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# Power Balancing Under Transient and Steady State 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.*

**Keywords:** *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

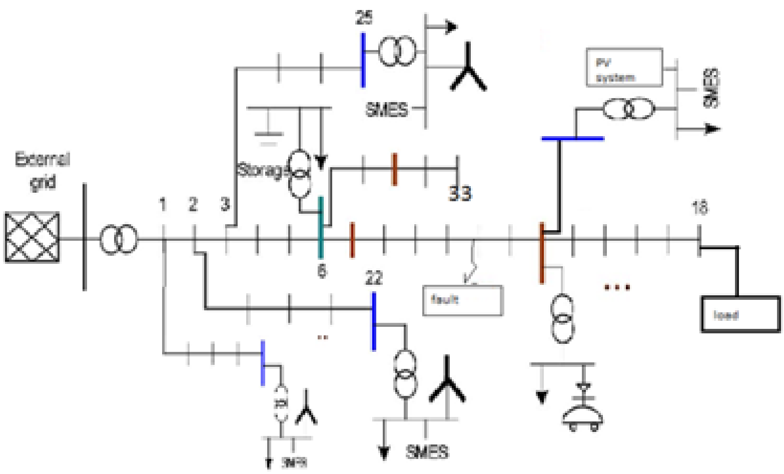


**Fig1.** *Proposed distribution system*

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 PHEVs is set to 10% of the total load demand, which are the near-term targets for modern cities.

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 crest of base load generally coincides with the trough of wind power and PV power.

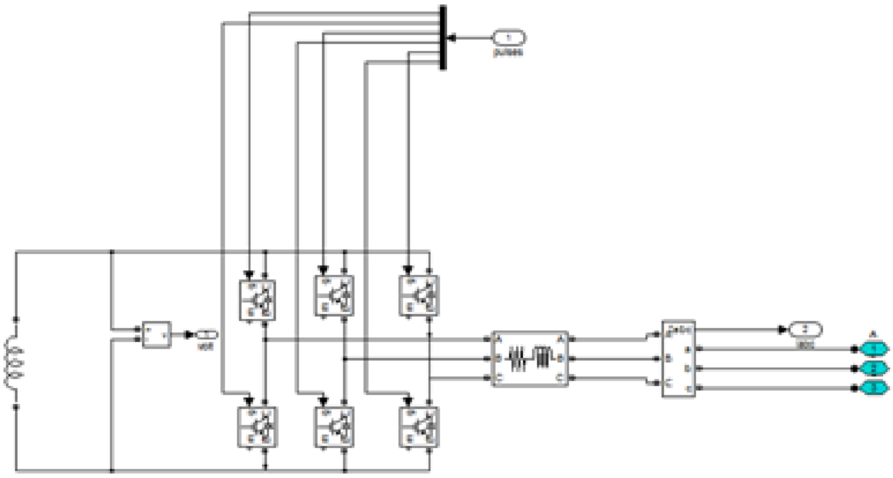

**Fig2.** *Subsystem for SMES*

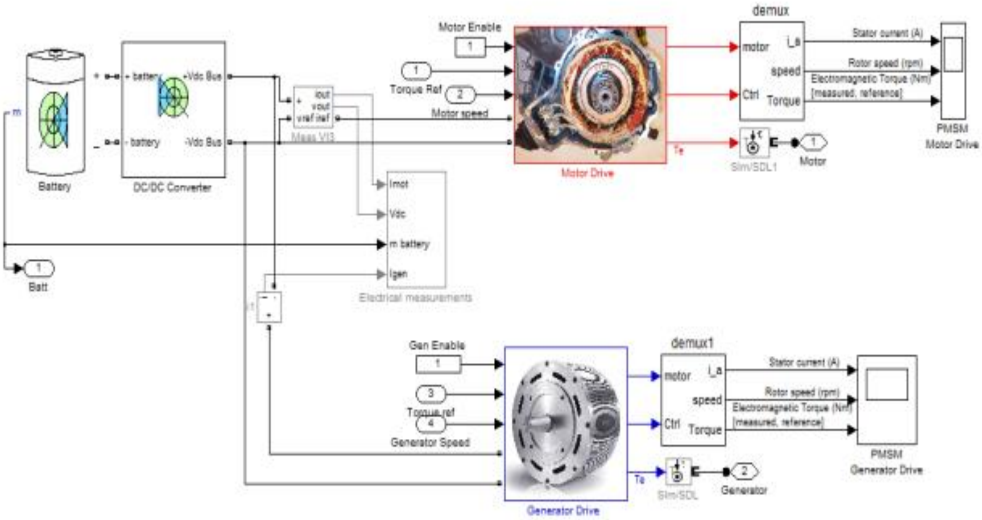


**Fig3.** *Subsystem for PHEV*

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 for 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 their on-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 units 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 time scale and the secondly time scale. In the hourly time scale, the EV charging and discharging are controlled to reform the load profile. In the secondly time scale, 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, $\Delta T$ is the time interval of wind power fluctuation ,$a_f$ is the coef- ficient 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 $\Delta p_{SMES}$ is the change of SMES power, $\Delta t$ 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 PHEVs to perform load regulation of the power grid are given by

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

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

Where $P_{PHEVi}(t)$ is the charging or discharging rate of the PHEV aggregation I, $E_{PHEVi,max}$ 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 en- ergy 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 time scale and to minimize the grid frequency fluctuation under the secondly time scale. The overall objective function $F_o$ is

$$F_O(P_{PHEV}(t_H), P_{SMES}(t_S), P_{PW}(t)) = \min(w_1F_1+w_fF_f) \quad (11)$$

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

### 4.1. 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

$$K_{SMES} = \frac{ESMES}{(\max(Ppv(t) - Ppv(t-\Delta T))\,\Delta T)} > a_f \quad (12)$$

Where $\Delta T$ 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.

### 4.2. Steady-State Regulation

The distribution of nominal load, namely the base load plus wind power and PV power generation, as well as the distributions 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.

It can be seen that the use of coordinated control can effectively reduce the peaky bus load at the 6 buses with PHEVs connected. Line loading rate is an important limiting factor for accommodating higher 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 6 pm to next morning 5 am. which indicates that 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.

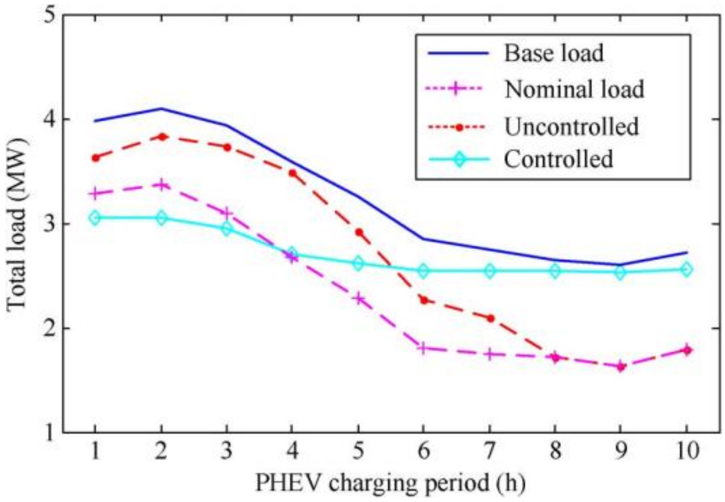


**Fig4.** *Load profiles with and without coordinated control.*

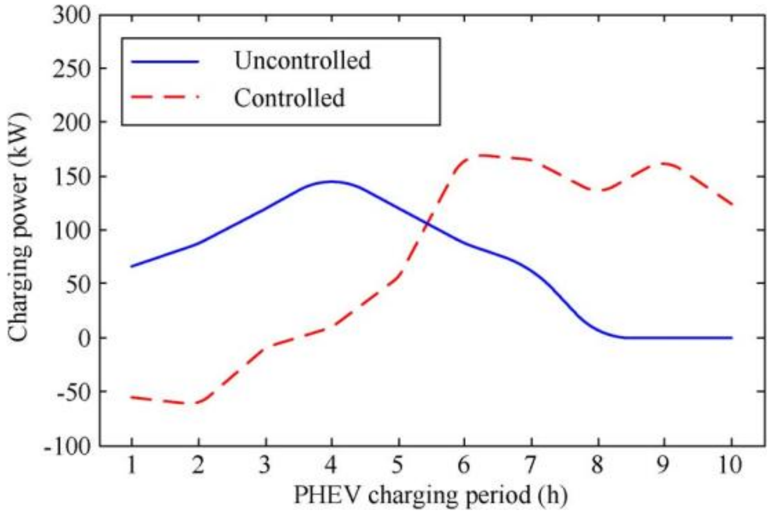


**Fig5.** *PHEV charging power profiles with and without coordinated control*

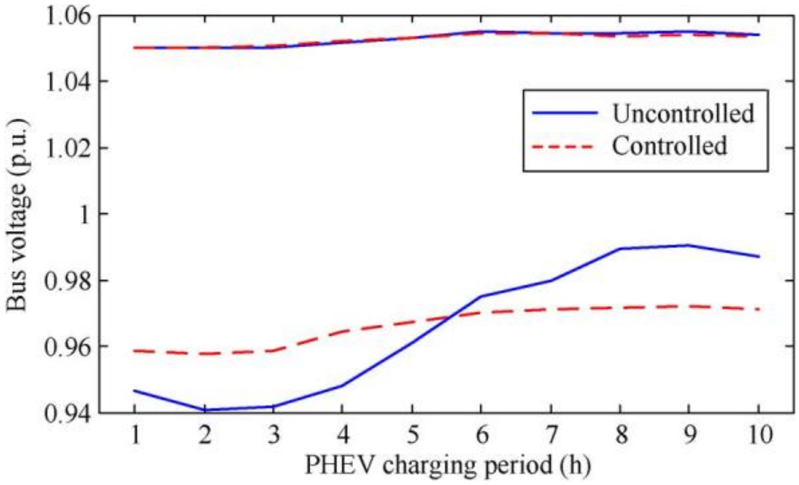


**Fig6.** *Bus voltage range profiles with and without coordinated control*

The charging and discharging rate of each PHEV aggregation is varied according to the solutions of optimal control algorithm. At a particular bus, both the uncontrolled and con- trolled 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 drop to less than 6% of the nominal value.

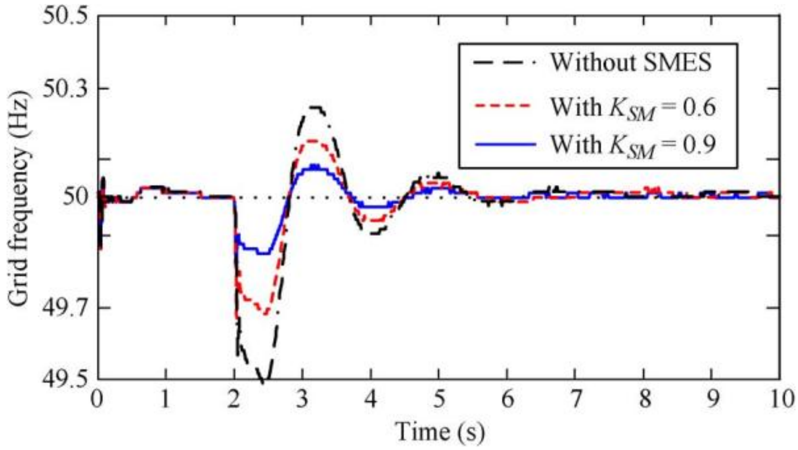


**Fig7.** *Frequency profile with and without the SMES system*

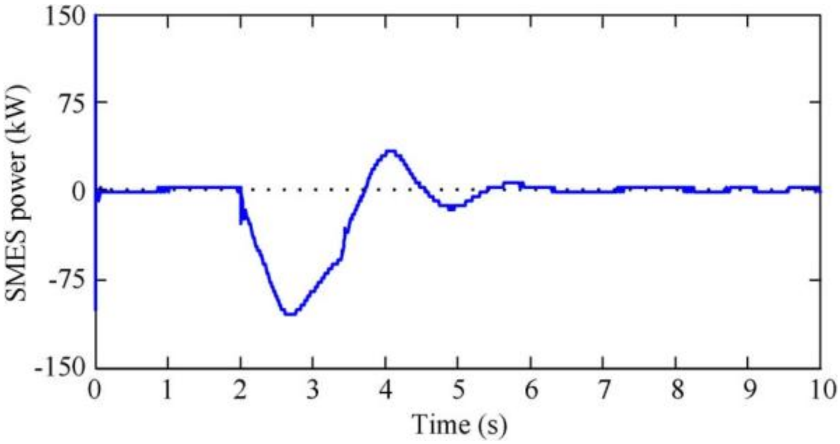


**Fig8.** *Response of the SMES to the sudden change in the wind power*

### 4.3. Fault Rectification

A three phase fault is a condition where either (a) all three phases of the system are short circuited 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.

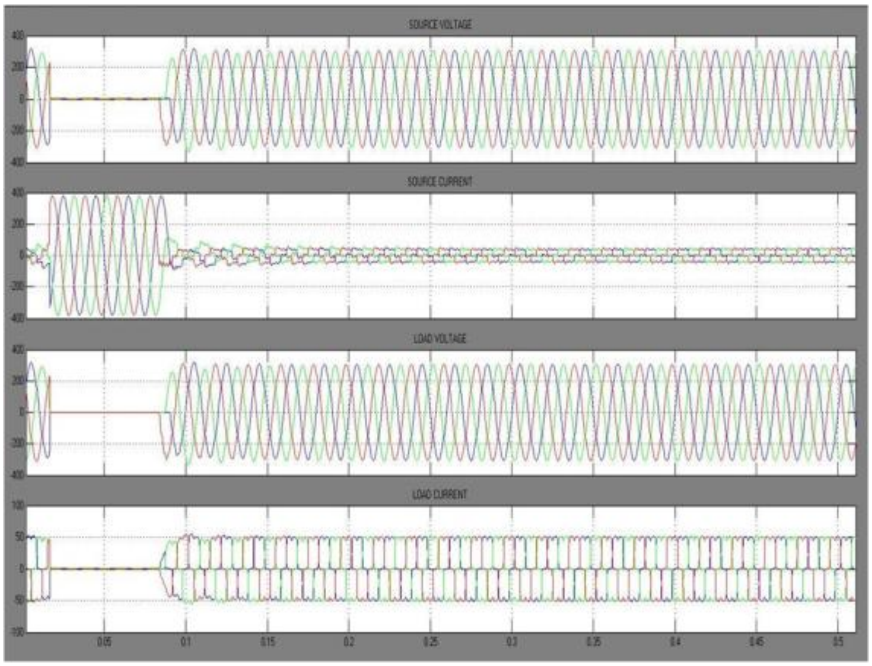


**Fig9.** *Grid system with fault*

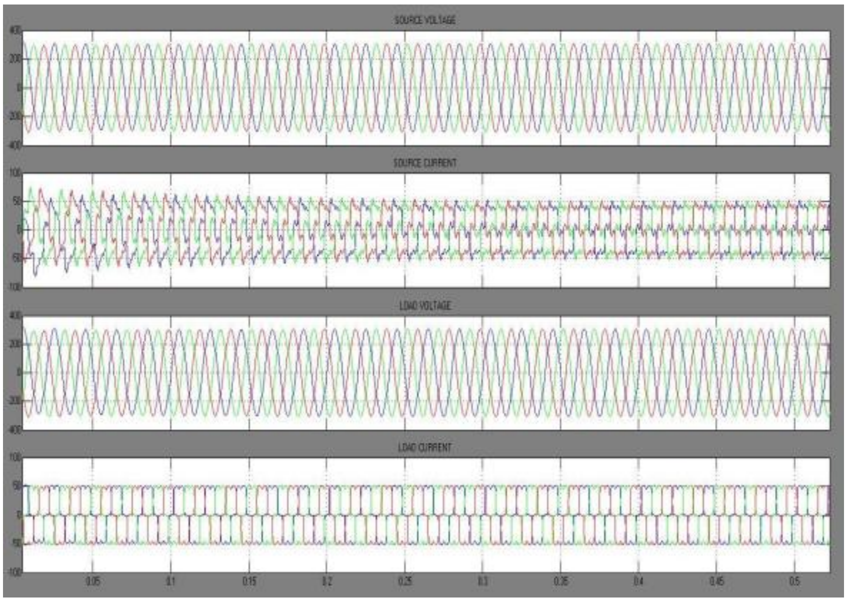


**Fig10.** *SMES and PHEV without fault*

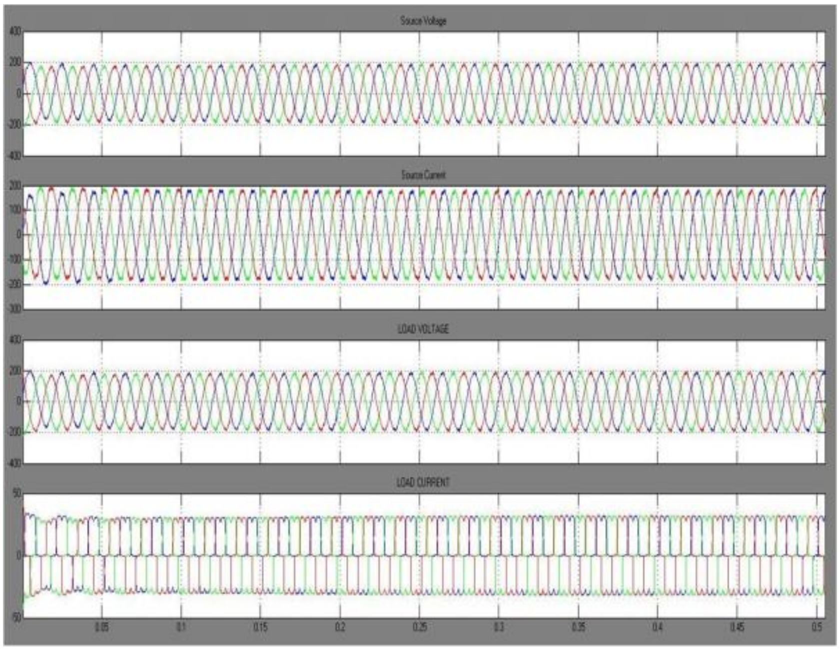


**Fig12.** *SMES and PHEV with fault*

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.

## REFERENCES


[1] C. Liu, K. T. Chau, and J. Z. Jiang, “Design of a new outer-rotor perma- nent-magnet hybrid machine for wind power generation,” IEEE Trans. Magn., vol. 44, no. 6, pp. 1494–1497, 2008.

[2] C. Liu, K. T. Chau, and X. Zhang, “An efficient wind-photovoltaic hy- brid generation system using doubly-excited permanent-magnet brush- less machine,” IEEE Trans. Ind. Electron., vol. 57, no. 3, pp. 831–839, 2010.

[3] K. T. Chau and C. C. Chan, “Emerging energy-efficient technologies for hybrid electric vehicles,” Proceedings of IEEE, vol. 95, no. 4, pp. 821–835, 2007.

[4] A. R. Kim, H. Seo, G. Kim, M. Park, I. Yu, Y. Otsuki, J. Tamura, S. Kim, K. Sim, and K. Seong, “Operating characteristic analysis of HTS SMES for frequency stabilization of dispersed power genera- tion system,” IEEE Trans. Applied Supercond., vol. 20, no. 3, pp 1334–1336, 2010.

[5] Database of State Incentives for Renewables and Efficiency [Online]. Available: http://www.dsireusa.org/incentives/index.cfm

[6] C. D. White and K. M. Zhang, “Using vehicle-to-grid technology for frequency regulation and peak-load reduction,” J. Power Sources, vol. 196, no. 8, pp. 3972–3980, 2011.

[7] P. S. Moura and A. T. Almeida, “The role of demand-side management in the grid integration of wind power,” Applied Energy, vol. 87, no. 8, pp. 2581–2588, 2010.

[8] S. Gao, K. T. Chau, C. C. Chan, C. Liu, and D. Wu, “Optimal control framework and scheme for integrating plug-in hybrid electric vehicles into grid,” J. Asian Electric Vehicles, vol. 9, no. 1, pp. 1473–1481, 2011.

[9] S. Gao, K. T. Chau, C. C. Chan, and D. Wu, “Loss analysis of ve- hicle-to-grid operation,” in IEEE Vehicle Power and Propulsion Con- ference, Lille, 2010, pp. 1–6.