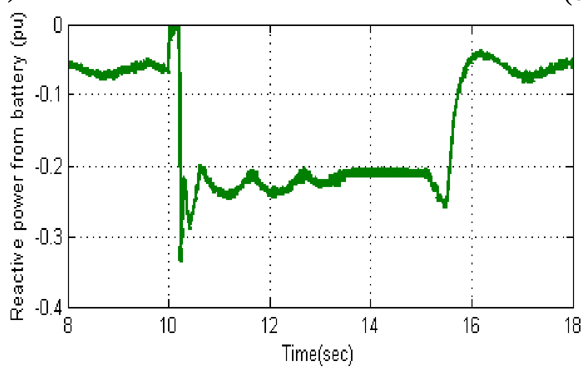
4.2. Dynamic-operating Condition

To test the support of the battery to the PCC voltage under dynamic condition, it is assumed that wind velocity at the turbines is 9m/s, PSO's order is 0.5pu and the initial value of SOC is 60%. Fault occurs at point N, which locates behind the circuit breaker of the local load feeder in Figure 1, at 10s with duration of 120ms. Simulation results are indicated in Figure 9.

As can be seen from Figure 9a, after fault clearance, the voltage at PCC is recovered while in the case of no battery, it is impossible. The main reason is that after fault, the battery system supports a lot of reactive power to the wind farm, as shown in Figure 9b. Consequently, amount of reactive power, which the wind farm absorbs from the connected grid, is smaller comparing to the case of no battery, Figure 9c. This makes the PCC voltage be restored easily. It is clear that with the battery system, the wind farm becomes stable after a fault on the grid.



(a) (b)



(c)

Figure 9. Simulation Results: PCC voltage (a), Reactive Power Absorbed by the Battery (b), Reactive Power at PCC (c)

5. Conclusion

This investigation aims to improve the SCIG-wind farm's power control ability, which allows it to generate among a generation schedule of PSO, by integrating the battery system. A control scheme, which is based on coordination between the storage system's controller and the pitch control system, is proposed. Simulation results indicated that the power output of this SCIG-based wind farm completely meets the order quantity of PSO. The battery system also operates as a STATCOM to support reactive power to the wind farm. Thanks to this, the PCC voltage in the normal operation is smoother than that in the case of no battery. Moreover, the battery system also contributes to maintaining a stable operation of the wind farm after a fault on the grid. Therefore, with the storage system and the suggested control scheme, the wind farm completely operates as a conventional plant like a thermal or hydro one.

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