IEEE Transactions on Energy Conversion, Vol. 9, No. 4, December 1994

# IMPROVEMENT OF SYNCHRONOUS GENERATOR DAMPING THROUGH SUPERCONDUCTING MAGNETIC ENERGY STORAGE SYSTEMS

A.H.M.A.Rahim, senior member
Department of Electrical Engineering
University of Bahrain, Bahrain.

A.M.Mohammad
Department of Electrical Engineering
UMIST, Manchester, UK.

*Abstract---Stabilization of a synchronous generator through control of firing angle of the converters in the super conducting magnetic systems is considered. An optimum strategy of the firing angle control is designed so as to eliminate the transients in minimum time. A nonlinear model of a synchronous generator, its governor and exciter systems, and a superconducting magnetic system connected to the generator terminal is considered. The optimum firing angle control is derived retaining the nonlinearities of the system dynamics. Digital simulation results indicate that the proposed strategy controls the slowly growing as well as first swing instabilities very effectively.*

Keywords: Superconducting magnet, stability, optimum control, damping control.

## I. INTRODUCTION.

Power systems having long transmission distances between the major load centers and generating stations may exhibit poorly damped or even negatively damped oscillations on certain disturbance conditions. These oscillations are normally the result of electromechanical synchronizing swings across long tie lines. Several stabilizing methods such as power system stabilizer (PSS) in the generator exciter, static var compensators (SVC) on the transmission line, etc. have been reported [1-3]. PSS is recently being used in most modern power systems. However, PSS alone may not be sufficient to control these oscillations, as was evidenced in the BPA 500 kv Pacific AC intertie [4].

The use of superconducting magnetic energy storage (SMES) systems for damping control of synchronous generators has drawn widespread interest [5-7] following successful installation of the 30 MJ unit at the Tacoma station in the BPA system [8-9]. Super conducting magnets were originally proposed as energy storage units which were to serve the same purpose as storage hydro plants. The SMES unit is designed to store electric power in the low loss super conducting magnetic coil. Power can be absorbed by or released from the coil according to system requirements. Besides stability improvement of interconnected systems, SMES units have been reported to be used in isolated systems for load leveling and damping control [10] and also for load frequency control of power systems [11]. Amongst all the studies made with SMES systems, only the BPA system tested actual hardware. Others were simulations.

One of the main components of a SMES unit is the converter bridge. By changing the firing angle of the thyristors in the bridge circuit, the voltage impressed on the superconducting coil is moved up and down in order to achieve the desired power interchange . The change in system frequency is normally considered as a measure for firing angle variation [5,12], though other feedback signals like inductor current and power variations are reported [10,11]. Frequency based control alone does not, in general, provide enough damping [4,5].

Improvement of power system damping through the use of SMES units has been reported in several references [5,6,7,10,11]. Wu and Lee [5] made a comparison of frequency deviation based thyristor angle control with and without a PID controller. The parameters of the PID controller were obtained by pole placement techniques applied to the linearized system model. The improvement of power system stability using real as well as reactive power control of SMES was presented in [6], and the derivation of these controls from a second order linearized system, along with the results, were presented in [7]. Reference [10] indicated that SMES can improve the stability of isolated systems. Feedback of inductor current as well as frquency deviation were used to control the d.c.voltage. Studies in [11] indicate that SMES units can be effectively used as load frequency stabilizer. Tie line power was used as feedback signal in the control loop in addition to the signals used in [10]. All the above studies used linear analysis for control design.

While simplified linear analysis give good insight into many complex problems and some reasonable inferences can be arrived at from it, more accurate and broader predictions demand control design in the nonlinear domain. This article investigates the stability enhancement of a power system having an SMES by, (1) considering the nonlinear system model, and (2) proposing the optimum or best firing angle control srategy retaining the nonlinearities in the dynamics. The optimum thyristor firing angle is derived so that the transients are eliminated in minimum time. The control strategy proposed has been tested on a synchronous generator connected to a power system bus. The initial results of the present study have been reported in [13].

## II. DYNAMIC SYSTEM MODEL.

A power system consisting of a synchronous generator connected to the major load center through a long transmission line is given in Fig. 1. An SMES unit is connected to the generator terminal. The dynamics of the generating unit, its exciter and governor system, and also of the SMES unit is given in the following.

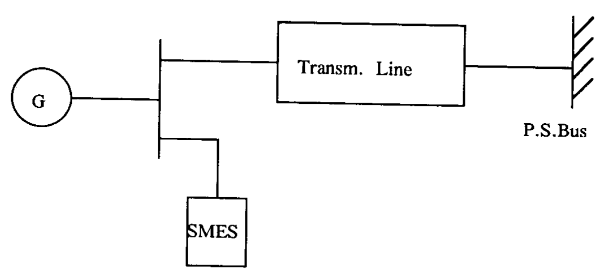


Fig. 1: Power System Configuration

94 WM 122-2 EC A paper recommended and approved by the IEEE Energy Development and Power Generation Committee of the IEEE Power Engineering Society for presentation at the IEEE/PES 1994 Winter Meeting, New York, New York, January 30 - February 3, 1994. Manuscript submitted July 8, 1993; made available for printing January 11, 1994.

The generator is represented by a fourth order dynamic model----the transient voltage equations along the direct(d) and quadrature(q) axes and the electromechanical swing equation and is written as [14]

$$pe_d' = [-e_d' + (x_q - x_q')i_q] / T_{qo}' \quad (1)$$

$$pe_q' = [e_{fd} - e_q' - (x_d - x_d')i_d] / T_{do}' \quad (2)$$

$$p\Delta\omega = [P_m - D\,\Delta\omega - P_e - P_{SM}] / M \quad (3)$$

$$p\delta = \omega_0\,\Delta\omega \quad (4)$$

where, $e_d'$ and $e_q'$ are direct and quadrature axes transient voltages ; $\omega$ and $\delta$ are angular frequency and rotor angular positions; $P_m$, $P_e$, $P_{SM}$ are the power input, electrical output and power to the SMES unit; M and D are the inertia constant and damping coefficients, respectively. x's and T's are the reactances and time constants along the respective axes of the machine. A list of symbols used in this article is included at the end. The transient electrical power output is related to the transient voltages and currents along the two axes by the relationship

$$P_e = e_d' i_d + e_q' i_q \quad (5)$$

The terminal voltage($v_t$) of the generator in terms of generator and transmission line quantities are given below

$$v_d = e_d' - r_a i_d + x_q' i_q \quad (6a)$$

$$v_d = v_o \sin\delta - r_e i_d - x_e i_q \quad (6b)$$

$$v_q = e_q' - r_a i_q - x_d' i_d \quad (7a)$$

$$v_q = v_o \cos\delta - r_e i_q - x_e i_d \quad (7b)$$

$$v_t^2 = v_d^2 + v_q^2 \quad (8)$$

Here, $v_o$ is the power system bus voltage ; $r_a$ is the generator armature resistance; $r_e$ and $x_e$ are the transmission line resistance and reactances, respectively. The static excitation system is shown in Fig. 2 and the turbine and governor models are given in Fig. 3[5,14].

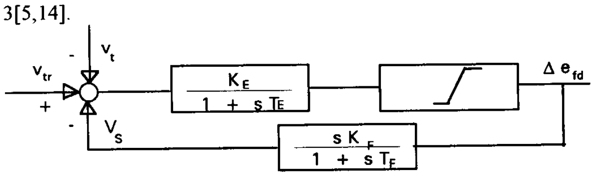


Fig. 2. The static excitation system

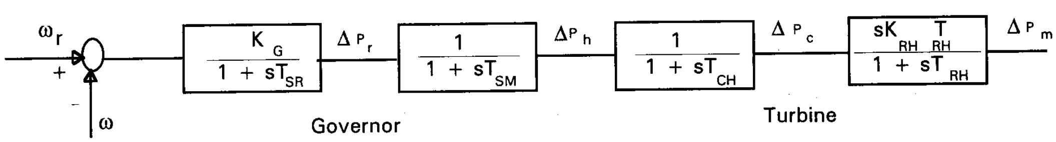


Fig 3: The Governor and turbine systems.

The exciter and voltage regulator are represented by two state equations, the state variables being $e_{fd}$ and $V_s$. The governor and turbine systems are represented by four state variables. These are shown at the outputs of each block in Fig. 3.

*The SMES Unit.*

The main components of the SMES system are the super conducting coil and two sets of six pulsed bridge power converters as shown in Fig. 4. The converter units are fed from a set of Y – Δ / Y – Y connected transformers.

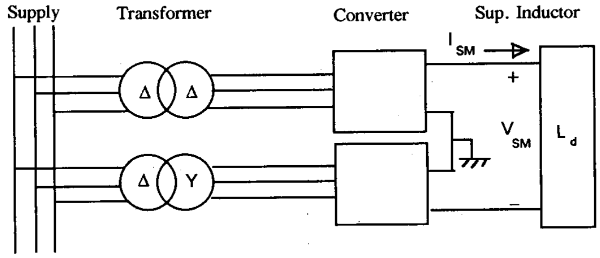


Fig 4: Converter and super conducting coil configuration.

The converter impresses $\pm V_{SM}$ volts on the superconducting coil. On the ac side of the converter, the phase angle between the voltage and current is 90° when no energy is transferred, about 0° for maximum storage (charge) and about 180° for maximum discharge. Charge and discharge are controlled through simple change of commutation angle $\alpha$ . Since the bridge current $I_{SM}$ is not reversible, the bridge output power $P_{SM}$ is uniquely a function of $\alpha$ , which can be positive or negative [12]. The current, voltage and power of the superconducting inductor are related by

$$pI_{SM} = 1/L_d \cdot V_{SM} \quad (9)$$

$$P_{SM} = V_{SM}\, I_{SM} \quad (10)$$

And the energy stored is

$$W_{SM} = W_{SO} + \int_{t_o}^{t} P_{SM}(\tau)\, d\tau \quad (11)$$

where, $W_{SO} = \frac{1}{2} L_d I_{SMO}^2$

The dc voltage $V_{SM}$ is controlled by changing the firing angle $\alpha$ of the thyristors. If $K_\alpha$ and $T_\alpha$ are the loop gain and time constants respectively, the equation for the SMES thyristor angle control loop can be written as

$$\Delta V_{SM} = \frac{K_\alpha}{1 + sT_\alpha} \Delta\alpha \quad (12)$$

The quantities $V_{SM}$, $I_{SM}$ and $\alpha$ are all bounded by appropriate upper and lower limits.

Equating $v_d$ and $v_q$ in equations (6) and (7), $i_d$ and $i_q$ are expressed in terms of the system states. These are substituted in (5) and, in turn, in equation (3). This gives four state equations for the generator in closed form. These equations combined with the exciter, governor and turbine, and the SMES dynamics gives the nonlinear state model of the form

$$x = f[x,u] \quad (13)$$

where the state vector x is [ $e_d'$, $e_q'$, $\omega$, $\delta$, $e_{fd}$, $V_s$, $P_r$ , $P_h$ , $P_c$, $P_m$, $I_{SM}$, $V_{SM}$] . The control u is the thyristor firing angle $\alpha$ .

## III. THE CONTROL STRATEGY.

As mentioned, the power absorbed or released by the superconducting coil can be varied by changing the firing angle $\alpha$ of the thyristors, thus controlling the electromechanical oscillations in the system. Some studies suggested change of $\alpha$ in accordance with the variation of system frequency [5,12]. However, it has been observed that frequency variation signal may not be adequate in controlling the transients[5]. In the following, an optimum strategy for control of $\alpha$ to stabilize the system is proposed.

If we assume that $\Delta\alpha = 0$ when there is no energy transfer between the superconducting magnet and the ac system(corresponding to 90° angle between voltage and current), the range of variation of $\alpha$ will be approximately $-\pi/2$ for complete charging (corresponding to 0°) and $\pi/2$ for total discharge (corresponding to 180°). The constraint on the control variable can be expressed as

$$|\Delta\alpha| \le \pi / 2 \qquad (14)$$

Often it is desired that following a disturbance in the system, the states should return to their normal operating range as quickly as possible. This is particularly needed if the disturbance tends to drive the system into slowly growing or transiently unstable conditions. The stability problem then can be formulated as an optimal control problem as: Given the system of equations (13) find control $u = \Delta\alpha$, such that the system is transferred from initial state $x_0$ to a stable equilibrium represented by $\Delta\omega=0$ and $p\Delta\omega=0$, while the steady state rotor angle $\delta(t_f)$ remain between 0 and $\pi/2$. For the transition of the states from the initial values to the desired ones in minimum time, the control should be such as to minimize the cost index

$$J = \int_{t_0}^{t_f} dt \qquad (15)$$

at the same time satisfy inequality (14).

A closed form solution of the stated nonlinear optimization problem as a function of the system states is generally not possible. A procedure for arriving at a quasi-optimal control is presented in the following.

Consider the frequency variation relationship from the electromechanical swing equation (3). Differentiate both sides of the equation with respect to time to get

$$p^2\Delta\omega = \frac{1}{M}[pP_m - D\, p\Delta\omega - pP_e - pP_{SM}] \qquad (16)$$

The damping term in (16) can generally be neglected. The derivative of the SMES power is

$$pP_{SM} = V_{SM}\, pI_{SM} + I_{SM}\, pV_{SM} \qquad (17)$$

Substituting equation (9) and (12) in (17), we get

$$pP_{SM} = V_{SM}^2 / L_d - V_{SM} I_{SM} / T_\alpha + I_{SM} K_\alpha \Delta\alpha / T_\alpha \quad (18)$$

Note that an expression for $P_e$ in terms of system states were obtained while arriving at equation (13). The derivative of $P_e$ can be obtained by substituting the appropriate equations from (13). Substituting derivative of $P_m$, $P_e$ and $P_{SM}$ in (16) and arranging the terms we can rewrite it as

$$p^2\,\Delta\omega = c(x) + d(x)\,\Delta\alpha \qquad (19)$$

The expression for c(x) will be simpler if governor action is not included in the dynamics. Assuming that c(x) and d(x) can be approximated by piecewise constant functions, the time optimal control for the second order system (19) subject to the constraint on control (14) is given as

$$\Delta\alpha = -\pi / 2 \,.\, \mathrm{sgn}\, \Sigma \qquad (20)$$

where, $$\Sigma = \Delta\omega - \frac{(p\Delta\omega)2}{2[c(x) + \pi / 2 . d(x).\ \mathrm{sgn}\,\{p\Delta\omega\}]}$$

The time optimum strategy (20) shows that control $\Delta\alpha$ will be either the maximum or minimum value depending of the polarity of the switching function $\Sigma$. Ideally, though the control should be switched instantaneously between the two extreme values, the control action can be made continuous between the limits by setting

$$\Delta\alpha = K\,\Sigma \qquad (21)$$

where, an appropriate value of K can be chosen so that the ceilings are reached quickly when the variations in the states are large.

## IV. RESULTS

The power system model given in Fig. 1 was simulated in this study. System data was taken from reference [5] and is included in the Appendix. Several loading conditions were considered and the system was subjected to various disturbances like torque pulses and symmetrical three phase faults at these loading conditions. Three different system models were considered. These are

- Nonlinear dynamic model of the power system including generator, transmission line, exciter, turbine and governor. The SMES is not included. This is referred to as no control case in the results.

- System model including SMES. Two additional differential equations are included in the model. The thyristor angle control has been set to be proportional to $\Delta\omega$.

- Model with SMES and proposed quasi optimal $\Delta\alpha$ control.

Figs. 5 and 6 show the angle and frequency variations when a 50% input torque pulse for a duration of 3.5 cycles is applied to the generator shaft. The nominal power output of the generator under this condition is 1.00 per unit at a power factor of 0.85 lag. The post disturbance system with and without SMES is stable, but poorly damped. The response with angle control proportional to frequency variation (curve b) is only slightly better compared to that without SMES (curve a). The proposed optimal thyristor firing angle control brings the transients to almost zero in less 0.5 sec. (curve c).

For the same loading condition but with a three phase fault of 3.5 cycles duration at the remote end of the transmission line, the generator frequency and terminal voltage variations, power-energy-current-voltage of the superconductor are shown in Figs. 7 through 12 respectively. The responses without SMES, and with SMES and $\Delta\alpha$ proportional to frequency both show oscillatory response. With SMES, the transients are reduced but damping is not satisfactory. The optimum control eliminates the transients very quickly restoring the generator terminal voltage in about 2 sec. The superconducting inductor charges to a maximum power of 30% while storing a peak of about 14 MJ of energy. The converter voltage is forced to about 45% higher while the current variation remains within a narrow range.

For a three phase fault on the transmission line when the generator is delivering 1.2 p.u. power at 0.85 lagging power factor, the system is unstable without SMES, and with SMES having $\Delta\alpha$ control proportional to $\Delta\omega$. This is exhibited by the frequency and angle variations given in Figs. 13 and 14. The proposed optimum control, however, stabilizes the system very quickly. This is achieved by having larger excursions of the converter voltages and power outputs. The variation of current remains insignificantly small similar to that in Fig. 12.

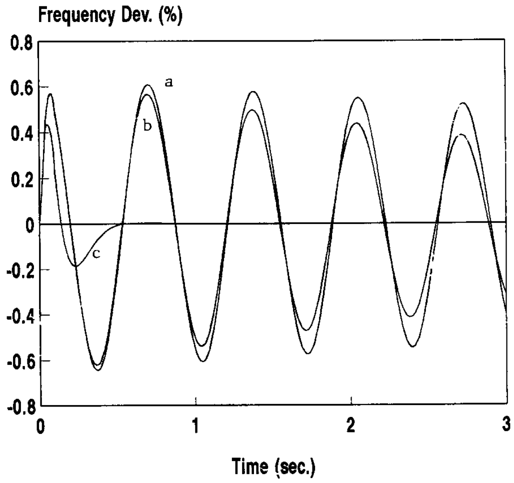


Fig. 5: Frequency deviation following a 50% torque pulse on the generator for a duration of 3.5 cycles. Generator output $P_0=1.00$ p.u.at 0.85 p. f. lagging. Responses are with (a) no control, (b) SMES and $\Delta\omega$ control and (c) with optimum control.

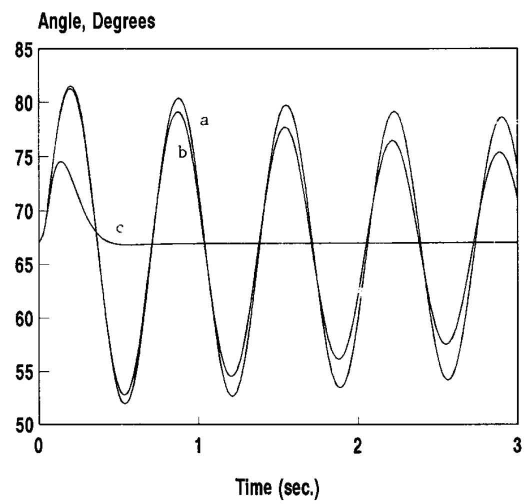


Fig. 6: Angle time response corresponding to Fig. 5, with (a) no control, (b) with SMES and $\Delta\omega$ control, and (c) optimum control.

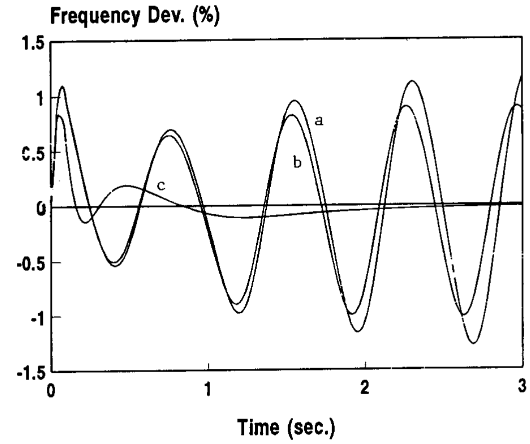


Fig. 7: Frequency variation following a three phase fault of 3.5 cycles duration at the remote end of the transmission line. The nominal power output of the generator is 1.0 pu at 0.85 p.f.lag. The responses are with, a) no control, b) SMES and $\Delta\omega$ control and, c) optimum control.

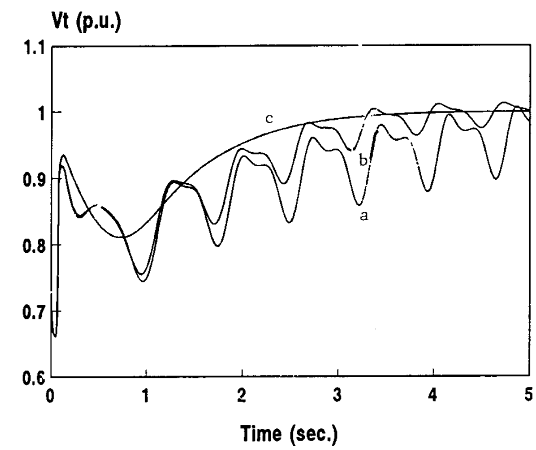


Fig. 8: Terminal voltage variation of generator corresponding to Fig. 7 with a) no control, b) SMES and $\Delta\omega$ control, and c) optimum control.

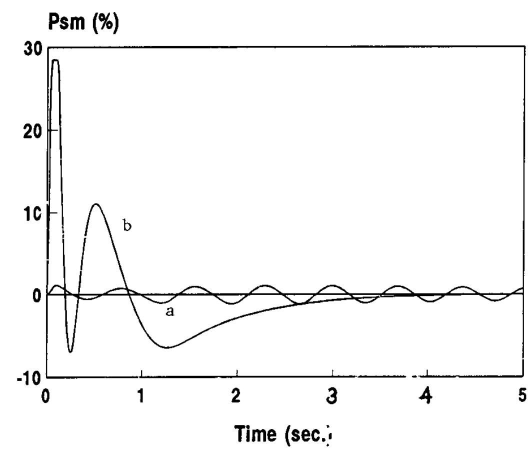


Fig. 9: Power input variation to the superconductor corresponding to Fig. 7 with a) SMES and $\Delta\omega$ control and, b) optimum control.

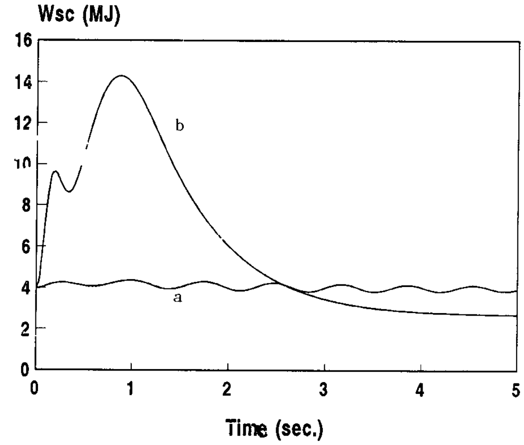


Fig. 10: Variation of stored energy in the superconductor. Symbols are as in Fig. 9.

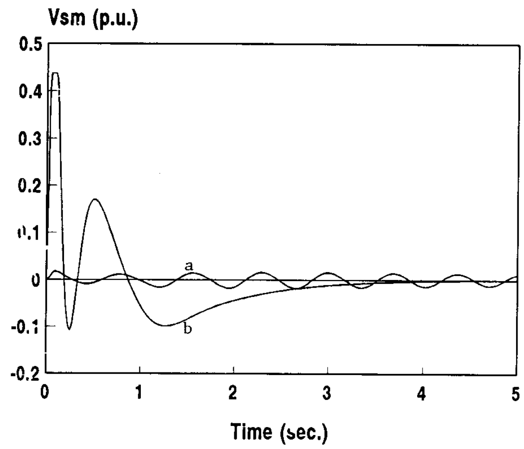


Fig. 11: Terminal voltage variation of the converters. Symbols are as in Fig. 9.

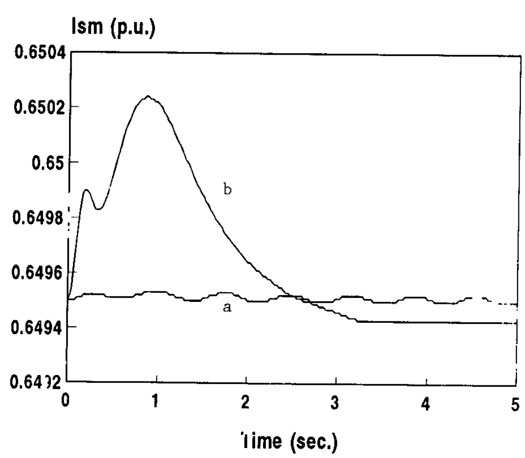


Fig. 12: Charging current variation in the super conducting magnet. Symbols are as in Fig. 9.

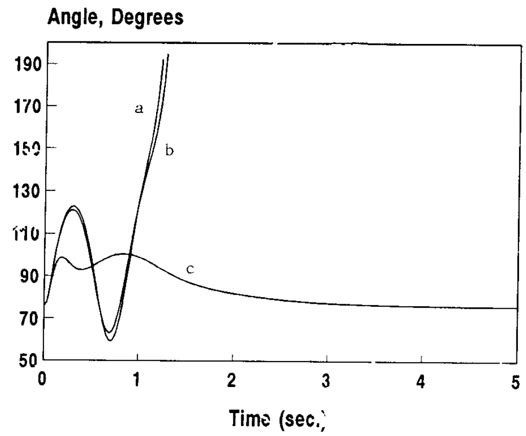


Fig. 13: Rotor angle variations following a 3-$\phi$ fault of 3.5 cycles duration when the generator is supplying 1.2 p.u. power. The responses are with a) no control, b) SMES and $\Delta\omega$ control, and c) optimum $\Delta\alpha$ control.

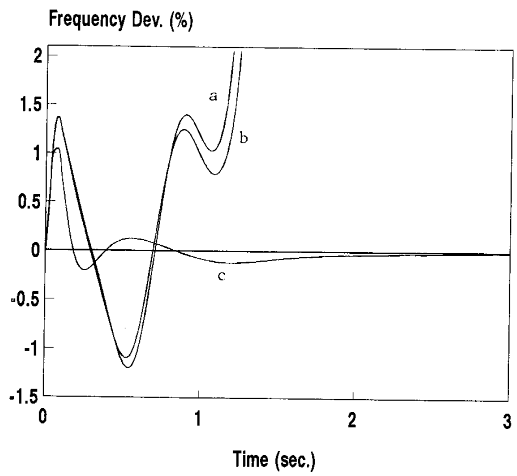


Fig. 14: Frequency variation corresponding to Fig. 13.

## V. CONCLUSIONS.

Stabilization of a power system through firing angle control of the thyristors in a superconducting magnetic system has been investigated. A control strategy is proposed which effects optimal power exchange between the SMES unit and the rest of the power system so that the electromechanical oscillations are controlled in minimum possible time. Simulation results indicate that the transients are controlled very quickly following even very severe disturbances.

The optimum control strategy presented takes the nonlinearities of the system dynamics into consideration. This makes the analysis valid for small as well as large perturbation conditions in the system. Also, the control is obtained directly as a function of system states and other measurable quantities which makes the implementation of the control relatively simple.

## VI. LIST OF SYMBOLS

| | |
|---|---|
| D | damping coefficient |
| M | generator inertia constant |
| $e_d'$ | direct(d) axis transient voltage |
| $e_q'$ | quadrature(q) axis transient voltage |
| $i_d$ | d-axis armature current |
| $i_q$ | q-axis armature current |
| $x_d$ | d-axis synchronous reactance |
| $x_d'$ | d-axis transient reactance |
| $x_q$ | q-axis transient reactance |
| $T_{do}'$ | d-axis open circuit field time constant |
| $T_{qo}'$ | q-axis open circuit field time constant |
| $e_{fd}$ | d-axis field voltage |
| $\Delta\omega$ | p.u.angular frequency variation |
| $\delta$ | generator rotor angular position |
| $P_m$ | generator input power |
| $P_e$ | electrical output of generator |
| $P_{SM}$ | power input to the SMES |
| $P_c$ | steam chest output power |
| $P_h$ | servomotor output power |
| $P_r$ | speed relay output power |
| p | operator d/dt |
| s | Laplace operator |
| $\alpha$ | converter firing angle |
| $\Delta$ | change from nominal values |
| $\omega_0$ | base angular frequency |
| $\omega_r$ | governor reference speed |
| $v_d$ | d-axis generator terminal voltage |
| $v_q$ | q-axis generator terminal voltage |
| $v_t$ | generator terminal voltage |
| $v_{tr}$ | reference terminal voltage |
| $v_o$ | power system bus voltage |
| $V_s$ | stabilizing transformer voltage |
| $r_a$ | generator armature resistance |
| $r_e$ | transmission line resistance |
| $x_e$ | transmission line reactance |
| $K_E$ | exciter gain |
| $T_E$ | exciter time constant |
| $K_F$ | stabilizer circuit gain |
| $T_F$ | stabilizer circuit time constant |
| $T_{SR}$ | speed relay time constant |
| $T_{SM}$ | servomotor time constant |
| $K_G$ | governor circuit gain |
| $T_{CH}$ | steam chest time constant |
| $K_{RH}$ | reheater gain |
| $T_{RH}$ | reheater time constant |
| $I_{SM}$ | superconducting inductor current |
| $V_{SM}$ | voltage across the inductor |
| $L_d$ | superconducting coil inductance |
| $W_{SM}$ | energy stored in the coil |
| $K_\alpha$ | converter loop gain |
| $T_\alpha$ | converter circuit time constant |

## VII. REFERENCES.


[1] F.P. deMello, P.J. Nolan, T.F. Laskowski, J. Undrill, "Co-ordinated Application of Stabilizers in Multimachine Power Systems". IEEE Trans. Power Apparatus and Systems, Vol. PAS-99, pp. 892-901, 1980.

[2] F. Aboytes, G.Arroyo, G.Villa, "Application of Static Var Compensators in Longitudinal Power Systems" IEEE Trans. Power Apparatus and Systems, Vol. PAS-102, pp. 3460-3466, 1983.

[3] A.R. Mehran, B.W. Hogg and M.L.El-Sayed, "Coordinated Control of Synchronous Generator Excitation and Static Var Compensator" , IEEE Trans. on Energy Conversion, Vol. 7, pp. 615-622, 1992.

[4] N.Chen, D.P. Carroll, "Damping Control of Power Systems with Magnetic Energy Storage", Int. Journal of Energy Systems, Vol. 10, no. 2, pp. 78-82, 1990.

[5] C. Wu, Y. Lee, "Application of Superconducting Magnetic Energy Storage Unit to Improve the Damping of Synchronous Generator", IEEE Trans. on Energy Conversion, Vol. 6, no. 4, pp. 573-578, 1991.

[6] Y. Mitani, K. Tsuji, Y. Marakami, "Application of Superconducting Magnet Energy Storage to Improve Power System Dynamic Performance", IEEE Trans. on Power Systems, vol. 3, no. 4, pp. 1418-1425, 1988.

[7] T. Ise, Y. Murakami, K. Tsuji, "Simultaneous Active and Reactive Power Control of Superconducting Magnet Energy Storage Using GTO Converters", IEEE Trans. Power Delivery, Vol. PWRD-1, no. 1, pp. 143-150, 1986.

[8] J.D. Rogers, R.I. Schermer, B.R. Miller, J.F.Hauer, "30 MJ Superconducting Magnetic Energy Storage System for Electric Utility Transmission Stabilization", Proc. IEEE, Vol. 71, no. 9, pp.1099-1107, 1983.

[9] H.J. Boenig, J.F. Hauer, "Commissioning Tests of the Bonneville Power Administration 30 MJ Superconducting Magnetic Energy Storage Unit", IEEE Trans. Power Apparatus and Systems, Vol. PAS-104, pp. 302-312, 1985.

[10] S.C. Tripathy, M.Kalantar and R.Balasubramanian, "Dynamics and Stability of Wind and Diesel Turbine Generators with Superconducting Magnetic Energy Storage Unit on an Isolated Power System", IEEE Trans. on Energy Conversion, Vol. 6, pp. 579-585, 1991.

[11] S. Banerjee, J. Chatterjee, and S. Tripathy, "Application of Magnetic Energy Storage Unit as Load Frequency Stabilizer", IEEE Trans. on Energy Conversion, Vol. 5, no. 1, pp. 46-51, 1990.

[12] I.El-Amin, M.Hussain, "Application of Superconducting Coil for Transient Stability Enhancement", Electric Power System Research, Vol. 17, pp. 219 -228, 1989.

[13] A.H.M.A. Rahim and A.M.Mohammad, "Superconducting Magnetic Energy Storage System for Power System Stabilization", 28th Universities Power Engineering Conference, Staffordshire, UK, September, 1993.

[14] Y.Yu, " Electric Power System Dynamics", Academic Press Inc. (1983).


## VIII. APPENDIX

The system data and the operating quantities in per unit are:

| | | | |
|---|---|---|---|
| $x_d' = 0.245$ | $x_d = 1.7$ | $x_q = 1.64$ | $r_a = 0.001096$ |
| $M = 4.74$ | $T_{do}' = 5.9$ s | $T_{qo}' = 0.075$s | $r_e = 0.02$ |
| $x_e = 0.04$ | $K_A = 400$ | $T_A = 0.05$ | $K_F = 0.025$ |

| | | | |
|---|---|---|---|
| $T_F = 1.0$ s | $K_G = 3.5$ | $T_{RH} = 8$ s | $T_{SM} = 0.2$ s |
| $T_{CH} = 0.05$ s | $T_{SR} = 0.1$ s | $K_{RH} = 0.3$ | $I_{SMO} = 0.649$ |
| $V_{SMO} = 0.0$ | $L_d = 0.5$ H | $K_\alpha = 1.83$ | $T_\alpha = 0.026$s |

**Abu H.M.A.Rahim** (S'69, M'72, SM'83) did his B.Sc. in Electrical Engineering from the Bangladesh University of Engineering and Technology (BUET), Dhaka in 1966 and Ph.D. from the University of Alberta, Edmonton, Canada in 1972. After a brief post doctoral work at the University of Alberta, he rejoined the Faculty in BUET, Dhaka. Dr. Rahim was a Visiting Fellow at the University of Strathclyde, Glasgow (U.K.) in 1978. He was with the King Fahd University of Petroleum and Minerals, Dhahran, Saudi Arabia during the period 1978 - 88. Presently he is a Professor at the University of Bahrain. Dr. Rahim's main fields of interest are Power System Stability, Control and Optimization. Dr. Rahim is a Fellow of the Institute of Engineers, Bangladesh.

**Abdullah M. Mohammad** did his B.Sc. in Electrical Engineering in March 1991. Following his graduation, he joined the Department of Electrical Engineering, University of Bahrain, as a Graduate Assistant. Mr. Mohammad is presently persuing his graduate studies at the, UMIST, Manchester,U.K. Mr. Mohammad's interest are in the area of Power System Analysis, Energy Systems, and Power System Control.