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Suppressing the Fluctuations Generated in an Active Power of the Wind Farm by SMES Using Optimized Coil Size

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Abstract: *Wind power generated varies from any conventional generations. This power when enters into interconnected power system creates a problem of power fluctuation. This power fluctuation can be controlled by using Super Conducting Magnetic Energy Storage (SMES). SMES is quite costly. Thus this paper suggest an Optimization method of optimizing the controller parameters, SMES current and Coil Size of the SMES and this will result in suppressing the power fluctuation in interconnected power system with wind farm. Here PI controller is used to control Active and Reactive power of the Tie-line. Based on the minimization of Time response specification active and reactive power fluctuation is reduced. The controller parameters, Coil Size and Initial SMES current are tuned by Particle Swarm Optimization and compared by Genetic Algorithm. This optimization and Controller model is realized by using MATLAB.*

Keywords: *Response Specification, power fluctuation, genetic optimization, particle swarm optimization, superconducting magnet energy storage, wind power.*

1. INTRODUCTION

Power systems have been facing exciting changes in electric power generation, transmission, distribution, and end-user facilities. Continuing electric load growth and higher power transfer in a largely interconnected network lead to complex and less secure power system operation. In addition, certain factors such as technical, economical, environmental, and governmental regulation constraints put a limitation on power system planning and operation. Power system engineers facing these challenges seek solutions to operate the system in more flexible and controllable manner. Recent development and advances on both superconducting and power electronics technology[12] have made the application of SMES (superconducting magnetic energy storage) systems a viable choice to bring solutions to some of the problems experienced in power systems. Although SMES was initially envisioned as a large-scale load-levelling device, it is now seen as mainly a tool to enhance system stability, power transfer, and power quality in power systems in the process of deregulation. The power industry demand for more flexible, reliable and fast real power compensation devices provide the ideal opportunity for SMES applications.

Super conducting magnetic energy storage provides the necessary active and reactive power in the tie-lines. But how much active and reactive power is required to compensate the fluctuation is determined by the PI controller.

This paper presents a new optimization technique of the SMES unit with optimal coil size for alleviation of power fluctuation in interconnected power systems with wind farms. Proportional-integral (PI) structure is used for active and reactive power controllers of SMES. The PI control parameters and the coil size are optimized so that the Response specification of power curve is reduced and the initial stored energy in a SMES coil is minimal.

2. ACTIVE AND REACTIVE POWER OF SYSTEM

The wind farm generators have a generating capacity of 500 MW. Due to the variation in the speed of wind the active power generated and the reactive power consumed in the power system is not alleviated. To alleviate the power fluctuation SMES unit is installed. Specification of the SMES is follows: 10H inductance of coil, 8GJ of energy capacity, 40KA of rated coil current and 1000 MVA of apparent power capacity [2]. The SMES with 10H of coil size is compared with proposed SMES with optimal coil size. The active power and reactive power variation is shown below.

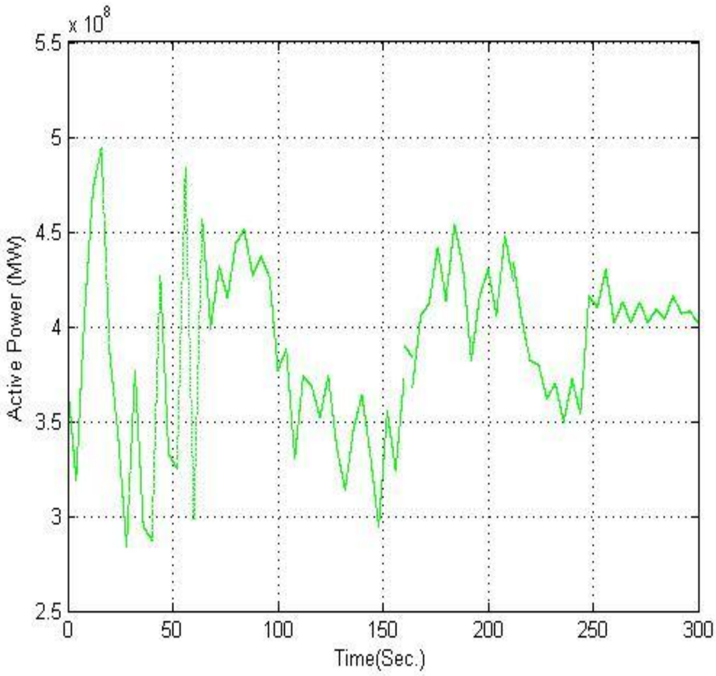

Fig1. *Active power variation curve in Tie- line*

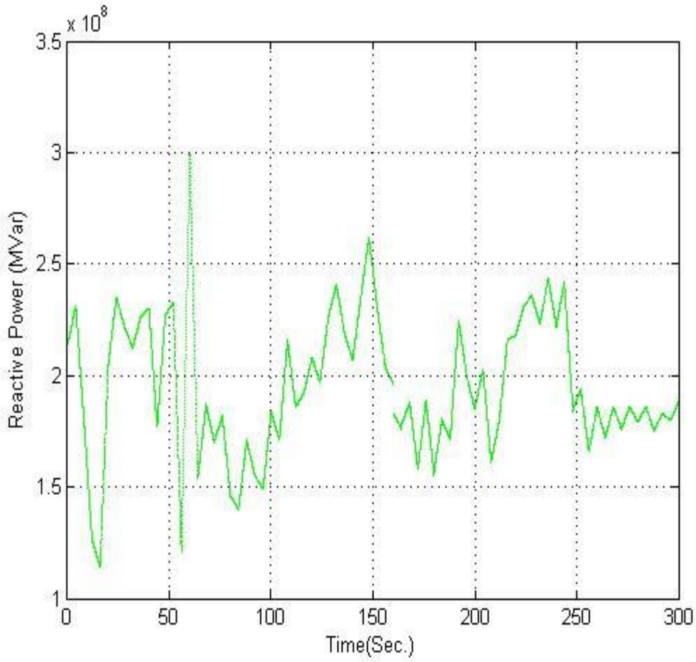

Fig2. *Reactive power variation curve in tie-line*

3. SMES MODEL

Figure 3 depicts a SMES device coupled to a wind power plant. The objective of the SMES device is to smooth the fluctuations in the power output of the wind power plant such that the power flow through the transmission line, that connects the wind power plant to the power system, follows a given reference value. The SMES device consists of the following basic components: (i) Voltage Source Converter (VSC); (ii) booster converter; and (iii) superconducting coil.

The SMES unit requires a cryogenic system which keeps the superconducting coil at lowest temperature thereby resistance of coil reduces which makes the coil superconducting

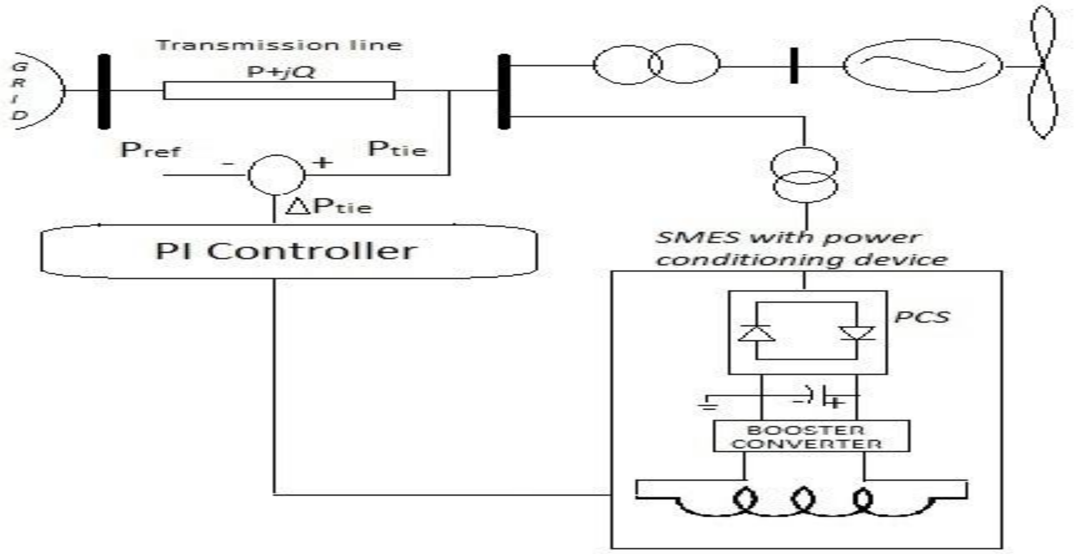

Fig3. *SMES with system*

3.1. SMES Control Scheme

Fig. 4 shows the SMES model with active and reactive power (P-Q) controls[1]. I_{sm} and Ism0 are the actual & initial current of SMES. Ism0 also defines an initial stored energy in the SMES coil. In practice, I_{sm} can be measured directly. But, I_{sm} is prevented so that it should not reach zero thereby discontinuous conduction is avoided during unexpected disturbances. On the other hand, greater values of I_{sm}, may lead to loss of superconducting properties. Based on the hardware operational constraints, the lower coil current limit and upper coil current limit are assigned as $0.30I_{sm0}$ and $1.38I_{sm0}$, respectively [2]. Here, can be calculated from the Energy power block (EPB) which has a relation as

$$Ism = \sqrt{Ism0^2 - \frac{2Eout}{Lsm*Ism,base^2}} \tag{1}$$

$$Eout = \int Psm * Ssm, base \tag{2}$$

where, L_{sm} =SMES coil inductance (H), E_{out} is the instantaneous energy output (J), P_{sm} is the active power output, $S_{sm,base}$ and $I_{sm,base}$ the SMES MVA capacity and the SMES rated current (A). The values of $S_{sm,base}$ and $I_{sm,base}$ which are equal to 1000 MVA and 40kA respectively [2], are selected as the MVA base and the current base of the power system. Using (1), the stored energy of SMES unit is E_{sm} (J) and stored initial energy E_{sm0} (J) can be found by

$$Esm = Esm0 - Eout \tag{3}$$

$$Esm0 = \frac{1}{2} Lsm * (Ism0 * Ism, base)^2 \tag{4}$$

In given model, K_P and K_Q are the P and Q controllers of SMES which are utilizes PI controlling strategy and controller equations are shown below as

$K_P=K_{PA}(1+(1/T_As))$ (5)

$K_Q=K_{QR}(1+(1/T_Rs))$ (6)

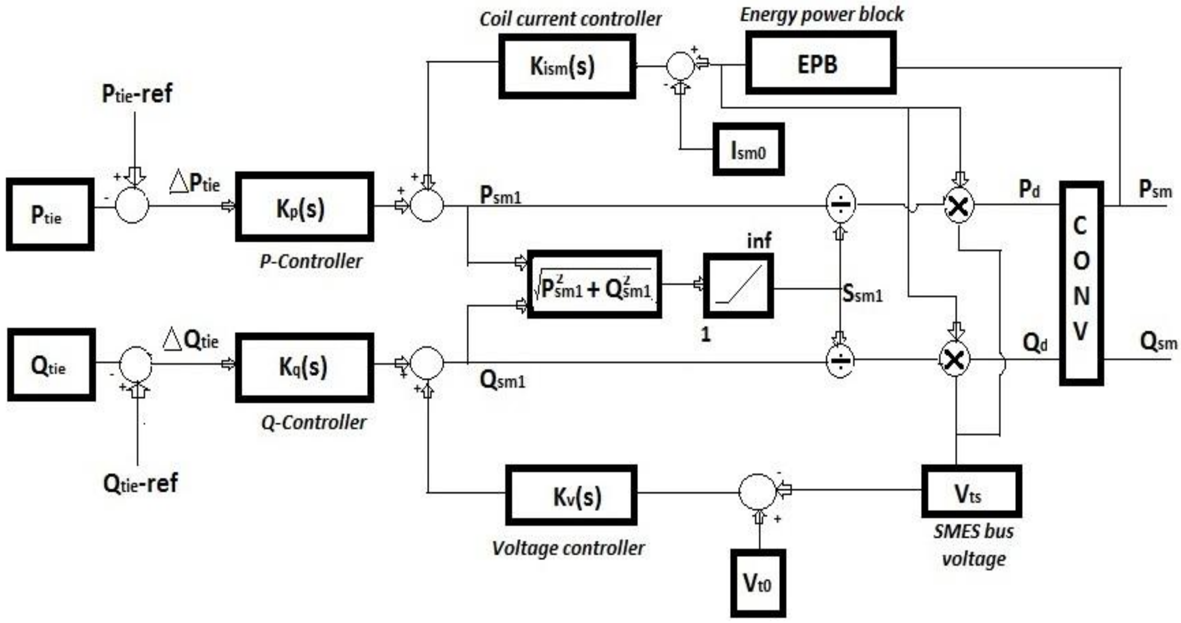

Fig4. *SMES Model with controllers*

Where, K_{PA} and K_{QR} are proportional gains, T_A and T_R are integral gains. Active power variation and reactive power variation in a tie-line are the input signals for P and Q controller of SMES. In this controller model, the response of the current in SMES coil is considered, since the dynamic behaviour of the Ism completely affects the performance of SMES. the current controller is shown in Fig. 4 can be expressed by

$K_{Ism}(s)=(K_{TR}+1/(T_Is))\ K_{TM}(I_{sm}-I_{sm0})$ (7)

where, I_{sm0} is the initial coil current which may be called the reference value for controlling the value I_{sm} in the desired limit i.e $0.30I_{sm0}$ and $1.38I_{sm0}$,K_{TR} and K_{TM} are controller gains, and T_I is a time constant. I_{sm} is controlled to be equal to I_{sm0} by $K_{Ism}(s)$. Where, I_{sm0} is the actual value of the initial coil current (A). Besides, the voltage controller is

$$Kv(s) = Kvs(Vt0 - Vts) \quad (8)$$

Where, K_{vs} is the gain, V_{t0} and V_{ts} are the reference and the actual voltages at the SMES bus, respectively. The desired Active and reactive powers (P_d and Q_d) can be calculated by

$$Pd = Vts * Ism * \frac{Psm}{\sqrt{Psm1^2 + Qsm1^2}} \quad (9)$$

$$Qd = Vts * Ism * \frac{Qsm}{\sqrt{Psm1^2 + Qsm1^2}} \quad (10)$$

Where $V_{ts}*I_{sm}$= Estimated apparent Power Output

$\frac{Psm}{\sqrt{Psm1^2 + Qsm1^2}}$ = Active power Fraction

$\frac{Qsm}{\sqrt{Psm1^2+Qsm1^2}}$ = Reactive power Fraction

Note that, $\frac{Psm}{\sqrt{Psm1^2+Qsm1^2}}$ is the output of combined signals from the control loops of active power and coil current, while $\frac{Qsm}{\sqrt{Psm1^2+Qsm1^2}}$ is achieved by the combined output signals from the control loops of terminal voltage and reactive power. In Fig. 4, P_{sm} and Q_{sm} obtained by passing Pd and Qd through SMES converter (CONV). The transfer function of the converter with time constantcan be represented by

$$CONV = \frac{1}{1+Tc(s)} \tag{11}$$

For SMES unit, the PI parameters in (5) and (6), L_{sm} and I_{sm0} in (4) are tuned by the proposed optimization.

4. PROPOSED PARAMETERS OPTIMIZATION BY PSO AND GENETIC ALGORITHM

Optimization is done by particle swarm optimization [5] and genetic algorithm[9]. The aim of optimizing the parameters are as follows.

1) To attain the satisfactory stabilizing effect of SMES. The SMES coil inductance and initial stored energy can be minimized by formulating a fitness function in which attained response specification is subtracted from desired response specification and these desired response specification can be found out from 10H coil size active power i.e desired response specification should be less than the response specification attained by 10H coil size (settling time (180-190sec), peak value(400-450MW), %over shoot(2-10)) under the specified constraints. Accordingly, the objective optimization problem can be expressed as minimize

$$f(\emptyset) = \{\emptyset d - \emptyset a\}$$

$$\emptyset d = [Tsd \quad \%Od \quad Pvd]$$

$$\emptyset a = [Tsa \quad \%Oa \quad Pva]$$

$\emptyset d =$ Desired response specification matrix [1*3]

$\emptyset d =$ Attained response specification matrix [1*3]

Tsd and Tsa=Desired and attained settling time

%Od and %Oa=Desired and attained overshoot

Pvd and Pva= Desired and attained peak value.

Subject to Constraints

1) $1 < Kpa < 20,\ \ 1 < Ta < 30$ (Controllers parameters range)
2) $1 < Kqr < 20,\ \ 1 < Tr < 30$ (Controllers parameters range)
3) $1 < Lsm < 10\ Hz$ (Inductance range)
4) $4 < Ism0 < 40\ KA$ (Initial Coil current range)

Desired response specification and attained response specification contains following subparts that is [settling time, overshoot, peak value]. If these 3 subparts are minimized the active and reactive power supplied by the SMES provides the alleviation in active and reactive power fluctuation.

5. SIMULATION STUDY

The constant value of the SMES model of fig-4 are given as K_{TR}=40, T_I=0.4, K_{TM}=1, Kvs=10, T_c=0.01, and Vt0 =0.95pu. The Active and reactive power shown in fig-1 and fig-2(that is P_{tie} and Q_{tie}) is applied to the model shown in fig-4 with the reference active and reactive power as 400MW and 186MVar. Here the optimal coil size is compared with the SMES of Lsm=10H and Ism0=25.51KA. This model generates the active and reactive power to be supplied to the line which stabilizes the varying active and reactive power.Case1-when Lsm=10H and Ism0=25.51KA and other parameters are optimized by PSO and the stabilized power is shown in Fig-5.1 and Fig-5.2. Case-2 in this all the 6 parameters are optimized by GA and the stabilized power is shown in Fig-6.1and 6.2. Case-3 in this all the 6 parameters are optimized by PSO and the stabilized power is shown in Fig-7.1 and 7.2. Optimized results are shown in table-1 and the response parameters are shown in table-2.

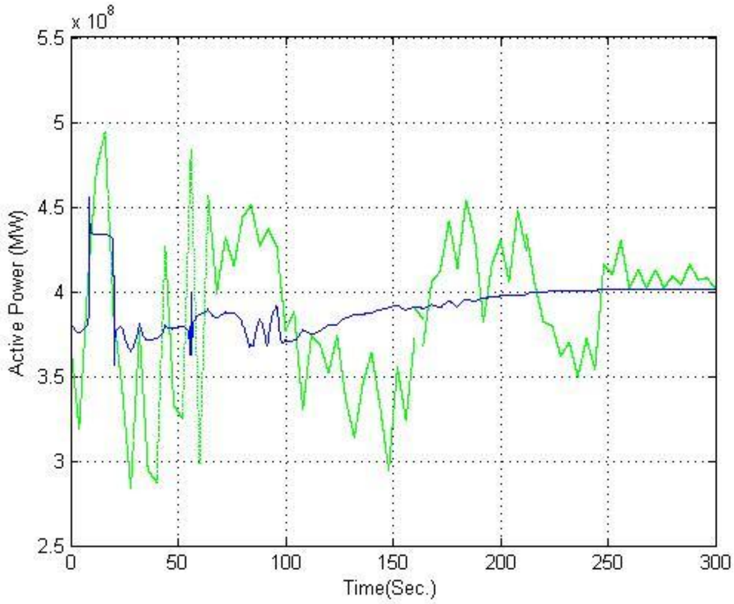

Fig5.1. *Active power using 10H SMES coil*

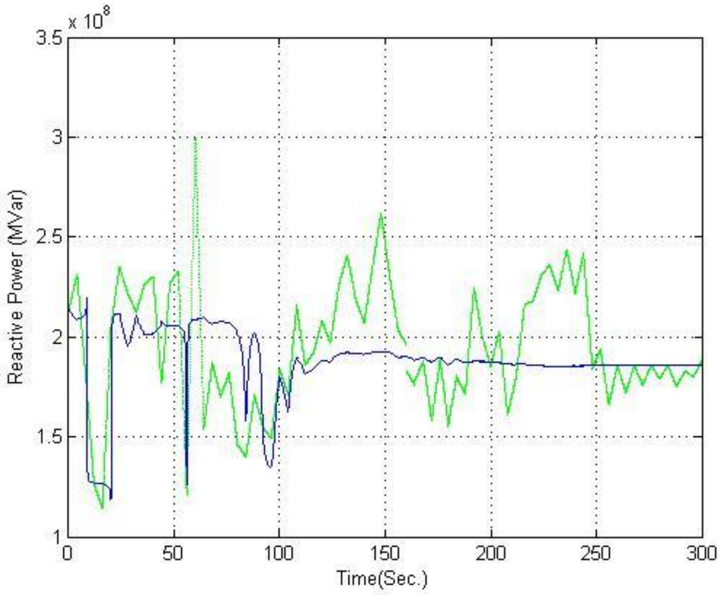

Fig5.2. *Reactive power using 10H SMES coil*

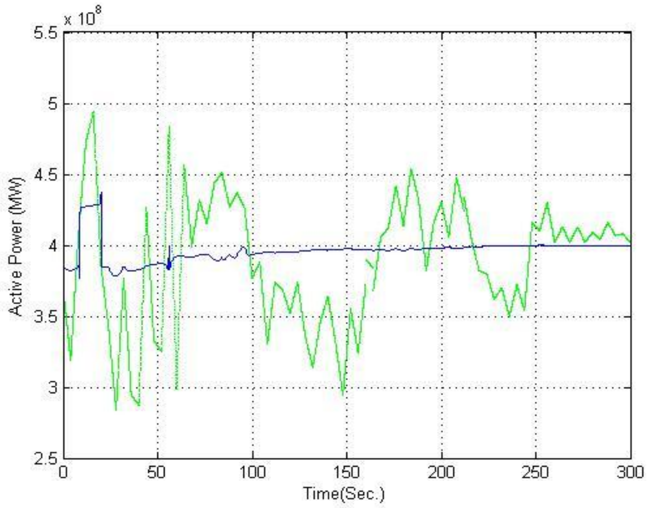

Fig6.1. *Active power suppression by optimized SMES coil size using GA*

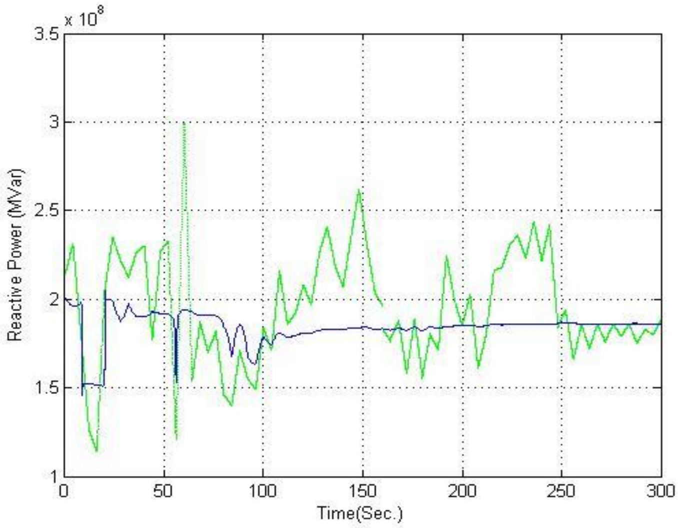

Fig6.2. *Reactive power suppression by optimized SMES coil size using GA*

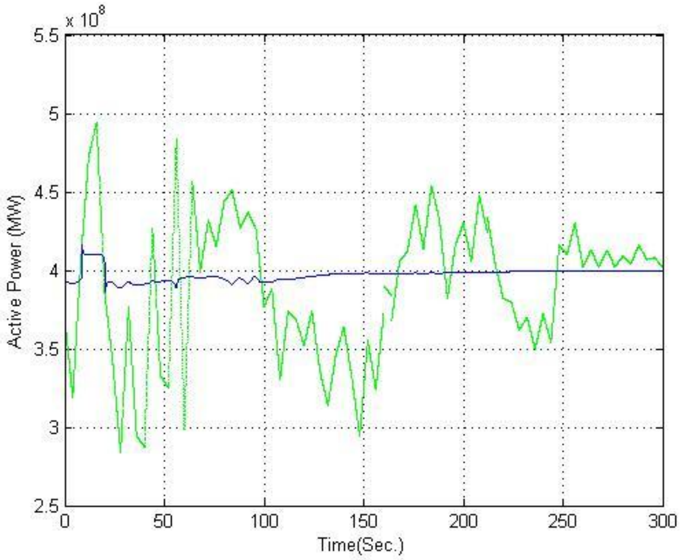

Fig7.1. *Active power suppression by optimized SMES coil Size using PSO.*

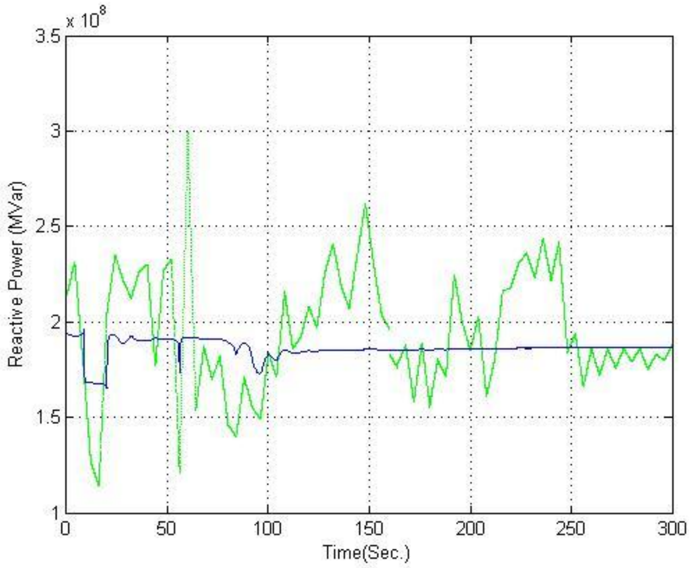

Fig7.2. *Reactive power suppression by optimized SMES coil Size Using PSO.*

Table1. *Response specification*

Response parameters	Active power 10H coil size	Active power from coil size Using GA	Active power from coil size Using PSO
Settling Time(s)	212.0059	189.7454	182.0839
%Over shoot	13.8353	9.3043	4.0062
Peak (MW)	455.34	432.22	416.02

Table2. *Optimized parameters Result*

Type of SMES	OPTIMIZED PARAMETERS	Initial stored Energy
SMES with 10H coil size	Kpa=8.7127, Ta=19.4850 Kqr=17.1494,Tr=13.2692 Lsm=10H, Ism0=25.51KA.	3.25GJ
SMES optimized by genetic	Kpa=7.6590, Ta=18.9540 Kqr=19.5419,Tr=14.5680 Lsm=4.5980H, Ism0=21.855KA	1.098GJ
SMES optimized by PSO	Kpa=7.6891, Ta=17.540 Kqr=14.1490,Tr=12.1693 Lsm=3.1307H, Ism0=20.999KA	0.690GJ

6. CONCLUSION

This paper proposes an optimization technique to utilize the wonders of superconducting magnetic energy storage devices. These devices are quite costly so by optimizing the size and intial stored energy these can be used efficiently. The optimized parameter table shows the values in which more stable waveform is obtained. This stabled power has reduced settling time, overshoot and peak value which confirms the alleviated power compared to the input power in control model. Rise time is not taken in response specification because minimizing overshoot increases the rise time [10][11] thus it cannot be utilized in fitness function. As we all know energy storage is main problem in the development of technology but large superconducting coils can store up to 41GJ of energy by 2014 [4].Control of power fluctuation using is effectively applied in 60Hz six area-interconnected system in western Japan[1]. An optimized SMES block can be visualized which can store huge amount of energy and compensate the active and reactive power during fluctuation thereby alleviates the wind power fluctuations and other misfortunes of power system like voltage sag, short circuit in networks etc. Other than power system application super conducting coil can be utilized in various fields like supply power for arc furnaces, starting train, protecting electrical networks, sending satellite into the lower orbit.

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