



POWER BALANCING UNDER VARIOUS STATES (TRANSIENT & STEADY STATE) AND FAULT WITH SMES AND PHEV CONTROL

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ABSTRACT

This paper presents a power balancing for the power distribution grid which integrates renewable energy generation (WIND/ SOLAR by PV) and electric vehicles together. With the use of superconducting magnetic energy storage control system (SMES) any transient and fault unbalance caused by wind power photovoltaic (PV) power variation can be recovered. So that the system frequency can be stabilized also, with the use of PHEV's, the steady state load demand and fault can be redistributed to facilitate the adoption of wind power and PV power generation. The simulation and experimental results confirm that with the use of both SMES and PHEV's can effectively perform power balancing from the transient, steady states and fault condition.

Index Terms— superconducting magnetic energy storage (SMES), Electric vehicles, frequency regulation, load regulation, power grid, renewable generation (WIND/ SOLAR by PV), fault rectification.

1. INTRODUCTION

The renewable generations especially wind power and photovoltaic power is becoming more desirable to integrate into the existing power grid to overcome global energy crisis, environmental pollution and fault rectification, while electric vehicles especially the plug-in hybrid electric vehicles (PHEV) are becoming attractive for green transportation. Because of the intermittent nature of the wind power, it is a challenge to maintain transient, steady state balances and fault clearance of the power grid. Recently, the super conducting magnetic energy storage has been introduced to alleviate the problem of power imbalance.

With ever increasing popularity of PHEVs, the vehicle-to-grid (V2G) operation provides an opportunity to utilize the energy stored in vehicle batteries as distributed power plants. Namely, the PHEVs not only draw power from the grid to charge batteries but can also feed power back to the grid when necessary.

In this paper, the SMES is incorporated into the power system having wind power units, PV power units and PHEVs. Then, a coordinated control algorithm is proposed to perform load, frequency regulations and fault clearance.

2. SYSTEM DESIGNING

Fig. 1 shows a 33-bus 4-lateral radial distribution system which includes 3 SMES units, 3 wind power units, 2 PV power units and 10 PHEV units. Initially, the capacity of wind power generation is selected as 35% and PV power generation is selected as 5% of the total generation capacity installed while the capacity of PHEV is set to 10% of the total load demand, which are the near-term targets for modern cities.

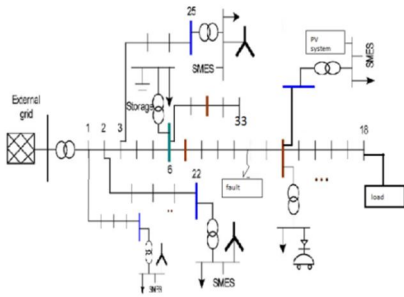


Figure.1Proposed distribution system

The subsystem for superconducting magnetic energy storage system is shown in fig.2. It can be observed that the wind power and PV power cannot directly relieve the base load without energy storage, since the rest of base load generally coincides with the trough of wind power and PV power.

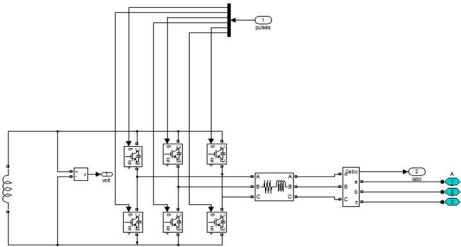


Figure 2 Subsystem for SMES

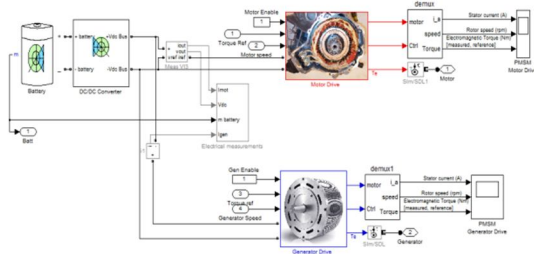


Figure .3 subsystem for PHEV

The wind power units are modeled as fixed-speed wind turbines. They include two types of power converters, namely the AC-DC and DC-AC, for the desired voltage conversion. The PHEV units comprise of PHEVs and bidirectional DC-AC converters.

Since each PHEV may not offer sufficient energy storage or V2G operation, an aggregator is used to represent a group of PHEVs. And the storage capacity of the PHEV aggregation can be determined based on the capacity of the iron-board battery packs, it shown in fig.3. The PV power units comprise

of PV cell and bidirectional DC-AC converters.

The control strategy for the SMES unit has three main functions namely, the frequency compensation control which detects the frequency fluctuation of the load and generates the reference value for the converter; the converter system control which regulates the power output of SMES; and the DC-DC chopper control which coordinates the power transfer according to the reference power output.

3. POWER BALANCING PROCESS

In the proposed distribution system, the energy from all sources and loads are coordinated to perform power balancing, frequency control and fault compensation. This coordinated control comprises of two parts: the hourly timescale and the secondly timescale. In the hourly timescale, the EV charging and discharging are controlled to reform the load profile. In the secondly timescale, the SMES system is used to compensate the transient fluctuation of wind power and PV power generation.

In order to devise the sizes of SMES and PHEVs with respect to the level of wind power and PV power generation, the average wind power and PV power generation are P_{WT} , P_{PV} respectively, the average PHEV charging power P_{PHEV} and the SMES power capacity P_{SMES} are described by

$$P_{PW} = P_{PV} + P_{WT} \quad (1)$$

$$P_{PW} = k_{PW} P_{AD} \quad (2)$$

$$P_{PHEV} = k_V P_{PW} = k_V k_{PW} P_{AD} \quad (3)$$

$$P_{SMES} = k_M P_{PW} = k_M k_{PW} P_{AD} \quad (4)$$

Where P_{AD} is the average power demand of the daily load

profile k_{PW} is the proportional constant of the wind power and PV power to the load demand, k_V is the proportional constant of PHEV charging power to the wind power, and k_M is the proportional constant of SMES power capacity to the wind power.

Since the PHEV serves for the steady-state power balancing while the SMES for the transient power balancing, their energy storage capacities should satisfy the wind energy fluctuation as described by

$$P_{PHEV} T + \int P_{SMES} dt > a_p \int P_{PV} dt \quad (5)$$

Where T is the charging period of PHEVs, a_p is the coefficient of the available energy constraint

provided by PHEVs and SMES. It actually shows the minimum PHEV and SMES storage capacities that can mitigate the fluctuation effect of wind power and PV power generation. Since the SMES is designed to perform transient stabilization of the power grid, the corresponding energy capacity E_{SMES} and power capacity P_{SMES} need to satisfy the following criteria

$$E_{SMES} > a_f(\max(P_{pv}(t) - P_{pv}(t - \Delta T))\Delta T) \quad (6)$$

$$P_{SMES} > b_f(P_{pv,max} - P_{pv,min}) \quad (7)$$

$$\Delta P_{SMES} / \Delta t > c_f(\max(P_{pv}(t) - P_{pv}(t - \Delta t)) / \Delta t) \quad (8)$$

Where P_{pv} is the wind and PV power generated output at time t , ΔT is the time interval of wind power fluctuation, a_f is the coefficient of the SMES energy capacity constraint, $P_{pv,max}$ and $P_{pv,min}$ are respectively the maximum and minimum values of wind and PV power fluctuation, b_f is the coefficient of the SMES power capacity constraint, ΔP_{SMES} is the change of SMES power, Δt is the time interval to assess the rate of change of SMES power, and c_f is the coefficient of the SMES power adjustment rate constraint. The boundary conditions for the PHEV stop

$$\int P_{PHEV_i}(t) dt = E_{PHEV_i,max} - E_{PHEV_i,int} \quad (9)$$

$$E_{V2G} / E_{PHEV} \leq r_{V2G} \quad (10)$$

Where $P_{PHEV_i}(t)$ is the charging or discharging rate of the PHEV aggregation I , $E_{PHEV_i,max}$ and $E_{PHEV_i,int}$ are respectively the maximum and initial energy storages of the PHEV aggregation at the end and beginning of the charging period. E_{V2G} is the energy that is discharged from PHEV batteries back to the power grid and r_{V2G} is the V2G ratio which is defined as the ratio of the energy fed back to the power grid by discharging the PHEVs to the energy drawn from the power grid for charging the PHEVs.

The power balancing control method is attractive for V2G operation which can optimize the load regulation of the power grid. In this paper, this method is extended to minimize the total power losses under the hourly timescale and to minimize the grid frequency fluctuation under these conditions. The overall objective function F_o is

$$F_o(P_{PHEV}(t_H), P_{SMES}(t_S), P_{PW}(t)) = \min(w_1 F_1 + w_f F_f) \quad (11)$$

Where

- t_H - time under hourly time scale
- t_S - time under secondly time scale
- w_1 - weight for load regulation
- w_f - weight for frequency regulation
- F_1 - function for load regulation
- F_f - function for frequency regulation

Consequently, the proposed power distribution grid incorporating wind power and PV power generation, PHEVs and SMES as well as the proposed coordinated control algorithm are analysed using MATLAB simulation.

4. SIMULATION RESULTS

A. Transient Regulation

Due to low storage capacity, the SMES unit cannot perform as a power source or load to level the hourly load profiles. Nevertheless, it can be used to effectively stabilize the grid frequency in the transient state. As shown in Fig. 8, the SMES unit is connected to the bus of the wind generator so as to directly compensate the power discrepancy due to the wind speed variation and solar energy variation.

As aforementioned, the energy and power capacities of SMES are sized by using. Particularly, the parameter a_f indicates the minimum amount of SMES energy capacity for the system. In order to assess the most appropriate amount of SMES energy capacity for satisfying the constraint of grid frequency variation, a SMES index K_{SMES} is defined as

$$K_{SMES} = \frac{E_{SMES}}{(\max(P_{pv}(t) - P_{pv}(t - \Delta T))\Delta T)} > a_f \quad (12)$$

Where

ΔT is the time interval that the SMES unit is activated to compensate the maximum power fluctuation of the wind generator and solar energy variation. Under the same condition of wind power fluctuation, the grid frequency profiles with and without using the SMES unit are shown in Fig. 7. It can be found that the grid frequency swings below 49.5 Hz in the absence of SMES, which is not acceptable for normal power distribution grid.

On the contrary, when adopting the SMES system with $K_{SMES} = 0.5$, the frequency variation can be significantly suppressed. Fig. 8 depicts the corresponding SMES

power under $K_{SMES}=0.5$, confirming that the SMES unit can instantaneously release and absorb power to stabilize the transient fluctuation.

B. Steady-State Regulation

The distribution of nominal load, namely the base load plus wind power and PV power generation, as well as the distribution of nominal load plus PHEV load under uncontrolled and controlled operations. The uncontrolled operation refers to the standard charging of PHEVs, whereas the controlled operation refers to the PHEV load under the proposed coordinated control.

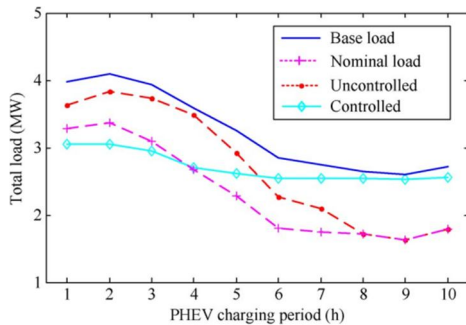


Figure 4 Load profiles with and with out coordinated control.

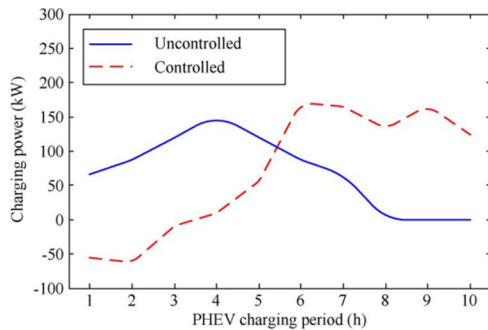


Figure 5 PHEV charging power profiles with and without coordinated control

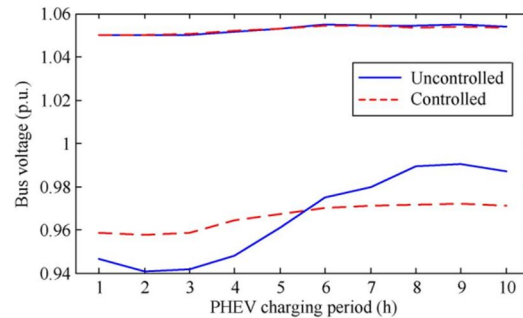


Figure 6 Bus voltage range profiles with and without coordinated control

It can be seen that the use of coordinated control can effectively reduce the peak bus load at the 6 buses with PHEV connected. Line loading rate is an important limiting factor for accommodating high load demand. The maximum line loading can be reduced by a third so that a higher level of PHEV penetration is allowed since all the PHEVs should be charged up before each daily usage, the charging period is set from evening 6pm to next morning 5am, which indicates that the heavy load occurs at first few hours whereas light load occurs at last few hours. Notice that the load fluctuation of the nominal load is larger than that of the base load, that the wind power is almost anti-phase with the base load. In the presence of coordinated control, the load profile can be effectively leveled. The charging and discharging rate of each PHEV aggregation is varied according to the solution of optimal control algorithm. At a particular bus, both the uncontrolled and controlled PHEV charging loads are plotted together in Fig. 5. It can be observed that the controlled PHEVs feed power back to the grid in first few hours, thus confirming the use of V2G operation under coordinated control. Moreover, the maximum and minimum bus voltages with and without using coordinated control are plotted together in Fig. 6. It confirms that the use of coordinated control can curtail the bus voltage droop to less than 6% of the nominal value.

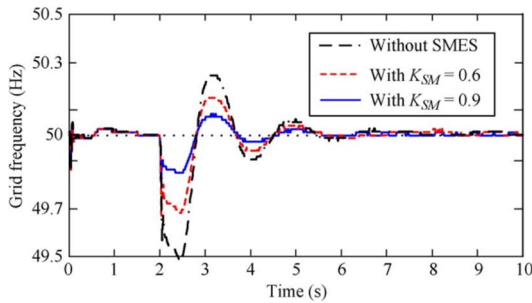


Figure 7 Frequency profile with and without the SMES system.

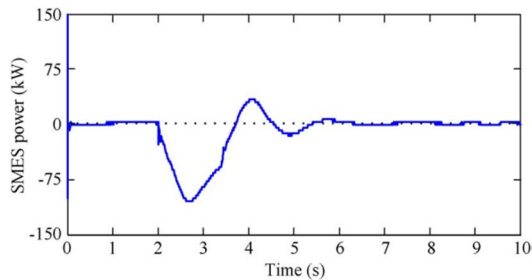


Figure 8 Response of the SMES to the sudden change in the wind power

C. Fault Rectification

A three phase fault is a condition where either (a) all three phases of the system are shortcircuited to each other, or (b) all three phase of the system are earthed. When the circuit breakers get opened as well as PHEVs and SMES discharged that maximum value with respect to the time.

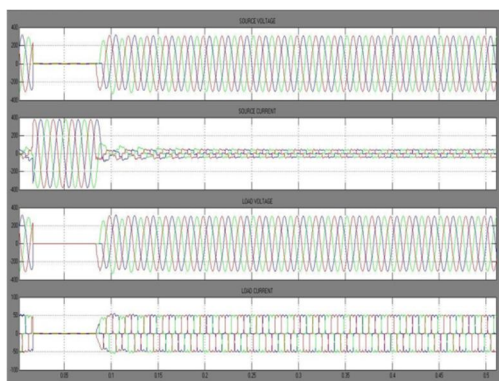


Figure .9 Grid system with fault

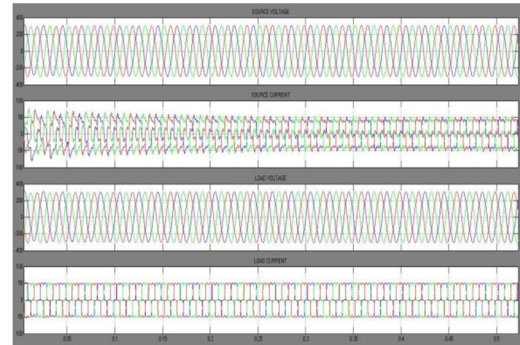


Figure.10 SMES and PHEV without fault



Figure.12 SMES and PHEV with fault

Then the maximum demand will be supplied by both SMES and PHEV power units. It can be observed that the controlled PHEVs feed power back to the grid in first few hours, thus confirming the use of V2G operation under coordinated control. The simulation output for the fault rectification is shown in fig.11.

5. CONCLUSION

In this paper, improve the power generation, by using the renewable sources as wind and solar, wind energy is the major sources for producing enormous power generation and also analyzing the maximum wind speed of the wind energy system by using MATLAB/SIMLINK. The coordinated control method of SMES to supply and absorb transient power, the transient frequency fluctuation can be effectively stabilized. Enhancing the fault clearance using SMES and PHEV. The grid interfacing inverter can inject real power generated from wind and PV to the grid and thus eliminates the power imbalance to improve the quality of power. Power quality enhancement can be achieved under three different



scenarios: i) $P_{PW} = 0$ ii) $P_{PW} <$ total load power and iii) $P_{PW} >$ total load power. The simulation results verify that the proposed power distribution grid and the proposed coordinated control can provide effective load regulation and frequency stabilization.

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