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TRANSIENT STABILITY IMPROVEMENT OF POWER SYSTEMS BY OPTIMAL SIZING AND ALLOCATION OF RESISTIVE SUPERCONDUCTING FAULT CURRENT LIMITERS USING PARTICLE SWARM OPTIMIZATION

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ABSTRACT

Employing Resistive Superconducting Fault Current Limiters (RSFCL) is one of the practical and effective methods to improve the transient stability of a power system by limiting the fault current. Regarding technical and economical constraints, optimal sizing and allocation of RSFCLs in a power system is of significant importance. It is the purpose of this paper to propose an algorithm based on the Particle Swarm Optimization (PSO) in order to improve the transient stability of a power system by optimal sizing and allocation of RSFCLs. The proposed algorithm is next applied to the New England 39-bus test system as a case study and the results are simulated in Matlab. Simulation results reveal that in the case of employing RSFCLs with sizes and locations resulted from the optimization algorithm, the transient stability of the power system under study is improved. Furthermore, it seems that the optimal locations of RSFCLs are to some extent near the fault location.

KEYWORDS

Transient Stability Improvement, Resistive Superconducting Fault Current Limiters (RSFCL), Particle Swarm Optimization (PSO)

1. INTRODUCTION

Electric power systems are always probable to face with various faults including short circuits as one of the frequent faults. The occurred fault is to be cleared as soon as possible and the fault current is to be limited otherwise, it may result in several problems in the power system such as stability problems especially transient stability risks. Hence, transient stability enhancement of a power system in the event of a short circuit will be of great importance. Employing Fault Current Limiters (FCL) is one of the useful methods to improve the transient stability of a power system by limiting the fault current using different methods. Superconducting Fault Current Limiter (SFCL) especially its resistive type, i.e. Resistive Superconductor Fault Current Limiter

(RSFCL), are two well-known categories of FCLs. Regarding technical and economical constraints, optimal sizing and allocation of FCLs in a power system has a large importance. According to the performed assessments, a little work has been done until now about the optimal sizing and allocation of FCLs to enhance the transient stability of power systems. Therefore, it is the purpose of this paper to improve the transient stability of a power system by optimal sizing and allocation of RSFCLs using the Particle Swarm Optimization (PSO).

A variety of methods have been studied so far to improve the transient stability of power systems. For instance, Slootweg et al [1], M. Reza et al [2-4], Coster et al [5], Le-Thanh et al [6], Emhemed et al [7], and Al-Hinai [8] have investigated the role of Distributed Generations (DG) in improvement of power systems transient stability. M. Noe and B.R. Oswald [9] have studied the technical and economical aspects of employing RSFCLs in power systems. Based on simulation results, Hoshyar and Savabeghi [10] have admitted the effectiveness of RSFCLs with shunt resistors in the transient stability improvement of a power system. Transient stability of a single machine power system in the presence of a non- superconducting fault current limiter is studied and simulated by Tarafdar Hagh, Jafari, and Naderi [11]. Employing optimal SFCLs based on the Genetic Algorithm (GA) to improve the transient behaviors in ring networks is analyzed by K. Hongesombut [12]. Utilizing a series proposed RSFCL to enhance the transient stability of power systems has been modeled and simulated by Byung Chul Sung et al [13]. The result of their work demonstrates the efficiency of the RSFCL in the stability and reliability improvement of power systems. Masaki Yagami et al [14] have simulated and analyzed the effect of SFCLs on the dynamic behavior of generators in the event of a three-phase short circuit demonstrating the efficient role of SFCLs in the transient stability enhancement of power systems. Finally, employing RSFCLs as a powerful controller to improve the transient stability of power systems has been simulated by Masaki Tsuda et al [15] resulting that the more the value of the resistance, the more the amount of transient stability improvement.

The paper is organized as follows: First, the concept of transient stability in power systems is reviewed and then, resistive superconducting fault current limiters are studied briefly. Next, Particle Swarm Optimization is reviewed. An algorithm is then proposed based on the PSO to optimize the considered objective function. The proposed algorithm is next applied to the New England 39-bus test system as a case study and the results are simulated and discussed in Matlab using Power System Toolbox [16]. Finally are the conclusions and the suggestions for further research.

2. A REVIEW OF TRANSIENT STABILITY CONCEPT

The synchronous machines connected to the power system run at synchronous speed of the grid. As far as a power system is operating in the steady state condition, there is equilibrium between the mechanical input power of each unit and the total losses in addition to electrical power output of that unit. However, an unpredicted change in the electrical power output caused by a severe and sudden disturbance will destroy this balance. Transient stability relates to electric alternating current (a.c.) power systems and demonstrates a situation in which a number of synchronous machines of the power system remain in synchronism after a fault occurs.

On the other hand, instability presents a condition having loss of synchronism. The problem comes up when there is an unexpected change in the electrical power output caused by a severe and sudden disturbance. The harshness is measured by the drop of this power to a very low or to zero value and a significant sudden acceleration of the machines controlled by the swing equation as follows [17]:

$$\frac{2H}{\omega_0}\frac{d^2\delta}{dt^2} = P_m - P_e \qquad (1)$$

Where,

δ= rotor angle, in electrical radian.
P_m= mechanical power, in p.u.
Pe = electrical power output, in p,u.
H= inertia constant, in MW-s/MVA.
ω_0 =nominal speed, in electrical radian/s

It is clear from (1) that a decrease in the mechanical power has the same impact on the rotor angle swings as the increase in the electrical power output has. Fast valving is for reducing the mechanical power input to the turbine and therefore the generated power. The loads can be expressed as:

$$P_L = P_O(1 + \lambda P_{nl}) \qquad (2)$$

where P_o stands for the active power base load, P_{nl} represents the load distribution factor, and PL is the active load at a bus L for the current operating point.

In order to evaluate the transient stability of a power system, an indicator is required. In [1], maximum rotor speed deviation and oscillation duration of the large scale generators after fault clearing have been utilized as the criterion. In [2], the Critical fault Clearing Time (CCT), i.e. the maximum duration of the fault which will not end in the synchronism loss in one or more generators, has been used as the indicator. Another very common indicator for the transient stability analysis is the comparison between the rotor angle (δ) oscillations of synchronous generators and that of the slack bus generator of the system [16]. In this paper, the latter is employed as the transient stability indicator.

3. RESISTIVE SUPERCONDUCTING FAULT CURRENT LIMITERS

Having a high non-linear resistance characteristic, the superconductor can be utilized as a Fault Current Limiter (FCL). The Superconducting Fault Current Limiter (SFCL) employs a quench characteristic for limiting the fault current. The superconductor makes it possible to have a quickly increased resistance and be variable from a superconducting state to a normal conducting state.

SFCLs have various types such as resistive types, inductive types, hybrid types, etc. among which the resistive type (RSFCL) is the most developable and commercial having a simple structure, a lighter weight, and a lower cost than the inductive type. Resistive superconducting fault current limiters use superconducting materials as the main current carrying conductor in the normal operation of power network. However, when a RSFCL operates, a hot spot is caused and an excessive amount of heat is generated. To solve this problem, the heat generated at the time of a quench phenomenon, i.e. when the superconductor is transmitted from the superconducting state to the normal conducting state, has to be dispersed. Moreover, in order to increase the voltage

capacity of the RSFCL, the quench phenomenon has to be simultaneously generated at the fault current limiting devices connected in series with each other [18].
For stability studies in power systems, RSFCLs are usually modeled as a resistor series with the transmission line. The single-line diagram of a single-machine system with RSFCL is illustrated in Fig. 1 [13, 19].

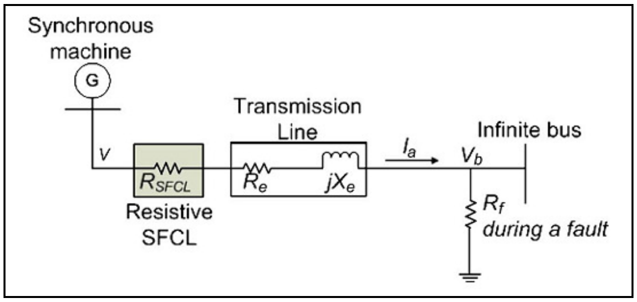


Fig. 1: A single-machine system with RSFCL

4. OVERVIEW OF PARTICLE SWARM OPTIMIZATION

First introduced by Kennedy and Eberhart in the mid 90s, Particle Swarm Optimization (PSO) is a population based stochastic optimization method developed through the simulation of social behaviors such as fish schooling and bird flocking [20-23]. PSO is based on exchanging information among the particles in a network. In comparison with other evolutionary optimization algorithms such as Genetic Algorithm, the application of PSO is simple and few parameters need to be adjusted. Moreover, the PSO is able to optimize complex constrained objective functions in multimodal search spaces. Hence in recent years, it has obtained wide applications in optimization problems [24].

The PSO is a history based algorithm in which the particles in each step use their own behavior associated with the previous iterations. To explain this idea in an explicit way, we can say that each individual in particle swarm, called as a “particle”, represents a potential solution, next, each particle moves its position in the search space and updates its velocity according to its own and neighbors’ flying experience aiming to find a better position for itself. It is mainly based on the principle that the probability of finding a better minimum near the so far found minimum is more than other places. Thus, the particles are diverted toward searching around the found minimum. In moving towards the minimum point, the velocity of each particle and its updated position is identified by (3) and (4), respectively.

$$\vec{v}_i(t+1)=C[\varphi\vec{v}_i(t)+r_1C_1(\vec{x}_{pbest_i}-\vec{x}_i(t))+r_2C_2(\vec{x}_{gbest_i}-\vec{x}_i(t))] \tag{3}$$

$$\vec{x}_i(t+1)=\vec{x}_i(t)+\vec{v}_i(t+1) \tag{4}$$

Where:

$\vec{v}_i(t)$: The current velocity of ith particle;
$\vec{v}_i(t+1)$: The next velocity of ith particle;

φ: inertia weight;
r_1: cognitive factor;
r_2: social factor;
C: contraction factor;
C_1 and C_2: acceleration constants.

The flow chart of the algorithm is shown in Fig. 2. The algorithm starts with a randomly generated population. The success of the algorithm to a great extent depends on correct setting of parameters such as problem dimension, number of particles, number of iterations, maximum velocity of particles, contraction factor, inertia weight, and acceleration constants [25].

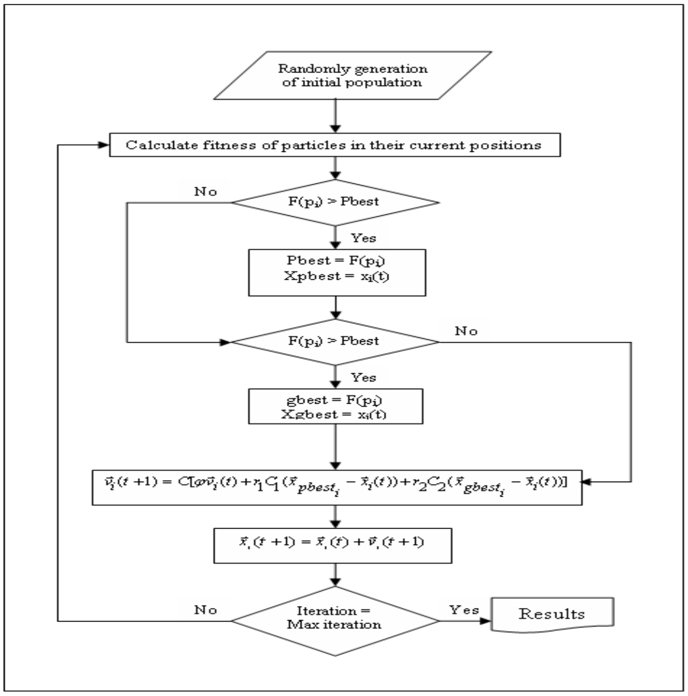


Fig. 2: Flow chart of the PSO algorithm

A change in these parameters will affect the algorithm sensitivity and accuracy to a great deal. The values for the above-mentioned parameters are all experimental and there is not theoretical method for their accurate calculation. Considering an upper bound for the velocity will cause the particles not to jump with a high velocity in the search area and thus, the space is more accurately assessed in order to find more desirable areas and furthermore, the algorithm divergence due to high velocities is prevented [26]. When the velocity vector of each particle is updated, the following constraint is applied:

$$\begin{aligned} &if : V_i(t) > V_{\max} \Rightarrow V_i(t) = V_{\max} \\ &if : V_i(t) < V_{\max} \Rightarrow V_i(t) = -V_{\max} \end{aligned} \tag{5}$$

The contraction factor controls the effect of velocity in updating the particles positions considering the parameters limits. The inertia weight controls the effect of previous velocity on the current velocity. Large values of this parameter will cause a larger search in the search space and its smaller values will lead in focusing on a smaller area. r1 and r2 are random numbers in the range (0, 1) and C1 as well as C2 are positive numbers. Due to a study on the effect of C1 and C2 on the particles movement paths, the following constraint is proposed as a necessary condition for the algorithm convergence:

$$C_1 + C_2 \leq 4 \qquad (6)$$

5. PROBLEM FORMULATION

In order to solve the optimization problem, an objective function is defined and then, it is minimized by the proposed algorithm to find the optimal sizes and locations of RSFCLs so that the transient stability of the power system is improved.

5.1. Objective Function

In a power system with (n) generators, a generator is considered as the slack one and (n-1) generators are remained. When a fault occurs, all of the generators lose their equilibrium and their rotor angle (δ) will oscillate. The oscillation of individual generators will be different with each other depending on the position of fault and fault clearing time. The δ oscillation of (n-1) non-slack generators are plotted compared to that of the slack one and the total sum of areas in individual δ curves can be considered as an index for the improvement of transient stability. That is, if the sum of these areas is reduced by applying the optimization results, it can be concluded that the transient stability has been improved. Consequently, if the sum of areas is the least, the best state for the transient stability enhancement will be achieved since this minimization means that in a specified time scale, the amplitude of the oscillations are decreased or the oscillations are damped faster which both of them result in the decrease of areas in (δi – t) curves. Hence, the objective function can be defined as:

$$FF = Min\left[J = \int_0^{\tau} |\ \delta_1(t)\ | d(t) + \int_0^{\tau} |\ \delta_2(t)\ | d(t) + \ldots + \int_0^{\tau} |\ \delta_{n-1}(t)\ | d(t) \right] \qquad (7)$$

where;

δj(t) is the magnitude of δ in (n-1) non-slack generators compared to that of the slack one in the [0 – τ] time scale after the fault clearing in which j= 1,2,….,(n-1).

Equation (7) can be written as follows:

$$FF = Min\left[J = \sum_{j=1}^{n-1} \int_0^{\tau} |\ \delta_j(t)\ | d(t) \right] \qquad (8)$$

5.2. Proposed Optimization Algorithm

The goal of the optimization algorithm is to minimize the defined objective function using the particle swarm optimization. In large power systems, considering RSFCLs in all of the lines is not practical nor is economically viable. Hence, the proposed approach is based on considering RSFCLs in limited lines. In this case, number of optimization problem parameters will be twice the number of lines considered to have RSFCLs. The upper and lower bounds of parameters are considered according to the power system under study. The proposed optimization algorithm is shown in Fig. 3.

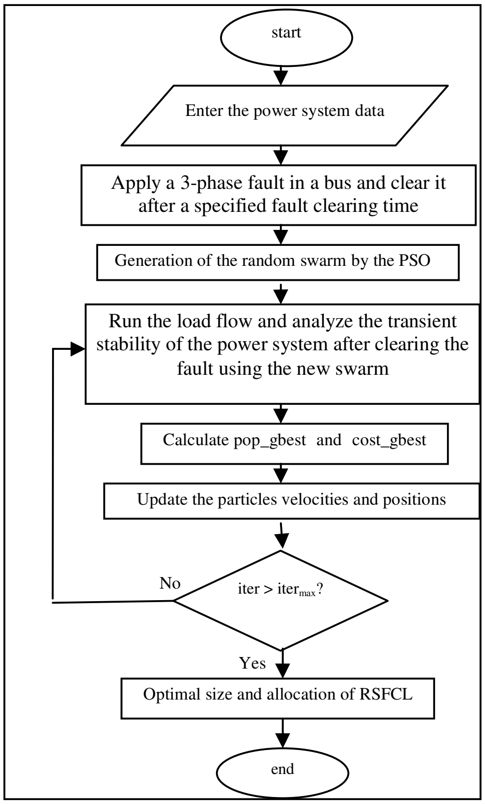


Fig. 3: The Proposed Optimization Algorithm

In the following, a brief description of each step is presented:

A. System data gathering: This data is required for transient stability calculations and include the power system operating frequency, buses data, lines data, and generators data.
B. Applying a fault to the power system: A three-phase fault is applied to a line in the power system under study and it is cleared after a specific time (fault clearing time) by opening this line from both ends. Since the fault type, its location, and its clearing time have important roles on the transient stability of the system, the optimization has to be performed for a specific fault. The fault type is considered as a three-phase fault as the worst fault type in power systems. The fault position and its clearing time are specified according to each case study.
C. Generation of the random swarm: A random swarm is generated by the PSO as the following matrix: $Initial\ Swarm = [\quad]_{n\times m}$
   where;

n is the number of matrix rows indicating the swarm size, m is the number of matrix columns indicating the parameters of optimization problem.

D. Performing the transient stability analysis: The random swarm is applied to the power system and system data is recalculated based on the random swarm. Then, the considered fault is applied to the power system and transient stability analysis is performed.
E. Calculation of the objective function: Once the transient stability analysis is done and required data are calculated, the value of the objective function is computed using Equation (7).
F. Calculation of the pop_gbest and cost_gbest: For each particle, the value of its corresponding objective function is compared with its individual best and if it is less than the pbest, this value is considered as the current pbest and its corresponding particle's position is saved. Moreover, the position of the minimum pbest, i.e. the individual best among the swarm particles, is selected and this value is considered as the Gbest.
G. Updating particles velocities and positions: Particles velocities and positions are updated using Equations (3) and (4), respectively. Then, the new swarm is generated.
H. Investigation of the maximum iteration: Once the particles velocities and positions are updated and the new swarm is generated, the maximum iterations index is checked. If the number of current iteration is more than that of the maximum iteration, the best sizes and locations among all iterations are presented as the optimal sizes and locations of the RSFCLs. Otherwise, the algorithm will jump to step (D) and the loop will be repeated considering the new swarm. Steps D to H will be continued as many times as the number of iterations is more than that of the maximum iteration.

6. CASE STUDY

The proposed algorithm is tested on the New England power system, which is often employed as a test system for stability studies. The single-line diagram of this system is illustrated in Fig. 4 and the system data is presented in [27]. Table 1 summarizes the general data of this system. In this case study, the optimization is performed considering five RSFCLs.

Table 1: General data of New England 39-bus power system

System parameter	Value
Number of buses	39
Number of generators	10
Number of loads	19
Number of lines	46

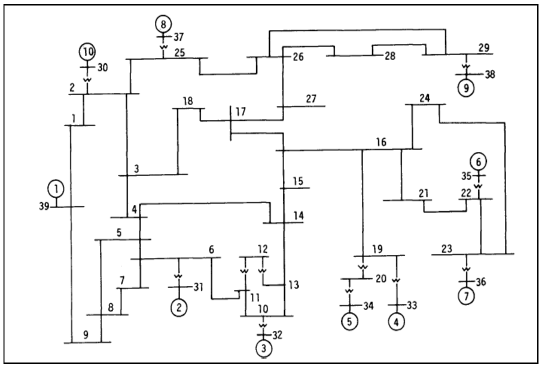


Fig. 4: Single-line diagram of New England 39-bus power system

The data related to the optimization algorithm for the present case study is summarized in Table 2. Table 3 presents the optimization results. Fig. 5 shows the convergence of the objective function against the number of iterations.

Table 2: Optimization data for the case study of New England 39-bus

Number of iterations in PSO		200
Swarm size		60
Number of parameters		10
Parameters bounds		
Parameter	Lower	Upper bound
1	1	46
2	0	0.03
3	1	46
4	0	0.03
5	1	46
6	0	0.03
7	1	46
8	0	0.03
9	1	46
10	0	0.03

Applied fault: Three-phase fault at line [14, 15]
Fault clearing time (sec.): 0.45
Simulation time (sec.): *1.5*
PSO setting parameters: $C_1=2$; $C_2=1$

Table 3: Optimization results for the case study of New England 39-bus

The line to install the RSFCL		Value of the RSFCL (p.u.)
Begin bus No.	End bus No.	
21	22	0.00011382
17	18	0.027127
0.26	29	0.0082893
0.15	16	0.026589
0.26	27	0.0069581

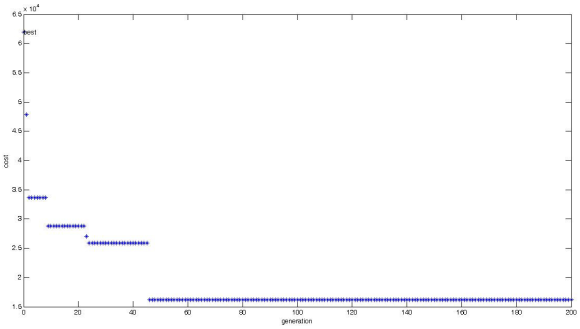
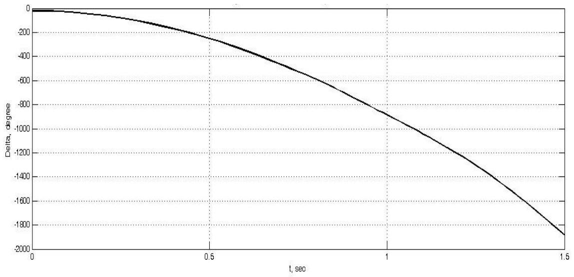
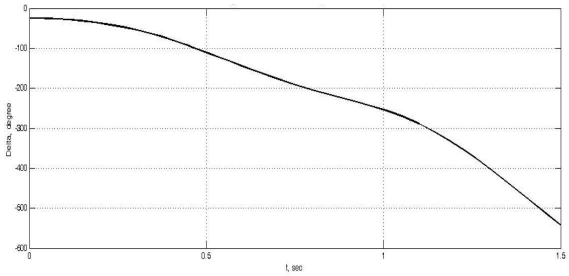


Fig. 5: The converge curve of the PSO for the proposed objective function

To investigate the optimization results, the considered three-phase fault in Table 3 is applied to the system under study and the transient stability of the system is simulated and analyzed in two cases: (1) without the RSFCLs and (2) in the presence of RSFCLs with optimal sizes and locations resulted from the proposed PSO algorithm. Fig. 6 to Fig. 14 illustrate the simulation results for the rotor angles of non-slack generators compared to that of the slack generator as an index for the transient stability improvement.

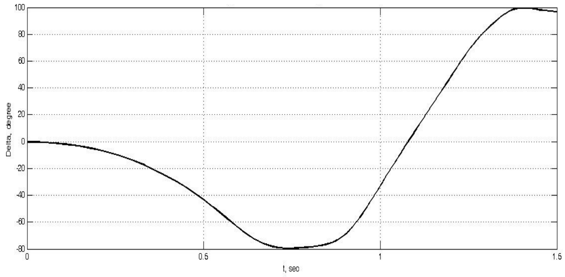


(a) without employing RSFCL

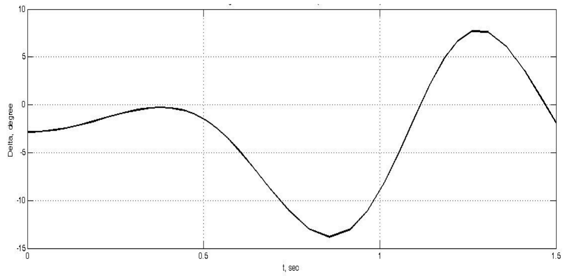


(b) in the presence of RSFCLs with optimal sizes and locations

Fig. 6: The rotor angle curve of generator No. 1 for the considered fault

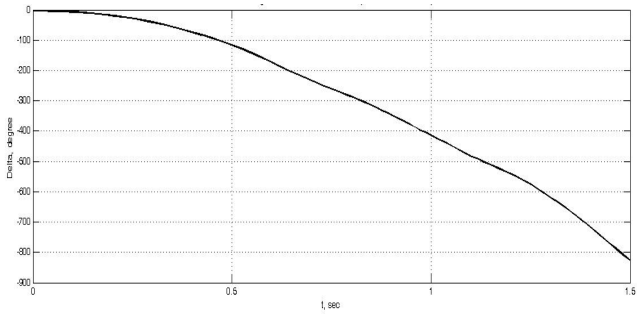


(a) without employing RSFCL

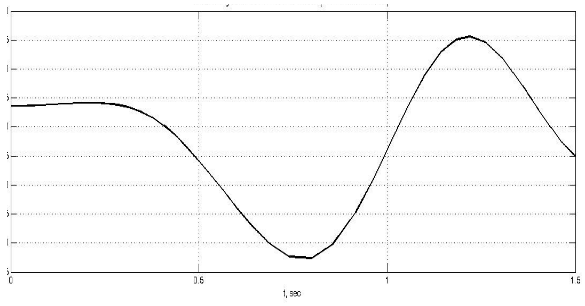


(b) in the presence of RSFCLs with optimal sizes and locations

Fig. 7: The rotor angle curve of generator No. 2 for the considered fault

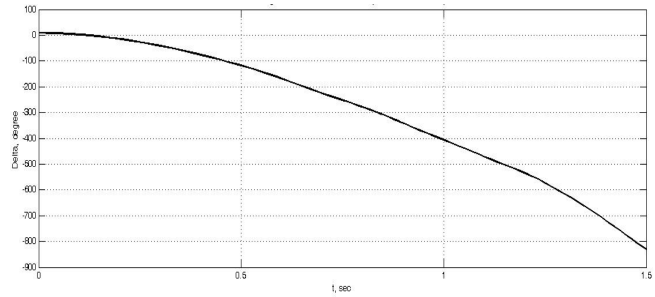


(a) without employing RSFCL

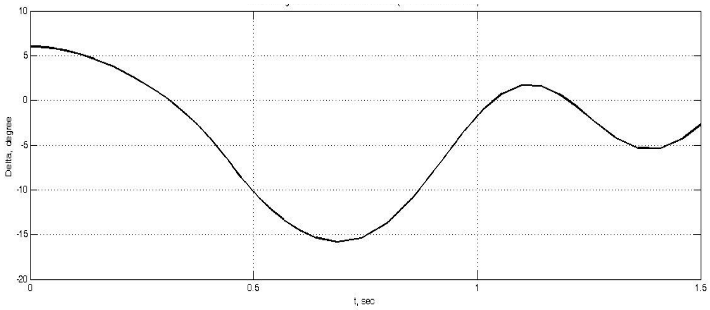


(b) in the presence of RSFCLs with optimal sizes and locations

Fig. 8: The rotor angle curve of generator No. 3 for the considered fault

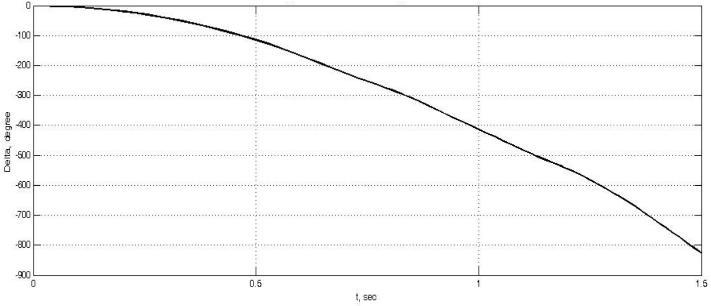


(a) without employing RSFCL

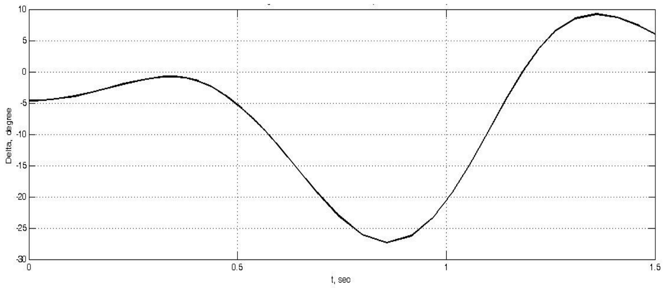


(b) in the presence of RSFCLs with optimal sizes and locations

Fig. 9: The rotor angle curve of generator No. 4 for the considered fault

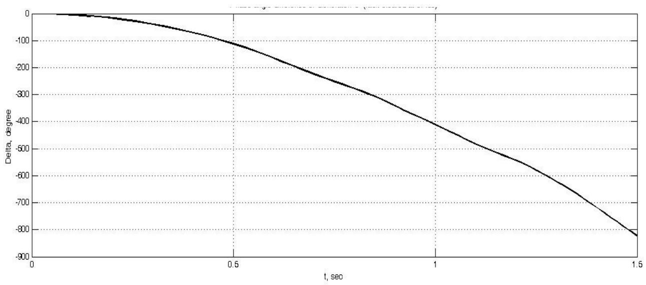


(a) without employing RSFCL

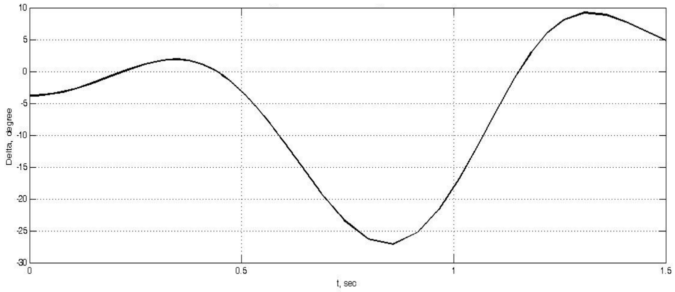


(b) in the presence of RSFCLs with optimal sizes and locations

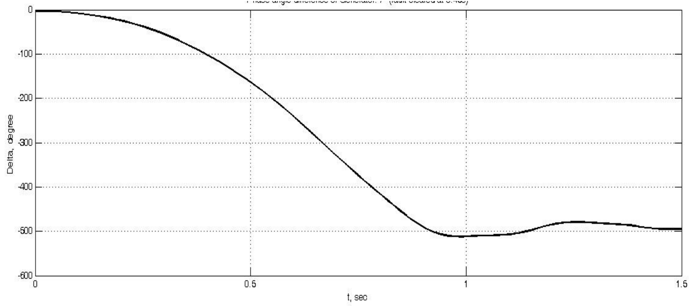
Fig.10: The rotor angle curve of generator No. 5 for the considered fault



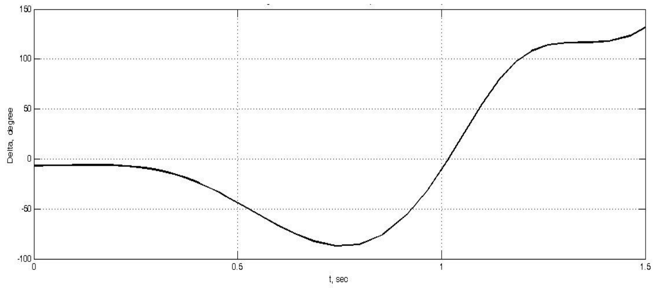
(a) without employing RSFCL



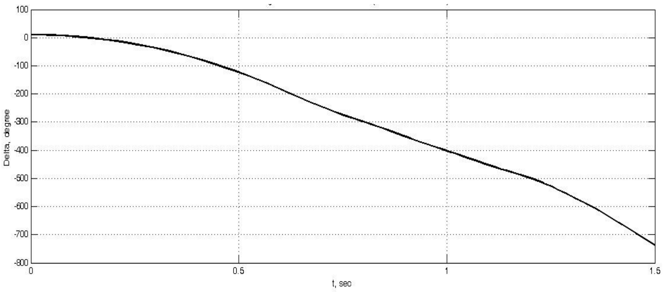
(b) in the presence of RSFCLs with optimal sizes and locations
Fig. 11: The rotor angle curve of generator No. 6 for the considered fault



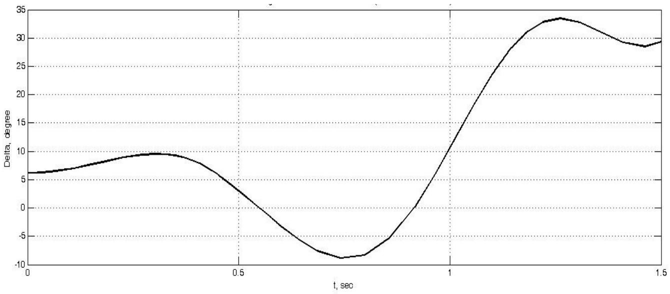
(a) without employing RSFCL



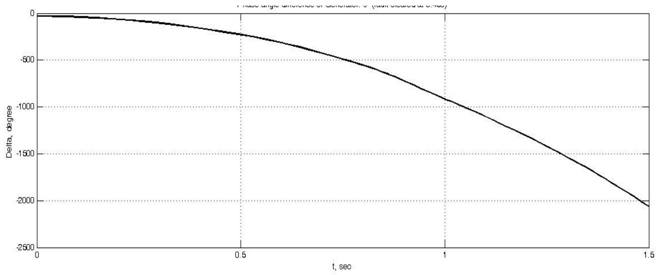
(b) in the presence of RSFCLs with optimal sizes and locations
Fig. 12: The rotor angle curve of generator No. 7 for the considered fault



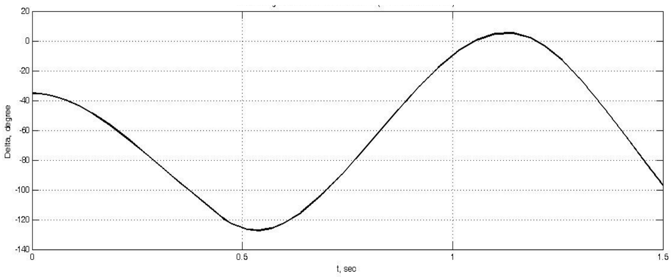
(a) without employing RSFCL



(b) in the presence of RSFCLs with optimal sizes and locations
Fig. 13: The rotor angle curve of generator No. 8 for the considered fault



(a) without employing RSFCL



(b) in the presence of RSFCLs with optimal sizes and locations
Fig. 14: The rotor angle curve of generator No. 9 for the considered fault

According to Fig. 6 to Fig. 14 it can be observed that compared to the case of which no RSFCL is utilized in the power system, in the case of employing RSFCLs with sizes and locations resulted from the optimization algorithm, most of the generators remain stable after the fault clearance and in those which are unstable, the amount of instability is less than that in the case of no RSFCL utilization. Therefore, it can be concluded that the transient stability of the power system under study and for the considered fault has been improved in the presence of RSFCLs with optimal sizes and locations resulted from the proposed PSO algorithm. Moreover, it seems that the optimal locations of RSFCLs are to some extent near the fault location. Of course, this matter needs to be investigated more in future works.

7. CONCLUSIONS

In this paper, a PSO-based algorithm was proposed based on an objective function for optimal sizing and allocation of RSFCLs to enhance the transient stability of power systems. The proposed algorithm was next applied to the New England 39-bus test system as a case study and the extracted results were simulated in Matlab. Simulation results revealed that in the case of employing RSFCLs with sizes and locations resulted from the optimization algorithm that the transient stability of the power system under study and for the considered fault was improved. Furthermore, it seemed that the optimal locations of RSFCLs were to some extent near the fault location. Of course, this matter needs to be investigated more in future researches. Moreover, considering assessment indexes other than what was utilized in the present paper and comparing the results seems to be an attractive subject. The proposed algorithm can also be studied based on other faults in different parts of the system. Finally, other optimization algorithms may be employed to solve the proposed optimization problem.

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REFERENCES

[1] J. G. Slootweg, W. L. Kling, (2002), "*Impacts of Distributed Generation on Power System Transient Stability*", IEEE Power Engineering Society Summer meeting, Volume 2, Pages:862- 867.

[2] M. Reza, J. G. Slootweg, P. H. Schavemaker, W. L. Kling, L. van der Sluis, (2002), "*Investigating Impacts of Distributed Generation on Transmission System Stability*", IEEE Bologna Power Tech Conference, Volume 2, Pages:1-7.

[3] M. Reza, J. G. Slootweg, P. H. Schavemaker, W. L. Kling, L. van der Sluis, (2004), "*Impacts of distributed generation penetration levels on power systems transient stability*", IEEE Power Engineering Society General Meeting, Vol.2, Pages:2150 – 2155.

[4] Reza, M.; Gibescu, M.; Schavemaker, P.H.; Kling, W.L.; van der Sluis, L., (2005), "*Transient stability impacts of a 'vertical-to-horizontal' transformation of power systems*", IEEE Power Tech.

[5] Coster, E.J.; Myrzik, J.M.A.; Kling, W.L, (2008), "*Transient stability of distributed generation in MV-Ring networks*", IEEE Transmission and Distribution Conference and Exposition, Pages:1 – 7.

[6] Le-Thanh, L.; Tran-Quoc, T.; Devaux, O.; Chilard, O.; Kieny, C.; Hadjsaid, N.; Sabonnadiere, J.C., (2008), "*Hybrid methods for transient stability assessment and preventive control for distributed*

generators", IEEE Power and Energy Society General Meeting - Conversion and Delivery of Electrical Energy in the 21st Century, Pages:1 – 6.

[7] Emhemed, A.S.; Tumilty, R.M.; Burt, G.M.; McDonald, J.R., (2008), "*Transient performance analysis of low voltage connected microgeneration*", IEEE Power and Energy Society General Meeting - Conversion and Delivery of Electrical Energy in the 21st Century.

[8] Al-Hinai, A.; Sedhisigarchi, K.; Feliachi, A., (2004), "*Stability enhancement of a distribution network comprising a fuel cell and a microturbine*", IEEE Power Engineering Society General Meeting, vol.2, Pages: 2156 – 2161.

[9] M. Noe and B. R. Oswald, (2008), "*Technical and economical benefits of Superconducting fault current limiters in power systems*", IEEE Trans. on applied superconductivity, vol.9, Pages: 1347 – 1350.

[10] Hooshyar, H.; Savaghebi, M., (2008), "*RSFCL optimum shunt resistance determination to enhance power system transient stability*", Universities Power Engineering Conference, Italy.

[11] Tarafdar Hagh, M. Jafari, M. Naderi, S. B., (2010), "*Transient stability improvement using Non-superconducting Fault Current Limiter*", Power Electronic & Drive Systems & Technologies Conference, Iran.

[12] K. Hongesombut, Y. Mitani, (2003), "*Optimal location assignment and design of superconducting fault current limiters applied to loop power systems*", IEEE Trans. on Applied Superconductivity, vol. 13, no. 2.

[13] Byung Chul Sung, Jung-Wook Park, (2009), "*Study on a series resistive SFCL to improve power system transient stability: Modelig, Simulation, and Experimental verification*", IEEE Trans. on Industrial Electronics, vol. 56, no. 7.

[14] Masaki Yagami, Toshiaki Murata, (2002), "*Improvement of power system transient stability by superconducting fault current limiter*", Transmission and Distribution Conference and Exhibition 2002: Asia Pacific. IEEE/PES, pages: 359 – 364, vol.1.

[15] Masaki Tsuda, et al, (2001), "*Application of resistor based superconducting fault current limiter to enhancement of power system transient stability*", IEEE Trans. on Applied superconductivity, vol. 11, no. 1.

[16] H. Saadat, "Power System Analysis", 3rd Edition, 2010.

[17] P.Kundur, "Power System Stability and Control", McGraw Hill, New York, 1994.

[18] Superconducting *Fault Current Limiters*: Technology Watch 2009. EPRI, Palo Alto, CA: 2009. 1017793.

[19] H. Hooshyar, et al, (2008), "*An investigation on optimum volume of superconducting element of RSFCL considering harmonic generation*", 3rd IEEE Conference on Industrial Electronics and Applications, Pages: 712 – 715.

[20] Xiaohui Hu, Russell Eberhart, (2002), "*Solving Constrained Nonlinear Optimization Problem with Particle Swarm Optimization*", Purdue University, West Lafayette, IN, USA.

[21] Xiaohui Cui, Thomas E. Potok, Paul Palathingal, (2005), "*Document Clustering using Particle Swarm Optimization*", IEEE conference.

[22] Yoshida, H., K. Kawata, Y. Fukuyama, Y. Nakanishi, (1999), "*A Particle Swarm Optimization For Reactive Power And Voltage Control Considering Voltage Stability*", IEEE International Conference on Intelligent System Applications to Power Systems (ISAP'99), Rio de Janeiro, April 4-8.

[23] He, S., J. Y. Wen, E. Prempain, Q. H. Wu, J. Fitch, S. Mann , (2004), "*An Improved Particle Swarm Optimization for Optimal Power Flow*", IEEE 2004 International Conference on Power System Technology, Singapore.

[24] Kennedy, J. and Eberhart, R.C., (1995), "*Particle Swarm Optimization*", Proc. IEEE Int. Conf. on N.N., pp. 1942-1948.

[25] Clerc. M., (2006), "*Particle Swarm Optimization*", Antony Rowe Ltd, Publication.

[26] Shi, Y. and Eberhart, R., (2001). "*Particle Swarm Optimization with Fuzzy Adaptive Inertia Weight*", Proc. of the Workshop on Particle Swarm Optimization. Indianapolis, IN: Purdue School of Eng. and Technology, IUPUI.

[27] Pai, M. A., (1989), "*Energy Function Analysis for Power System Stability*", Boston: Kluwer Academic Publishers, pp.223-227.

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