SMES Implanted Smart Grid- For the EV Charging System

Sunu Antony

Engineering Student, Electrical and Electronics Dept., A P J Abdul Kalam Technological University, Kerala, India

Abstract- **The battery lifetime of an electric vehicle (EV) has significant impact on the development of EV. In this paper a method with Superconducting Magnetic Energy Storage (SMES) is used to improve the battery lifetime of EV. The SMES is stabilizing the EV charging system voltage to improve battery life and charge efficiency on a smart grid. To verify the influence of the controlled SMES improves the system transient stability, situations under load fluctuation and fault, and the SMES capacity for system compensation have been investigated. The results obtained from the analysis indicate the compensating instantaneous voltage dip in the grid and improving the power system quality. So SMES increasing the power quality and stability of the EV system.**

Index Terms- Electric vehicle (EV), smart grid, voltage stability, superconducting magnetic energy storage (SMES), Current Source and voltage source converter (CSC and VSC), Fuzzy logic control.

I. INTRODUCTION

ELECTRIC vehicles are principal choice for green transportation .Electric vehicle (EV) technology is recognized by many countries as a key component to reduce harmful green-house gas emissions. The main component of greenhouse gas is carbon di oxide. Burning one gallon of gas creates 20 pounds of carbon dioxide, and the average car emits about six tons of carbon dioxide every year. So zero-emission battery-powered electric vehicles (EVs) are making the road transport system to green transportation system. So the demand of EV increases. The EV development will result in more and more EV-charging-stations being built in the near future. The increased number of power system will increases the burden of the power system and it will affect the stability and safety of the power supply. How adequately distribute the power supply is the challenging subject. At the same time quality and continuity of the electric power supplied is also important for the effective function of the EV. The studied identified the possible influences on the power system due to the electric vehicle charging and discharging time.

Some studies present optimal charging/discharging method for minimizing costs of charging or maximizing profits from discharging, i.e., vehicle-to-grid (V2G).In EV were assumed to be charged from a state-of-charge (SOC) of 30%at a constant charge rate until full, EVs were assumed to be charged from the fully discharged state and charge rates of each EV were assumed to vary in a continuous manner.

So the enable device in the power supply, superconducting magnetic energy storage (SMES), may eliminate the influence. When EV charged, SMES will mitigate the secondary side voltage fluctuation of the transformer caused by the fault or variable load on the grid.

Due to the burden of the power supply, increases the usage of renewable energy resources such as photovoltaic power plant. By using SMES system the load curve, diminishing the voltage fluctuation, increasing the power quality and stability. SMES is an outstanding power compensator, will provide active and reactive power with very quick response in order to compensate the voltage in the EV charging stations.

Since EV introduce uncertainty in charging or discharging state, smart grid with EV face much more complicated situation. Nowadays several fault is occur in metropolitan area especially during thunderstorm, the transient stability must be essential. So the dynamic performance analyzed under balanced fault such as three phase to ground fault.

II. SMES: OVERVIEW

SMES is initially conceived as load leveling devices that is it is used to store energy in bulk and also to smoothening the utility's daily peak demand. In SMES, the electricity is stored by circulating a current in a superconducting coil. Because of no conversion of energy to other forms is involved, its efficiency is very high. SMES can respond very rapidly to absorb or receive power from the grid/load. Because of its fast response, SMES can provide benefit to a utility not just as a load-leveling device, but also for enhancing transmission line stability and power quality. So SMES can be viewed as a Flexible Transmission system (FACTs)

SMES applications in Transmission Substation are;

Transmission Stability, Voltage/VAR Support. Load Leveling.

SMES applications in Generation System are;

Frequency Control, Spinning Reserve, Dynamic Response

The basic principle of SMES is to store energy in the magnetic field generated by a dc current flowing through the coiled wire. Magnetic field produces heat when normal wire is used for wounding the coil. The coil is a DC device, the charge and discharge are usually done through an AC utility grid, so a power conditioning system (PCS) is required as the interface. PCS can use a standard solid state DC/AC converter for transferring the power back and forth between the superconducting coil and load/grid.

The PCS interfaces the superconducting magnet(DC) with the utility grid(AC).The DC/AC conversion is done using through inverter/rectifier composed of SCR and GTO arrangement with a specified duty cycle. The losses in PCS during idling and conversion are important for determining the plant efficiency. SMES system shows the difference depending upon the size and duty cycle. The core of the SMES is High Temperature Superconducting coil (HTS).Depending upon the size of application, the coil may be solenoid or toroid. Solenoid coil are much more cost effective for large SMES system.

III. SYSTEM MODEL

A.SMES Modeling:

There are two classes of SMES model-Current Source Converter (CSC) and Voltage Source Converter (VSC) based on the different connection way of converter. Both converters used to control power exchange between the system and power into the system SMES by independently adjusting its active and reactive. The main requirement of converter in the power transmission system is to control the active and reactive power flow to maintain its system voltage stability. It is achieved by the electronic converter and the electronic convert electrical energy from AC to DC.

For VSC, the input voltage is kept constant and output voltage is independent of load. For CSC, the input current is kept constant and output current is independent of load. Modern High Voltage DC (HVDC) transmission using VSC or CSC. Self commutated VSC is more flexible than that of conventional CSC since they allow to control active and reactive power and reactive power independently. The VSC consisting of a DC chopper and a PWM inverter. So VSC is a two stage circuit whereas CSC is a single stage circuit. Hence the current source converts are cheaper compared to voltage source converters when only reactive power is to be converted. Compaired with VSC based SMES, the CSC based SMES hold the advantages of simple structure, much lower cost and easier control.

The CSC based SMES is shown in Fig 1.The CSC based SMES consist of a 3 Winding Transformer, High Tension Superconducting coil(HTS coil),2 sets of 6–pulse bridge converter,12-pulse generator, controllers, filters and the refrigeration system. The SMES unit simply controlled by changing the delay angle α of the 12-pulse generator which generate correct gate signal control signal to control the successive firing angle of the thyristor.

Here 3 winding transformer is used. This transformer having 3 windings and the 3rd winding is known as tertiary winding. The main advantages of 3 winding transformers are it reduces the unbalancing in primary winding due to the 3phase fault and redistributing the flow of fault current.

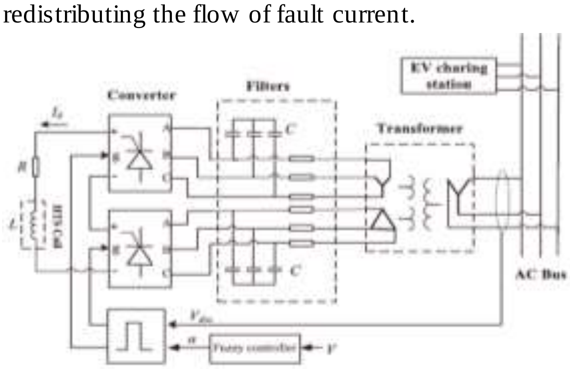

Fig. 1. Scheme of the SMES incorporated to an EV charging system.

If the delay angle α is greater than 90º, thyristor converter work as inverter. So the SMES units release power to the smart grid. If the delay angle α is less than 90º, thyristor converter work as rectifier .So the SMES unit absorb power from the smart grid. The assumption that thyristor voltage drop in converter is neglected for CSC based SMES.

Parameters	Values
HTS material	Bi 2223
HTS inductance (L)	2H
Filter capacitor (C)	0.03 F
Snubber resistance (R_s)	$1\times 10^{5}\ \Omega$
Turn-On resistance (R_l)	$1\times 10^{-3}\ \Omega$
Lossy resistance (R_L)	$1\times 10^{-5}\ \Omega$
Load resistance (R)	2Ω

TABLE II Parameters of SMES

When HTS coil charged, the current flowing through the HTS coil at any time t;

$$I(t) = I(0)\ e^{-Rt/L} + [V_{dc}/R] * [1 - e^{-Rt/L}] \quad \ldots\ldots \quad (1)$$

When HTS coil discharges, the current flowing through the HTS coil at any time t;

$$I(t)=I(0)\ e^{-[R+R_{load}]t/L} \quad \ldots\ldots\ldots\ldots\ldots \quad (2)$$

Where;

I(t)- Final current flowing through the HTS coil

I(0)- Initial current flowing through the HTS coil

V_{dc}-DC voltage of the converter

R- Resistance of the converter DC side

R_{load}- Equivalent load resistance when discharging start

B. Control Modeling:

Fuzzy logic is an approach to compute based on the degree of truth rather than using usual true or false Boolean logic. The SMES unit having 2 input variable and one output variable. The practical voltage V and the deviation rate of voltage ΔV are selected as input variable. The delay angle α is selected as output variable.

Fig 2 shows the block diagram of fuzzy control algorithm;

It is used in EV charging station to operate the SMES unit.

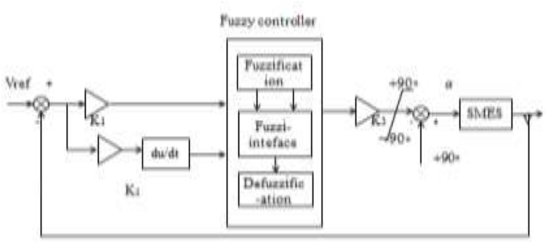

Fig 2 Block diagram of fuzzy controller algorithm

The proportional coefficient K1, K2, K3 is used to adjusting the range of fuzzy field. The fuzzy logic control conduct fuzzy interface according to the fuzzy rule table.

α	ΔV			
		N	Z	P
V	N	S	D	D
	Z	A	S	D
	P	A	A	S

TABLE II Fuzzy Rule Table

Gaussian membership functions for V and ΔV are shown in the Fig 3 and the triangular membership function α shown in Fig 4.

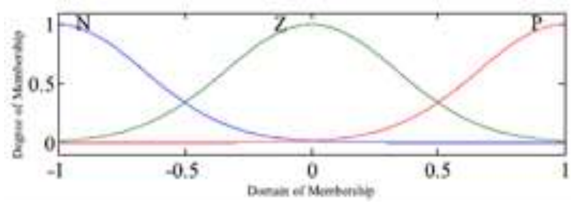

Fig 3 Membership function for V and ΔV

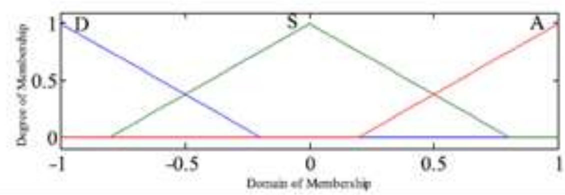

Fig 4. Membership function of α

The letters N, Z, P in Gaussian membership functions are Negative, Zero and Positive respectively. The letters D, S, A in Triangular membership functions are Decrease, Standby and Add respectively. Fuzzy controllers are very simple conceptually. They consist of an input stage, a processing stage, and an output stage. From the block diagram, the fuzzy logic controller consists of Fuzzification, Fuzzy interface and Defuzzification process.

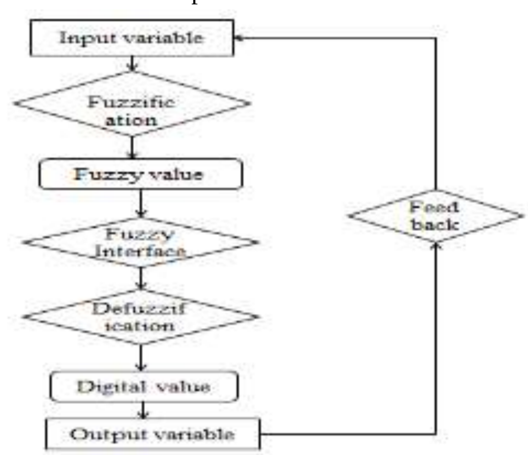

Fig 5 Step of fuzzy logic controller design

The step of the fuzzy logic controller design is described in the following;

Fuzzification: It is the process of changing real scalar value into fuzzy values.
Fuzzy rule base: The specific feature of the proposed fuzzy controller has two input variables and one output variable

Fuzzy interface: For the inference of the fuzzy controller design, Mamdani's method is used. When analogy input is transformed into digital figure, microcontroller will judge the best subordinate degree for the variable. Then, according to the fuzzy rule, the output can be worked out.

Defuzzification: It is the process of producing quantifiable result in crispy logic. Centroid way is adopted in the proposed system. Firstly, in this method, one needs to compute the area that membership functions and abscissas axis enclosed. Secondly, the centrality of this region will be regarded as the value of variable set.

C.EV-Charging –station Modeling:
Li-ion battery with very high energy density is are widely used in EVs.Li-ion battery is a special type of rechargeable battery in which the Lithium ions move from the negative electrode to positive electrode during discharge and back when charging. Li-ion battery uses intercalated lithium compound as electrode. Instead of using intercalated lithium, metallic lithium used as electrode in non-rechargeable lithium battery. Properties of Li-ion batteries are as follows;

Specific Energy	100-265 W.h/Kg
Energy Density	250-693 W.h/L
Specific Power	250-350 W/Kg
Charge/Discharge Efficiency	80-90%
Self-Discharge Rate	2% per month
Cycle Durability	400-1200 cycles
Nominal Cell Voltage	NMC 3.6/3.85V LI Fe PO4 3.2V

A reliable and high energy density battery has achieved through the use of NMC cathode material and employment of a laminated cell structure. The layered structure of the NMC cathode material contributes large battery capacity So it helps to store high density of lithium-ion. The laminated cell structure contributes to space-saving, high cooling performance and simple structure. The battery capacity is highly reliable and durable and it has a warranty of 160,000km or 8 years.
The battery lifetime of Li-ion battery depends on the charge /discharge cycle, operation temperature and range of charging voltage. In order to avoid damaging of battery and improve the battery lifetime, the charge/discharge rate of EVs must be strictly limited to 20-80% of nominal capacity.
Assume that there are 5 EV charging station and 50 EV in an area is shown in the Fig 4.One EV enter into Charging station with same probability. At a particular time,
EV enter into EV charging station is approximately take as Poisson's Distribution with a mathematical expectation of 10.The probability of EV entering into an EV charging station is 5-15over 90%.So the SMES unit is not operated on the condition where the number is less than 4 and greater than 16

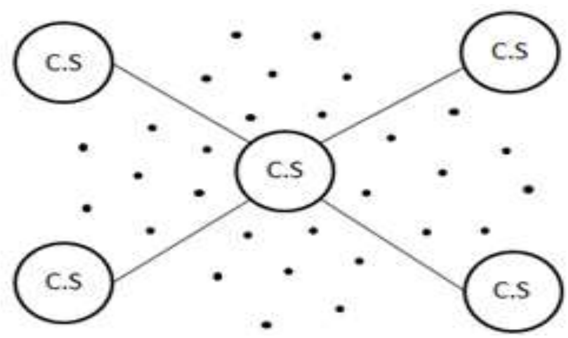

Fig 6. Sample area of grid with EVs
Where ;
● - Electric vehicle EV

-Electric vehicle charging station

D. Simulation System:

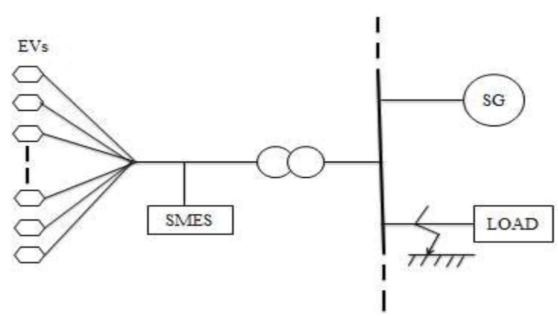

Fig 7. Topology of smart grid with EVs
Fig 7 shows the topology of smart grid with EVs. The system consists of a synchronous generator (SG), EV aggregated grid, CSC based SMES and load. The

CSC based SMES is connected to the grid to allow the power flow regulated properly. The CSC based SMES is connected to the grid only when the number of EV is large. The dynamic performance of the system is analyses under the balanced fault such as 3 phases to ground fault. The dynamic performance is analyzed for checking the transient stability of the system because the transient stability is essential.

The dynamic equation of synchronous generator (SG) is expressed as follows;

$$\frac{M}{\omega}\frac{d^2\delta}{dt^2} + \frac{D}{\omega}\frac{d\delta}{dt} = P_{mech} - P_{elect} \quad (3)$$

M -Inertia constant

D – Damping coefficent

δ - Load angle

ω – Rotor speed

Pmech – Mechanical power

Pelect – Electrical power

When fault occur, Pmech greater than Pelect .So the load angle δ will increases until the SMES unit starts to work.

IV.EFFECT OF SMES ON SMART GRID WITH EVS

Fig 8 shows the flowchart of SMES system working procedure.

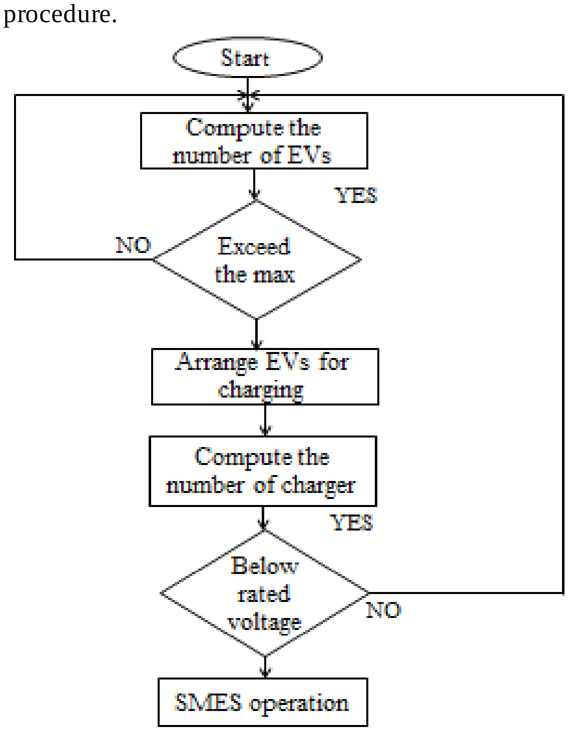

Fig 8 Flowchart of the system working procedure

Each EVs has only one electric battery with a rated capacity of 15 KWh.and the rated voltage of EV is set as 220V.The charging and discharging rate are considered as equal and its capacity is set as 0.3MWh.The number of EV is randomly selected as 5 to 15 in this simulation. When 10 EVs are enter into the station at the time 1 second, then the voltage of charger with and without SMES are different. That means the voltage of charger is 220V if the SMES is connected to the grid. Without SMES system, the voltage of charger is 1st 220V and then it decrease to a value due to the instability of voltage in the power system.

The SMES unit will smooth the concussion voltage of EV charging station charger when EVs are connected to the grid. The response of load angle δ for a 3 phase fault is obtained when simulation done.The SMES system with fuzzy control is effective for incresing the transient stability and the perormance of SMES with fuzzy control is better than that of SMES without the ontrol.

When the number of EVs is 15, then the fault period and compensation effect of voltage is determined by the SMES capacity. The current upper limit is adjusted to accommodate different capacity SMES systems. SMES can reduce the voltage fluctuations due to the jump of the SG electromagnetic power when the fault occurs and recovers.

So by using the SMES;

When considering the influence of the fault, the system with SMES shows better stability than without SMES.

For a certain number of EVs, the greater the capacity of the SMES is, the better the compensation of the voltage drop.

If the capacity of the SMES is determined, the smaller the number of EVs is, the better the compensation effect.

V.CONCLUSION

The controlled SMES unit improves the system transient stability, diminishing the voltage fluctuation, increasing the power quality and stability. SMES unit is connected to the grid only when the number of EVs is more. The SMES units will smoothen the concussion voltage of EV charging station agter the EVs are connected to the grid. If any fault occur , SMES unit able to respond quickly to restore load terminal voltage by compensating both active and reactive power of the system and improve system transient stability. Because SMES is an outstanding power compensator that provides active power and reactive power with a quick response to compensate the voltage in the EV charging station. The SMES unit has also been confirmed to be able to effectively compensating the instantaneous voltage dip of the load terminal, stabilize the power distribution network with EVs and improve their power quality.

REFERENCES

[1] K. T. Chau and C. C. Chan, "Emerging energy-efficient technologies for hybrid electric vehicles," Proc. IEEE, vol. 95, no. 4, pp. 821–835, Apr. 2007.

[2] S. P. Richardson, D. Flynn, and A. Keane, "Optimal charging of electric vehicles in low-voltage distribution systems," IEEE Trans. Power. Syst., vol. 27, no. 1, pp. 268–279, Feb. 2012.

[3] J. X. Jin and X. Y. Chen, "Study on the SMES application solutions for smart grid," Physics Procedia, vol. 36, pp. 902–907, 2012.

[4] C. A. Luongo, "Superconducting storage systems: An overview," IEEE Trans. Magn., vol. 31, no. 4, pp. 2214–2223, Jul. 1996.

[5] H. A. Peterson, N. Mohan, and R. W. Boom, "Superconductive energy storage inductor-converter units for power systems," IEEE Trans. Power App. Syst., vol. PAS-94, no. 4, pp. 1337–1346, Jul. 1975.

[6] M. H. Ali, T. Murata, and J. Tamura, "A fuzzy logic-controlled super-conducting magnetic energy storage (SMES) unit for augmentation of transient stability," Int. Conf. Power Electron. Drives Syst., 2005, vol. 2, pp. 1566–1571.

[7] S. C. Wang and J. X. Jin, "Design and analysis of a fuzzy logic controlled SMES system," IEEE Trans. Appl. Supercond., vol. 24, no. 5, Oct. 2014, Art. no. 5701205.

[8] T. Sannomiya and H. Hayashi, "Test results of compensation for load fluctuation under a fuzzy control by a 1kWh/MW SMES," IEEE Trans. Appl. Supercond., vol. 11, pp. 1908–1911, Aug. 2001.