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Enhancement of Superconducting Generator Stability Using Coordinated Governor Controller and SVC-Based Fuzzy Logic Stabilizer

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ABSTRACT. In this paper, superconducting generator (SCG) stability enhancement via coordinated design of a governor controller (GC) and a static VAR compensator (SVC)-based fuzzy logic stabilizer is investigated. The GC is a conventional lead stabilizer activated by the speed error signal, while the signal produced by the SVC-based stabilizer is based on the SCG speed deviation and acceleration, and on two fuzzy membership functions reflecting few simple control rules. An objective function is defined and the design problem of efficient GC and SVC-based fuzzy stabilizer is formulated as an optimization problem. Particle swarm optimization (PSO) technique is employed to search for optimal parameters of GC and SVC-based stabilizer. Simulation results show that the proposed PSO-tuned control scheme provides good damping to the SCG, and enhances its stability over a range of operating conditions.

Keywords: Superconducting generator, Transient stability, FACTS, Fuzzy logic control, Particle swarm optimization

List of Symbols

B : susceptance of the SVC
F : fractional contribution of the turbine stage into T_m
G_M , G_I : main and interceptor valve positions
G_s : gain of governor controller
H : inertia constant
i : current
K_s , K_d : synchronizing and damping coefficients
K_{svc}, T_s : gain and time constant of the SVC
p : derivative operator
P_o : boiler steam pressure
P_t , Q_t : active power and reactive power at generator terminal
R : resistance
T_1 , T_2 : time constants of governor controller
T_e : air-gap torque
T_m : mechanical torque
u : stabilizing signal generated by governor controller
U_g : governor actuating signal
u_{SVC} : stabilizing signal generated by SVC-based stabilizer
X : voltage
Y : output of a turbine or reheat stage
δ : rotor angle with respect to infinite bus
τ : time constant of stage
ψ : flux linkage
ω : rotor speed deviation from synchronous speed (rad/s)
ω_o : synchronous speed (rad/s)

Subscripts

a : armature winding
d,q : d and q axis circuits of stator winding
$D1,Q1$: d and q axis circuits of outer screen
$D2,Q2$: d and q axis circuits of inner screen
f : field winding
HP : high pressure stage
IP : intermediate pressure stage
LP : low pressure stage
RH : reheat stage

1. Introduction

Superconducting generators have several potential advantages such as small size, light weight, high efficiency and increased steady state stability limit [1-2]. The advantages of SCG have drawn more interest in industrial countries since 1970's, such as in USA, UK and Japan where many R&D projects on SCGs have been conducted at utility companies, power plant manufacturers and other organization toward a 200 MW class pilot-machine [3-7]. Despite these advantages, SCG field winding has an extremely large time constant. The excitation system is therefore not able to change quickly the field current to meet the grid requirements under transient conditions. SCG is also characterized by low inertia and low inherent damping, each of which adversely affects the machine stability when connected to a power system. Inevitably, governor control becomes the feasible technique to enhance stability of superconducting generators. The availability of electro-hydraulic governors and fast operation of steam valves has now made it possible to obtain very fast turbine response. Research works reported in Ref. [8-9] have shown that SCG stability can be improved by introducing a phase advance network in the governor feedback loop, activated by the speed error signal.

Recently, the flexible AC transmission systems (FACTS) have been introduced, in which various power electronics-based controllers are used to maximize the utilization of transmission assets efficiently and reliably [10-11]. In addition, FACTS devices regulate power flow and, through rapid control actions, can mitigate low frequency oscillations and enhance power system stability [12-13].

On the other hand, fuzzy logic stabilizers have appeared as a viable alternative to the conventional stabilizers for enhancing power system stability [14-15]. Control scheme based on fuzzy logic is important to consider in view of its potentially lower computational burden and flexible reconstruction. The application of fuzzy control techniques appears to be particularly useful whenever the system to be controlled is complex and has uncertainty and imprecision. These properties certainly apply to power systems incorporating superconducting generators.

Early investigation on the dynamic performance of a SCG when equipped with a static VAR compensator at its terminal was reported in Ref. [16]. In that study, the stabilizing signal was not optimized. Moreover, the governor role in damping the machine oscillation was not considered. However, some efforts have been made towards stability enhancement of SCG using coordinated governor controller and FACTS device-based conventional stabilizer [17]. The conventional stabilizer parameters are fixed to ensure optimum performance at a specific operating point. However, because of the high nonlinearity of the machine/power system combination, the stabilizer's performance becomes lower when the system operating condition moves significantly away from the specific point. Therefore, the conventional stabilizer should have some degree of robustness to be able to stabilize the system over a wide range of operating conditions.

In this paper, enhancement of SCG stability using coordinated design of a static VAR compensator (SVC)-based fuzzy stabilizer and a governor controller (GC) is studied. The coordinated optimal parameters of SVC-based fuzzy stabilizer and GC are sought by utilizing the PSO technique [18]. Various non-linear simulation studies are carried out to investigate the effectiveness of the proposed scheme.

2. System Description

The system considered in this study is a SCG connected to an infinite bus power system as shown in Fig. (1) [17]. The SCG has superconducting field windings in the rotor, surrounded by two separate screens. The inner screen, which has a relatively long time constant, shields the superconducting field windings from external, time varying magnetic fields. The outer screen serves as a damper and has a substantially shorter time constant than that of the inner screen [19]. The SCG is driven by a three-stage steam turbine with reheat between the high pressure and intermediate pressure stages. The turbine is controlled by fast acting electro-hydraulic governors fitted to the main and interceptor valves, which are working in unison. The system is equipped with a governor controller and a SVC at the terminal of the SCG. The exciter voltage, U_e , of the SCG is kept constant during transients.

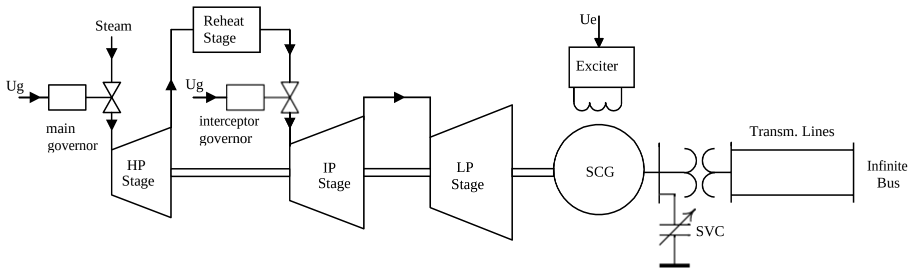

Fig. (1). SCG system under study with SVC

3. Mathematical Model

The mathematical models for SCG, turbine and governor are shown below, while the parameter values and physical constraints are given in the Appendix. All the state variables used in the mathematical models for the system under study is in per unit except δ is in radian and ω is in radian/s.

3.1. Superconducting Generator Model

Based on Park's *d-q* axis representation, seven non-linear differential equations are used to represent the mathematical model of the SCG's electric circuits. These equations along with the mechanical equations of motion give the flux linkage model of the SCG [9] as follows:

$$p\psi_d = \omega_o[V_d + i_d R_a + \psi_q] + \psi_q \omega \quad (1)$$

$$p\psi_q = \omega_o[V_q + i_q R_a - \psi_d] - \psi_d \omega \quad (2)$$

$$p\psi_{D1} = -\omega_o i_{D1} R_{D1} \quad (3)$$

$$p\psi_{Q1} = -\omega_o i_{Q1} R_{Q1} \quad (4)$$

$$p\psi_{D2} = -\omega_o i_{D2} R_{D2} \quad (5)$$

$$p\psi_{Q2} = -\omega_o i_{Q2} R_{Q2} \quad (6)$$

$$p\psi_f = \omega_o[V_f - i_f R_f] \quad (7)$$

$$p\delta = \omega \quad (8)$$

$$p\omega = \frac{\omega_o}{2H}[T_m - T_e] \quad (9)$$

$$T_e = \psi_d i_q - \psi_q i_d \quad (10)$$

3.2. Turbine and Governor Model

The mathematical model of the turbine and governor system is represented by six non-linear differential equations [18] as follows:

$$pY_{HP} = (G_M P_o - Y_{HP}) / \tau_{HP} \quad (11)$$

$$pY_{RH} = (Y_{HP} - Y_{RH}) / \tau_{RH} \quad (12)$$

$$pY_{IP} = (G_I Y_{RH} - Y_{IP}) / \tau_{IP} \quad (13)$$

$$pY_{LP} = (Y_{IP} - Y_{LP}) / \tau_{IP} \quad (14)$$

$$pG_M = (U_g - G_M) / \tau_{GM} \quad (15)$$

$$pG_I = (U_g - G_I) / \tau_{GI} \quad (16)$$

The output mechanical torque is given as:

$$T_m = F_{HP} Y_{HP} + F_{IP} Y_{IP} + F_{LP} Y_{LP} \quad (17)$$

The main and interceptor valves are conventionally actuated by a normalized speed error signal incorporating a droop, typically 4%. Constraints are imposed on valve positions and rates of movement. The rate constraint is based on complete opening or closing time for the valves of 150 ms. The rate limits correspond to the fastest valve operation reportedly available in literature [20].

4. The Proposed Approach

4.1. Control Objective

The control objective is to generate two stabilizing signals using the speed error signal. The first control signal is produced via a conventional controller and then introduced into the governor loop of the SCG system as shown in Fig. (2). The control signal, *u*, generated by the conventional controller is given as:

$$u = G_s \cdot \frac{(1+T_1 s)}{(1+T_2 s)} . \omega \tag{18}$$

where ω is the speed error signal, G_s , T_1 and T_2 are the controller parameters, which have to be designed properly to achieve a satisfactory performance. The phase advance network is a lead compensator, which increases the stability by increasing the gain and phase margins. The network provides both speed error and speed derivative (acceleration) signals. An advantage of existing a derivative term in the stabilizer output is that it possesses an anticipatory characteristic and initiates an early correcting or stabilizing action.

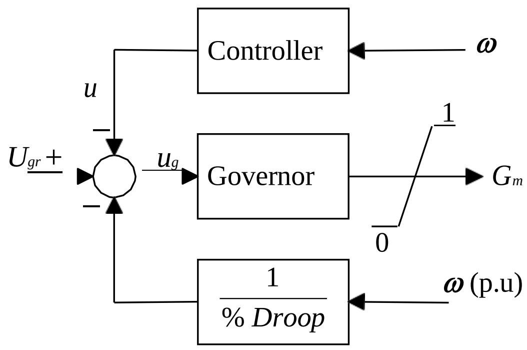

Fig. (2). The governor control system

The second signal is produced via a SVC-based fuzzy stabilizer. The two stabilizing signals are coordinated to enhance the damping of the rotor oscillations after disturbances, and hence to improve the transient and dynamic performance of the system.

4.2. SVC-Based Fuzzy Stabilizer

The block diagram of an SVC with a fuzzy stabilizer is shown in Fig. (3). Functionally the SVC is thought of as an adjustable shunt susceptance that can be varied with sufficient rapidity. Elaborated model for SVC can be seen in Ref. [21]. However, the susceptance, *B*, of the SVC can simply be expressed as:

$$pB = (K_{svc}(B_{ref} + u_{SVC}) - B)/T_{svc} \tag{19}$$

where K_{svc} and T_{svc} are the gain and time constant of the SVC. B_{ref} is the reference susceptance of the SVC and u_{SVC} is the stabilizing signal generated by the fuzzy stabilizer installed in the feedback loop of the SVC shown in Fig.(3), instead of the conventional lead stabilizer used in ref. [17].

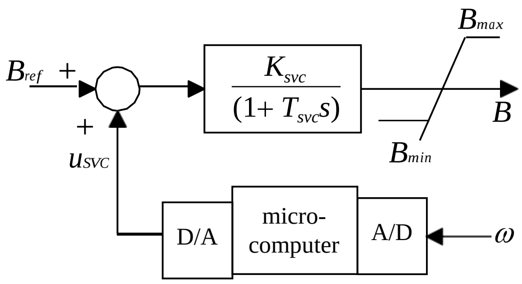

Fig. (3). SVC with digital (fuzzy) stabilizer

The signal u_{SVC} is synthesized using fuzzy logic as follows. Fuzzy logic is the logic underlying modes of reasoning which are approximate rather than exact. Thus it is closer to human reasoning and real world than formal logic.

The SCG condition is defined at every sampling time, kT_s , in terms of its speed deviation and scaled acceleration, [$\omega(k)$, $F* d\omega(k)/dt$], where $d\omega(k)/dt=[\omega(k)-\omega(k-1)]/T_s$, T_s is the sampling interval and F is a predefined scaling factor. This condition represents a certain point, Z, in the [$\omega(k)$, $F*d\omega(k)/dt$] phase plane as shown in Fig. (4). The polar displacement D(k) of this point from the origin, and the corresponding angle $\theta(k)$ are computed as:

$$D(k) = [(\omega(k))^2 + (F*\dot{\omega}(k))^2]^{0.5} \tag{20}$$

$$\theta(k) = \tan^{-1}(F*\dot{\omega}(k)/\omega(k)) \tag{21}$$

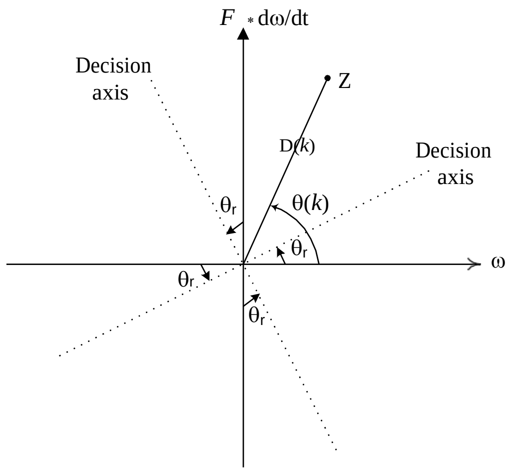

Fig. (4). Definition of SCG condition in the phase plane

The phase plane is divided into four quadrants. Each quadrant has simple control rules according to the degree of deceleration and/or acceleration control required to restore the machine condition, after the disturbance, to the origin of the phase plane as soon as possible with an acceptable performance. Generally, deceleration control and hence a positive control signal, is only required when the SCG status locates in a certain quadrant (say the first quadrant). Acceleration control and hence a negative control signal is required only when the SCG status lies in the opposite quadrant (i.e. the third quadrant). Decreasing (or increasing) deceleration and increasing (or decreasing) acceleration as well are required when the SCG status lies in the other two (i.e. the second and the fourth) quadrants. Two fuzzy membership functions, $N(\theta)$, shown in Fig.(5), associated with the desired deceleration, and $P(\theta)$ associated with the desired acceleration, are defined in terms of the polar angle, θ, defined by equation (21) to reflect the actions of the control rules. The defining relations for $N(\theta)$ and $P(\theta)$ are:

$$N(\theta)=\begin{cases}1 & \text{for } \theta\le\theta_i\\ (\theta_1-\theta)/(\theta_1-\theta_i) & \text{for } \theta_i<\theta\le\theta_1\\ 0 & \text{for } \theta_1<\theta\le\theta_2\\ (\theta-\theta_2)/(\theta_f-\theta_2) & \text{for } \theta_2<\theta\le\theta_f\end{cases} \qquad (22)$$

$$P(\theta)=1-N(\theta) \qquad \text{for all}\,\theta \qquad (23)$$

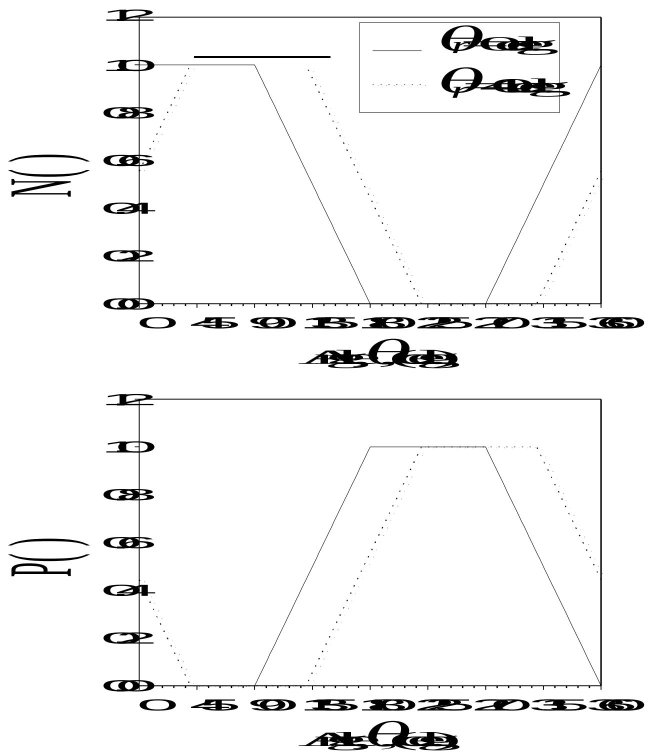

Fig. (5). Proposed fuzzy membership functions *N*(θ) and *P*(θ)

The angles θ_i, θ_1, θ_2, and θ_f are normally fixed at 90, 180, 270 and 360 degrees respectively with excitation control of conventional generators [22]. The fuzzy membership functions described by equations (22) and (23) can be portrayed in terms of a pair of what can be termed "decision axes", shown in Fig. (4), on the phase plane. It was found by the present investigator that, for best results, the angles θ_i, θ_1, θ_2, and θ_f should again progress in 90 degree steps, but that an offset angle θ_r between the phase plane axis set (i.e. the $\omega(k)$ and $F*d\omega(k)/dt$ axes) and the decision axis set (i.e. quadrant boundaries) should be introduced as shown in Fig. (4) [23]. This offset angle θ_r, which can be regarded as a new tuning parameter, is hence introduced when designing the fuzzy logic-based stabilizer. It specifies the best location for each quadrant with its particular control rules on the phase plane. In effect, the offset angle θ_r rotates the decision axis set anti-clockwise until the minimum of a predefined performance index is obtained.

This has the effect in turn of changing the final shapes of fuzzy membership functions over the whole universe of discourse, *i.e.* another set of control rules is generated according to the degree of rotation θ_r. The resulting two membership functions then lead to a stabilizing signal, $u_{SVC}(k)$, given by:

$$u_{SVC}(k) = G(k)\,[N(\theta(k)) - P(\theta(k))]\,u_{\max} \tag{24}$$

where G(k) is the gain whose value is defined as:

$$G(k) = D(k)/D_r \qquad \text{for } D(k)<D_r \tag{25}$$

$$G(k) = 1 \qquad \text{for } D(k)\geq D_r \tag{26}$$

The parameter D_r is a set value of polar displacement at which the gain is required to saturate at unity. However, the implementation of the above SVC-based fuzzy stabilizer requires the following steps in each sampling time:

Step1: SCG speed deviation, $\omega(k)$, is sampled and the scaled acceleration, $F*d\omega(k)/dt$, is computed.

Step2: D(k) and $\theta(k)$ are determined using equations (20, 21).

Step3: Values of both fuzzy membership functions, $N(\theta)$ and $P(\theta)$, are calculated.

Step4: The control signal $u_{SVC}(k)$ is determined using equation (24).Both of u and u_{SVC} have upper and lower limits, i.e.

$$u_{\min} \leq (u, u_{SVC}) \leq u_{\max} \tag{27}$$

5. Stabilizer Parameters Selection Using PSO

Recently, a heuristic search method called *particle swarm optimization* (PSO) has been introduced. PSO is characterized as a simple concept, easy to implement, and computationally efficient. Theses features make PSO technique able to accomplish the same goal as genetic algorithm (GA) optimization does in a new and faster way. A number of very recent successful applications of PSO on various power system problems has been reported in literature [18].

The tuning parameters of the proposed coordinated control scheme are F, D_r and θ_r for the SVC-based fuzzy stabilizer and G_s , T_1 and T_2 for the governor controller (GC). u_{max} (the maximum size of the control signal) is a pre-specified constant parameter. For optimal settings of the tuning parameters, the quadratic performance index, J, defined by equation (28) is also used. For convenience, it is recalled here:

$$J = \sum_{k=1}^{N} \{[kT.\omega(k)]^2 + [\Delta\delta(k)]^2 + [\Delta G_M]^2\} \tag{28}$$

Where $\Delta\delta$ (k) and ΔG_M (k) are the deviations of the rotor angle and the governor valve position, respectively, from their steady state values. In addition, N denotes the total number of time steps. This index is chosen because a low value of it reflects small settling time, small steady state error, and small overshoots in each of rotor speed, rotor angle, and valve position. The tuning parameters are selected to minimize this performance index subject to the following constraints:

$$F_{\min} \leq F \leq F_{\max} \tag{29}$$

$$D_{r,\min} \leq D_r \leq D_{r,\max} \tag{30}$$

$$\theta_{r,\min} \leq \theta_r \leq \theta_{r,\max} \tag{31}$$

$$G_{S,\min} \leq G_S \leq G_{S,\max} \tag{32}$$

$$T_{1,\min} \leq T_1 \leq T_{1,\max} \tag{33}$$

$$T_{2,\min} \leq T_2 \leq T_{2,\max} \tag{34}$$

The digital simulation for the SCG system is used in conjunction with the PSO process, which is then used to search for the optimal set of the tuning parameters, which minimizes the performance index chosen. PSO itself has a number of parameters to be properly specified. The main PSO parameters are the initial inertia weight, w^0, and the maximum allowable velocity, V_{max}. These parameters and other PSO parameters are set as in [17].

6. Simulation Results

A number of simulation studies has been performed to investigate the effectiveness of the proposed SVC-based fuzzy stabilizer in improving stability of the SCG under study. The performance index was evaluated, in all cases, in response to a three-phase to ground fault of 120-ms duration at the sending end of the transmission line with the operating point (P_t=0.8 p.u, Q_t=0.6 p.u). Variation of the performance index J with the number of iterations is shown in Fig. (6) in two cases. In the first case, the optimal set of (F, D_r , θ_r) for the SVC-based fuzzy stabilizer was searched for using PSO; considering governor controller (GC) with G_s=0.1 T_1,=0.5s and T_2=0.01s [24]. In the second case, coordinated design for best combination of (F, D_r , θ_r) for the SVC-based fuzzy stabilizer and (G_s , T_1, T_2) for the GC was sought using PSO and GA. Three remarks are drawn from Fig. (6). First, lower values for the performance index were reached to in the second case, either using GA or PSO. Second, PSO converged to a lower value for the performance index than that obtained by GA. Third, the GA pre-maturely converged (it did 62 iterations), while PSO did many more iterations to find out more optimal settings of the tuning parameters. Therefore, it is concluded that the coordinated design (using PSO) for the SVC-based fuzzy stabilizer and the GC results in the highest possible improvement in the SCG performance for the cases considered.

The optimal coordinated values selected by PSO for (F, D_r , θ_r) and (G_s , T_1, T_2) are (0.028, 0.923, 3.84º) and (0.061, 1, 0.01) respectively. Performance of the SCG system with the optimally designed control scheme following a 3-phase short circuit fault at the sending end of the transmission line, at [(P_t, Q_t) = (0.8, 0.6), (0.9, 0), (0.7, -0.2) p.u] is shown in Figs. (7 to 9), in comparison with the performance when governor controller (GC) [24] is considered only. Figures (10 to 12) show the system response to a temporary (100-ms long) 10% step increase in the governor set point (U_{gr}) at the previous loading conditions.

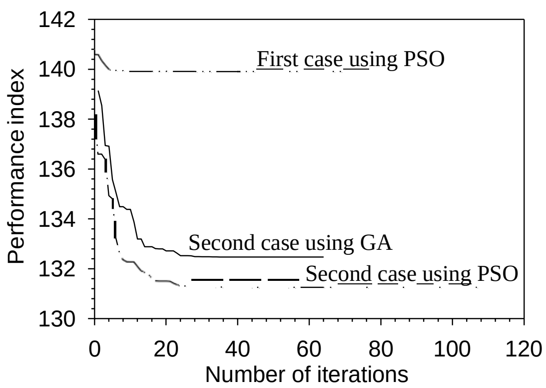

Fig. (6). Convergence of performance index with iterations using PSO & GA.

First case: Optimizing parameters of SVC-based fuzzy stabilizer only.

Second case: Optimizing parameters of both SVC-based fuzzy stabilizer and GC.

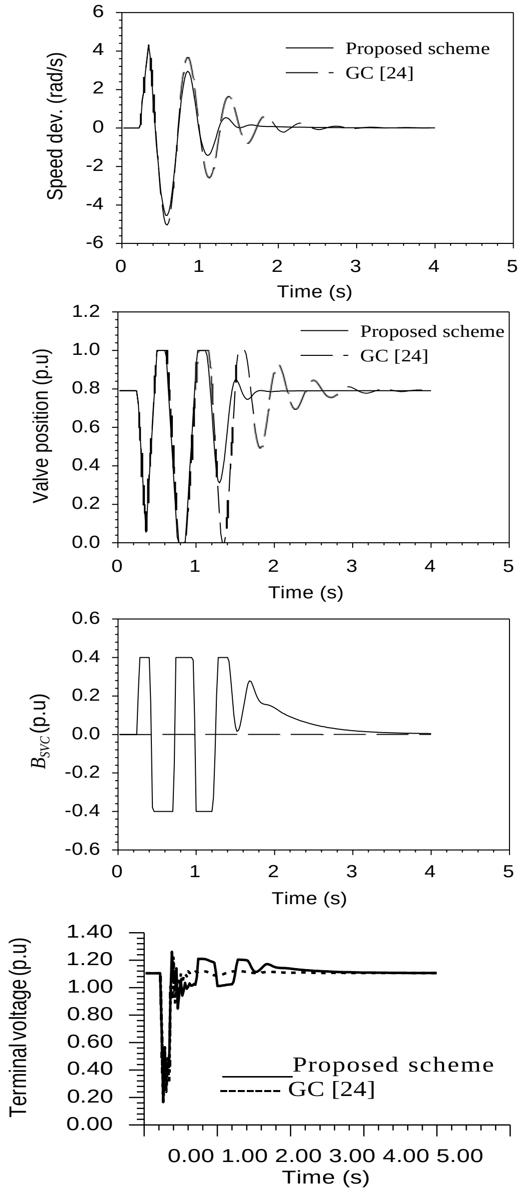

Fig. (7). Response to a 3-phase SC at P_t=0.8 pu, Q_t=0.6 pu.

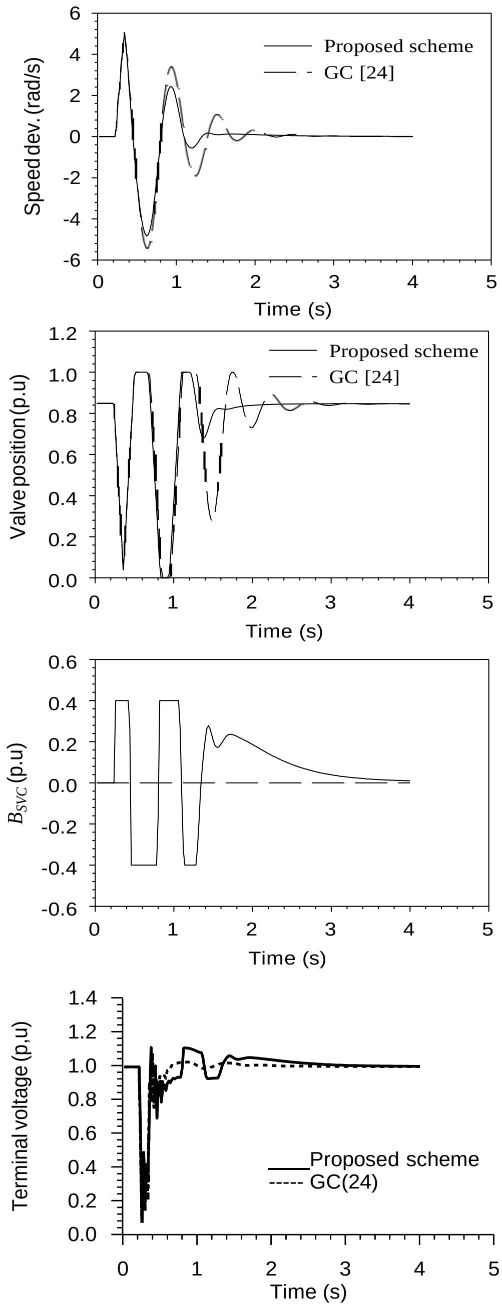

Fig. (8). Response to a 3-phase SC at P_t=0.9 pu, Q_t=0 pu.

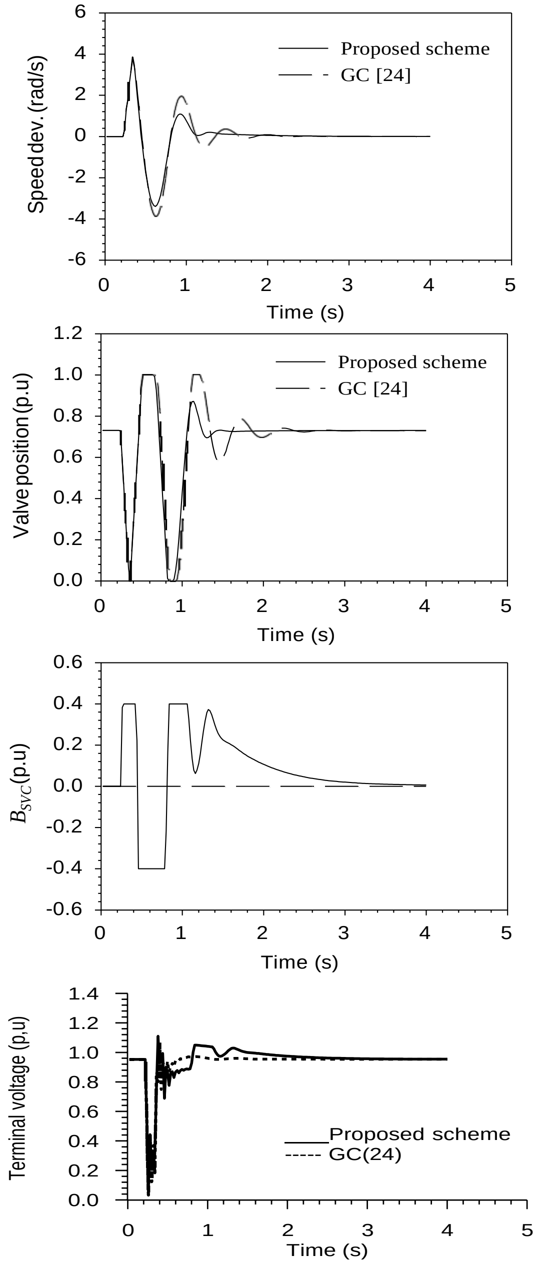

Fig. (9). Response to a 3-phase SC at P_t=0.7 pu, Q_t=-0.2 pu.

The results show that the proposed control scheme results in a considerable reduction in the rotor oscillations with acceptable valve movements at various loading conditions, the matter that represents an improvement in the SCG transient performance (after major and minor disturbances). In addition, the results show that the SVC sometimes operates in bang-bang control mode when a major disturbance (3-phase SC fault) occurs. This happens because the rating of the SVC is limited to a small value for economic consideration. The variation of susceptance B_{SVC} of the SVC is controlled by the signal u_{SVC} produced by the SVC-based fuzzy stabilizer. As is seen and concluded from the figures, this signal is so well synthesized and optimized that the SVC produces or absorbs reactive power in a way that increases damping of the mechanical-mode oscillations of the SCG under study.

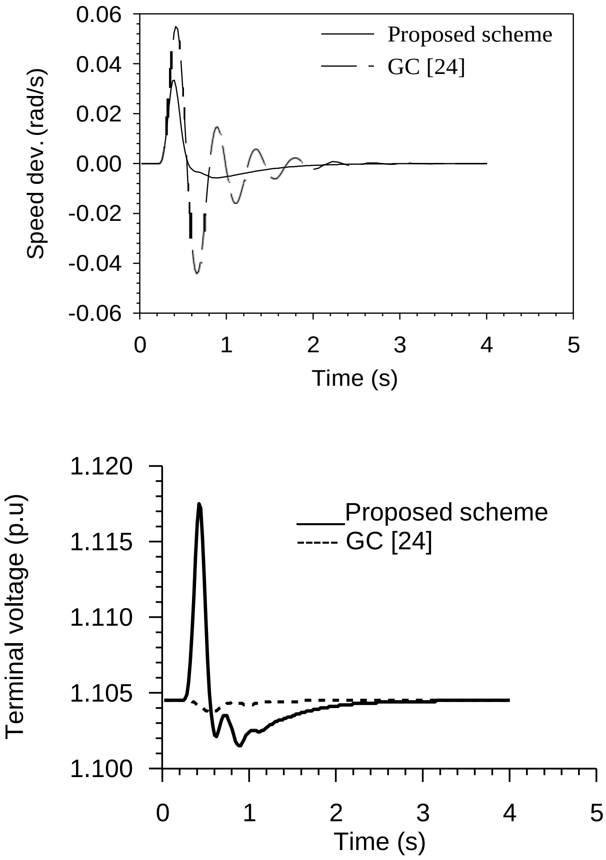

Fig. (10). Response to a 10% pulse in U_{gr} at P_t=0.8 pu, Q_t=0.6 pu.

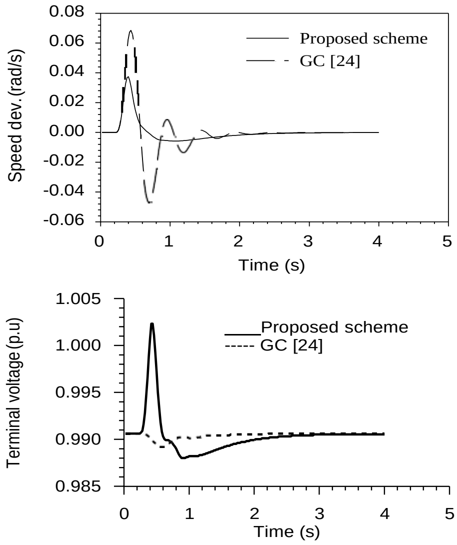

Fig. (11). Response to a 10% pulse in U_{gr} at P_t=0.9 pu, Q_t=0 pu.

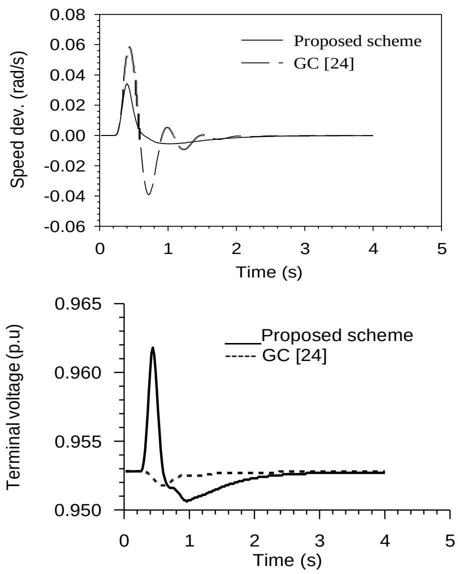

Fig. (12). Response to a 10% pulse in U_{gr} at P_t=0.7 pu, Q_t=-0.2 pu.

7. Damping and Synchronizing Torques Analysis

The object of this section is to investigate the effects of the proposed control scheme and other schemes on the SCG dynamic performance using the concept of damping and synchronizing torques, which was initially introduced by Demello and Concordia [25]. According to this concept, the change in electrical torque acting on the rotor, ΔT_e , can be divided into two components: one is in time phase with, and proportional to the rotor angle deviation $\Delta\delta$. This is called the "synchronizing torque". The other, which is in time phase with and proportional to the rotor speed deviation ω is called the "damping torque". The change in electrical torque can be written as follows:

$$\Delta T_e = K_s \Delta\delta + K_d \omega \tag{35}$$

where K_s and K_d are the synchronizing and damping coefficients respectively. It is now well recognized that machine stability is highly degraded if there is lack of either or both of synchronizing and damping torques. The values of K_s and K_d are determined from the time responses of electrical torque, rotor angle and rotor speed, using the technique explained in Ref. [26-27]. In that technique, the error between the actual torque deviation and that obtained by summing the damping and synchronizing torque components is defined as:

$$E(t) = \Delta T_e(t) - [K_s \Delta\delta(t) + K_d \omega(t)] \tag{36}$$

The error squares can be summed over the simulation time period. Minimizing this summation with respect to K_s and K_d yields the following dependent algebraic equations:

$$\sum_n \Delta T_e \Delta\delta = K_s \sum_n (\Delta\delta)^2 + K_d \sum_n \omega\Delta\delta \tag{37}$$

$$\sum_n \Delta T_e \omega = K_d \sum_n \omega^2 + K_s \sum_n \omega\Delta\delta \tag{38}$$

Solving the equations (37) and (38) gives the values of K_s and K_d, where n is the discrete-simulation time.

A summarized comparison of the proposed scheme and other schemes (viz. SVC with GC [17], and GC [24] only) is shown in Table (1).

Table (1). Comparison of the proposed scheme and other schemes.

(P_t, Q_t) p.u	(0.8, 0.6)			(0.7, -0.2)	
	J	K_d	K_s	K_d	K_s
Proposed scheme	131.25	0.25	1.996	0.242	1.223
SVC with GC [17]	130.2	0.231	1.941	0.212	1.184
GC [24]	261.7	0.014	2.011	0.016	1.251

Table (1) shows that the GC [24] offers the SCG the lowest damping, while adding SVC-based stabilizer with the GC to stabilize the SCG increases the damping of the system, whether the SVC-based stabilizer is the conventional type [17] or the fuzzy type proposed here. The results show that the proposed scheme increases the damping coefficient K_d by 8% and 14% at [(P_t, Q_t) = (0.8, 0.6), (0.7, -0.2) p.u] respectively, compared with that using SVC with GC [17], and by 16.85 times and 14 times respectively, compared with that using the GC [24]. Therefore, it can be concluded that the proposed scheme outperforms the other considered schemes at the operating points studied. It provides the SCG system with the highest possible degree of damping while keeping the synchronizing torque at a high level.

8. Conclusion

This paper investigated the application of one of FACTS devices for stability enhancement of superconducting generators. An approach was proposed for the design of a static VAR compensator-based fuzzy stabilizer in coordination with a governor controller to provide more damping to mechanical oscillations of the SCG studied. A performance index was defined and the PSO technique was used to select the optimal parameters of both SVC-based fuzzy stabilizer and GC. Simulation results show the effectiveness of the proposed control scheme in damping the rotor oscillations, and enhancing the SCG stability over a range of operating conditions and various disturbances. Analysis of damping and synchronizing torques was used to provide another quantitative assessment of the SCG performance with the designed SVC-based fuzzy stabilizer and GC. Results of non-linear simulation studies show the effectiveness of the proposed approach in enhancing SCG stability.

9. ACKNOWLEDGMENT

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11. APPENDIX A

The parameters of the SCG system used in this study (inductance and resistance values in p.u; time constants in seconds) are [8, 9]:

Superconducting generator parameters:

L_f=0.541, L_d=L_q=0.5435, L_{D1}=L_{Q1}=0.2567, L_{D2}=L_{Q2}=0.4225

L_{fd}=L_{fD1}=L_{dD1}=L_{dD2}=L_{D1D2}=0.237

L_{fD2}=0.3898, L_{qQ1}=L_{qQ2}=L_{Q1Q2}=0.237

τ_f=750, R_d=R_q=0.003

R_{D1}=R_{Q1}=0.01008, R_{D2}=R_{Q2}=0.00134

H=3 kW.s/kVA

Transformer and transmission line parameters:

X_T =0.15, R_T =0.003, X_L =0.05, R_L =0.005

Turbine and governor parameters:

τ_{GM} =τ_{GI} =0.1, τ_{HP} =0.1, τ_{RH} =10,

τ_{IP} =τ_{LP} =0.3, P_o = 1.2 p.u.

F_{HP} = 0.26, F_{IP} = 0.42, F_{LP} = 0.32

Valve position and movement constraints are defined by:

$0 \le (G_M, G_I) \le 1$ and $-6.7 \le (pG_M, pG_I) \le 6.7$

تعظيم استقرار المولد فائق التوصيل باستخدام ضابط الحاكم المنسق مع موازن غيمي المنطق مؤسس على معوض القدرة غير الفعالة الساكن

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الملخص العربي. يعد استخدام المولدات فائقة التوصيل في أجهزة القدرة الكهربائية مثل المحولات و المولدات من التكنولوجيات المتقدمة في العصر الحالي. كما يعد استخدام المولدات فائقة التوصيل في نظم القوى الكهربائية أحد الحلول الواعدة للتغلب على الطلب المتزايد للقدرة الكهربائية و ما يتعلق به من مشاكل في التوليد والنقل والتكلفة. تمتاز المولدات فائقة التوصيل مقارنة بالمولدات الأخرى بصغر الحجم و الوزن و زيادة الكفاءة و بانخفاض ممانعتها التزامنية. و لهذه المولدات أيضا مزايا بيئية نتيجة الانخفاض في الوقود المستهلك و انبعاث ثاني أكسيد الكربون. من ناحية أخرى تعاني هذه المولدات من ضعف الخمد الذاتي للاهتزازات الطارئة وصعوبة التحكم فيها من جهة المغذي, و لذلك تعتبر زيادة استقرارها من القضايا الهامة لتطوير هذه المولدات. يقدم هذا البحث طريقة فعالة لتحسين استقرار هذه المولدات باستخدام معوض القدرة غير الفعالة الساكن, حيث يتم تصميم موازن باستخدام الذكاء الاصطناعي لإخماد الذبذبات الميكانيكية)بالتنسيق مع حاكم البخار الداخل للتوربيني(لمولد فائق التوصيل متصل بالشبكة الكهربائية عن طريق خط نقل مزدوج و محول رفع, و مزود عند طرفيه بمعوض ساكن للقدرة غير الفعالة. تم استخدام طريقة السرب لتحديد القيم المثلى لثوابت الموازن المقترح. و تمت دراسة و تقويم أداء النظام المدروس عند ظروف تشغيل مختلفة و مقارنة النتائج مع تلك المنشورة في المراجع. توضح نتائج المحاكاة أن الموازن الغيمي المقترح و المصمم بواسطة طريقة السرب يؤدي إلى تحسن واضح في أداء و استقرار النظام المدروس.