

Modeling and Control of Power System Containing PV System and SMES using Sliding Mode and Field Control Strategy

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ABSTRACT

Although the great advance in power system production and operation, storage energy technologies and its control techniques can be considered as one of the most important and critical topics of power companies, government and consumers, especially when the power system containing renewable source and storage system simultaneously. In this paper, a novel electrical grid structure including photovoltaic system and storage system based on Superconducting Magnetic Energy Storage (SMES) has been proposed and investigated. The SMES produced power is injected in power system during specific time or when it required. Two control strategies for exchanged power Grid- SMES have been proposed and analyzed, the first uses sliding mode and the second uses field oriented control based on PI controller, also the injected SMES power is controlled by PID controller. In addition, the photovoltaic system operates at the MPP employing PID MPPT method. The proposed control strategies have been tested successfully in which many scenarios have been studied: standby and discharging of SMES, injection of SMES storage energy for variable and constant load and control of grid containing PV system. In addition, a comparative study of exchanged power Grid- SMES control using Sliding mode and field oriented control based on PI controller has been presented and discussed.

Keywords: Grid-PV-SMES, power integration, sliding Mode.

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1. INTRODUCTION

The last years have seen gradually an expansion on application in the storage energies, through all storage energies, the SMES (Superconducting Magnetic Energy Storage) is placed in this group, the SMES is coil which is in a superconducting state at cryogenic temperature, this means that the energy losses during the operation is almost zero[1-5], the SMES is an electrical energy that stores the energy in the magnetic field, it has the Ability to rapidly release stored energy, very high storage energy, Quick to recharge (millisecond) with high efficiency and almost infinite cycle life, also the SMES used to control the active and reactive power, used to the transmission and distribution system stability and stabilize system frequency[6-8].

The SMES can stores the energy directly from electrical power, because the SMES resistance almost equal zero and the mobility is very high at very low temperature, which called critical temperature, the SMES unit consists of three main components: superconducting unit, cryogenic refrigerator and vacuum-insulated vessel fig 1, the SMES is connected to the grid in three modes as is shown in fig 2, voltage source converter (VSC)[9-12], current source converter (CSC)[13-15], and thyristor[16, 17].

In VSC mode, the SMES energy is controlled by DC-DC chopper in the absorbing or injection power, in ref [18] the authors charge and discharge the SMES using dc-dc chopper which is controlled by proportional and integral (PI) controller, in ref [8] fuzzy logic controller (FLC) is applied on the SMES charging and discharging of the SMES active and reactive powers. The FLC is controlled by two inputs: wind speed and SMES current variations.

To support the increasing energy demand and the development of renewable energies (solar and wind,...etc) whose production is variable, non-controllable and decentralized, hence, increasing the storage capacity of electricity is a necessity. However, there are still many technical and economic problems that reduce the deployment of new storage technologies. Significant research efforts are underway around the world. In this document, power grids containing photovoltaic system and storage system based on Superconducting Magnetic Energy System (SMES) has been proposed and analyzed for different possible scenarios and load levels.

$$\begin{cases} V_{dref} = e_d + u_{cd} - L_f \omega i_q \\ V_{qref} = e_q + u_{cq} + L_f \omega i_d \end{cases} \quad (4)$$

$V_{d,qref}$ is the calculated reference voltage.

e_d and e_q are the park transformation voltages of the grid common connection points.

L_f represents the coupling inductance of a phase of the filter between the VSC and the grid.

$$\begin{bmatrix} i_{dref} \\ i_{qref} \end{bmatrix} = \frac{1}{e_d^2 + e_q^2} \begin{bmatrix} e_d & e_q \\ -e_q & e_d \end{bmatrix} \begin{bmatrix} P_{ref} \\ Q_{ref} \end{bmatrix} \quad (5)$$

where P_{ref} and Q_{ref} are the references of the active and reactive powers.

The $i_{d,q}$ current regulation loop are based on PI regulators to calculate $u_{cd,q}$, as is shown in figure 5:

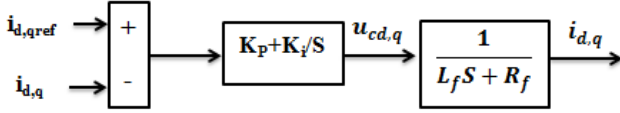


Figure 5. Current regulation loops using PI regulator

2.2. Control of injected power into grid based on sliding mode control

In order to reduce the PI regulator disadvantages such as the response time and the overshoot, a robust command named sliding Mode controller (SMC) has been developed as shown in fig 06.

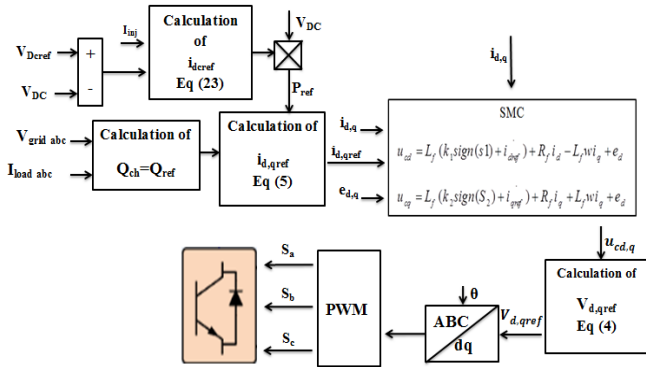


Figure 6. Voltage source converter control based on SMC controller

Sliding Mode controller (SMC) is robust method, it is a non-linear type control that has been introduced for the control of variable structure systems and is based on the concept of controller structure change with the state of the system in order to obtain a desired response. The sliding mode control is therefore all or nothing type.

Sliding Mode is based in three steps:

- Choice of sliding surfaces $S(X)$.
- Definition of the conditions of existence and convergence of the sliding regime.
- Determination of the control law.

The sliding mode control law is expressed by [26]:

$$U = u_{eq} + u_n \quad (6)$$

Where u_{eq} is the calculated control and u_n is given by:

$$u_n = -k * \text{sign}(S) \quad (7)$$

S: slotine surface.

k: constant value

In this paper, we chose slotine surface [26-28], and apply it in equation 8 and 9 to calculate $u_{cd,q}$:

The first system:

$$L_f \frac{di_d}{dt} = u_{cd} - R_f i_d + L_f \omega i_q - e_d \quad (8)$$

The second system:

$$L_f \frac{di_q}{dt} = u_{cq} - R_f i_q - L_f \omega i_d - e_q \quad (9)$$

The first surface is used to calculate u_{cd} :

$$S_1 = \left(\frac{d}{dt} + \lambda \right)^{n-1} e_1 \quad (10)$$

For $n=1$, the surface can be written by:

$$S_1 = e_1 = i_{dref} - i_d \quad (11)$$

The derivate surface is expressed[26]:

$$\dot{S}_1 = i_{dref} - \dot{i}_d = u_{n1} = -k_1 \text{sign}(S_1) \quad (12)$$

By replacing equation (8) in equation (12):

$$i_{dref} - \frac{1}{L_f} (u_{cd} - R_f i_d + L_f \omega i_q - e_d) = -k_1 \text{sign}(S_1) \quad (13)$$

$$u_{cd} = L_f (i_{dref} + R_f i_d / L_f - L_f \omega i_q / L_f + e_d / L_f) + L_f k_1 \text{sign}(S_1) \quad (14)$$

The voltage control is:

$$u_{cd} = L_f (k_1 \text{sign}(S_1) + i_{dref}) + R_f i_d - L_f \omega i_q + e_d \quad (15)$$

The second surface is used to calculate u_{cq} :

$$S_2 = \left(\frac{d}{dt} + \lambda \right)^{n-1} e_2 \quad (16)$$

The order of the system is $n=1$, in that case:

Fig 18 shows the power grid, power SMES and load in variable loads scenario, it clear that both control strategies sliding mode and PI regulator provide a high performances with small superiority of sliding mode in term of low oscillations.

□ CONCLUSION

In this paper, power grids containing photovoltaic system and storage system based on Superconducting Magnetic Energy Storage (SMES) has been proposed and analyzed for different possible scenarios and loads. Modeling and operating principle of SMES and Power-PV-SMES have been explained in details. Injected SMES energy in power system has been controlled perfectly by both developed control strategies sliding mode and field oriented control based on PI controller, where sliding mode ensures better performance compared to field oriented control. Beside the efficiency of proposed control methods, obtained results demonstrate the great benefit of use of combined renewable energy-SMES to confront the future demand with the exiting power production capacity and maintain the power system operation under hard conditions. Hence, renewable energy-SMES can be widely used for quality power improvement.

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