Pertanika J. Sci. & Technol. 25 (S): 129 - 138 (2017)

SCIENCE & TECHNOLOGY

Journal homepage: http://www.pertanika.upm.edu.my/

A Corrective Action Scheme for Contingency Monitoring of Transmission Line Overloading

Mohammad Lutfi Othman*, Mahmood Khalid Hadi and Noor Izzri Abdul Wahab

Centre for Advanced Power and Energy Research (CAPER), Dept. of Electrical and Electronic Engineering, Faculty of Engineering, Universiti Putra Malaysia, 43400 UPM, Serdang, Selangor, Malaysia

ABSTRACT

Special Protection Schemes (SPSs), are corrective action schemes that are designed to protect power systems against severe contingency conditions. In planning of SPSs, protecting transmission network from overloading issue due to critical situations has become a serious challenge which needs to be taken into account. In this paper, a Special Protection and Control Scheme (SPCS) based on Differential Evolution (DE) algorithm for optimal generation rescheduling has been applied to mitigate the transmission line overloading in system contingency conditions. The N-1 contingency has been performed for different single line outages under base and increased load in which generation rescheduling strategy has been undertaken to overcome the overloading problem. Simulation results are presented for both pre-and post system emergency situations. The IEEE 30-bus test system was utilised in order to validate the effectiveness of the proposed method.

Keywords: Special Protection Scheme, transmission line overloading, line contingency, generation rescheduling, Differential Evolution (DE) algorithm

INTRODUCTION

Special Protection Schemes (SPSs), also known as Corrective Action Schemes (CASs), are schemes aimed at creating an incredible system contingency condition in order to initiate pre-determined preventive actions, not only the isolation of faulted elements but also to overcome the consequences of severe system conditions in addition to maintaining good system performance. The corrective actions comprise changing system demand (load shedding), changing utility generation and system configuration in order to maintain system stability and an acceptable bus voltage or branch power flow. The operation of SPSs

ARTICLE INFO

Article history:
Received: 24 August 2016
Accepted: 02 December 2016

E-mail addresses:
lutfi@upm.edu.my (Mohammad Lutfi Othman),
mhm_mhm_80@yahoo.com (Mahmood Khalid Hadi),
izzri@upm.edu.my (Noor Izzri Abdul Wahab))
*Corresponding Author

ISSN: 0128-7680

is presented by the incidence of disturbances such as frequency and/or voltage instability, transient angular instability, and instability resulting from cascade transmission line tripping (Vinnakota et al., 2008).

Nomenclature

P_i, Q	Active and reactive power injected to the system at bus i.
$V_{i,} V_j$	Bus voltage magnitude at buses i and j.
G_{ij}, B_{ij}	Self-conductance and susceptance of the element between bus i and j.
θ_{ij}	Voltage angle between bus i and j.
P_{Gi}, Q_{Gi}	Active and reactive power generated bus i.
P_{Li}, Q_{Li}	Active and reactive power consumed in bus i.
$P_{Gi}^{min}, P_{Gi}^{max}$	Minimum and maximum generation limits of active power at bus i.
$Q_{Gi}^{min}, Q_{Gi}^{max}$	Minimum and maximum generation limits of reactive power at bus i.
V_i^{min}, V_i^{max}	Minimum and maximum voltage limits of bus i.
NB	Number of system buses.

The main goals of applying the special protection schemes are to (Seyedi & Sanaye-Pasand, 2009):

- To operate the power systems within their acceptable limits.
- To increase system security through critical disturbances, and
- To improve the power system operating conditions.

Due to the growing complexity of utility operation, many factors such as growth in demand, increased power imports/exports have stressed the transmission network during its normal operation. In designing SPS, protecting of transmission lines from overloading risk in critical contingencies is a significant challenge which needs to be taken into account. This could happen due to some disturbances such as line and/or transformer outage, load perturbation, and when there is no communication between system generation and transmission grids. To avoid a network collapse in overloading situations, some corrective actions are needed such as load shedding and/or generation rescheduling strategies, phase shift transformers, and transmission line switching (Awais et al., 2015). Load shedding and generation rescheduling schemes are commonly utilised to overcome grid overloading issue and in which no more reserves are needed. Building new transmission lines to meet N−1 contingency condition is costly and time-consuming. Overloading issues could take place due to unexpected line and/or generator outage, a sudden increase in system demand, and failure of any of system component and resulted in cascade line outages and system collapse. One of the most effective and obvious approaches to relieve line overload is the generation rescheduling plan under system disturbances (Pandiarajan & Babulal, 2014). Alleviation of transmission line overloading has been performed using different techniques. Balaraman Kamaraj (2012) had applied a generation rescheduling method based on back propogation neural network to predict line overloading amount and mitigation of this overload according to N-1 contingency conditions. In (Sharma and Srivastava, 2008), an algorithm based on neural network presented for identification of the overloaded lines and prediction of overloading amount in the overloaded lines for different generation / loading conditions. Congestion management via optimal generation rescheduling based on Particle Swarm Optimization (PSO) algorithm was proposed in (Dutta & Singh, 2008). In (Hagh & Galvani, 2010), a modified Genetic Algorithm was used to find the location and the load amount to be shed and generation rescheduling in post contingency conditions such as line overloading as well as voltage violations.

In this paper, generation rescheduling methodology has been performed based on Differential Evolution (DE) algorithm to alleviate transmission line overloading along with the severity index philosophy. The validation of the applied algorithm was examined on IEEE 30-bus system with the aid of the power flow analysis. Line overloads according to sudden line outage was also considered.

METHODOLOGY

Mathematical Formulation

The major aim of the presented algorithm is to determine the optimum power rescheduling based on minimising severity and to overcome the overloading in post contingency. Thus, a minimum severity index has been considered as the objective function in this study. During the proposed solution of the problem, the optimal rescheduling values are subjected to the operating constraints and are divided into two groups:

- Equality constraints:

Equality constraints in a power system represent active and reactive power injected to the system buses as shown below:

$$P_i = V_i \sum_{j=1}^{NB} V_j \left(G_{ij}\cos\theta_{ij} + B_{ij}\sin\theta_{ij}\right) \qquad \text{where} \quad P_i = P_{Gi} - P_{Li} \tag{1}$$

$$Q_i = V_i \sum_{j=1}^{NB} V_j \left(G_{ij} \sin\theta_{ij} - B_{ij} \cos\theta_{ij}\right) \quad = Q_{Gi} - Q_{Li} \tag{2}$$

• Inequality constraints:

Active and reactive power generated, bus voltage magnitude, as well as line flow limits are considered as inequality constraints and can be represented as follows:

$$P_{Gi}^{min} \leq P_{Gi} \leq P_{Gi}^{max} \qquad i = 1,2 \ldots \ldots NG \tag{3}$$

$$V_i^{min} \leq V_i \leq V_i^{max} \qquad i = 1,2 \ldots \ldots NB \tag{4}$$

$$S_{ij} \leq S_{ij}^{max} \qquad i = 1,2 \ldots \ldots NL \tag{5}$$

Severity index (SI)

The severity state of any power system contingency condition which is associated to a line overloading can be presented in terms of the severity index formula that refers to the stress in a power system during a post contingency condition (Alsac & Stott, 1974; Balaraman & Kamaraj, 2012):

$$SI = \sum_{k=1}^{ovl} \left(\frac{S_{ij}}{S_{ij}^{max}}\right)^{2m} \tag{6}$$

where: *SI* = severity index, S_{ij} = line flow in a branch between bus *i* and *j*, Sij^{max} = maximum line flow limit, *ovl* = a set of overloaded lines, and *m* = an integer exponent.

The line flow is obtained from one of the load flow solutions such as Newton-Raphson method which has been applied in this work. Only overloaded lines are considered when computing the severity index for security assessment and the value of *m* is fixed to 1 to avoid the masking effects (Balaraman & Kamaraj, 2012). For a secure operation in power system, the value of *SI* must be zero. The greater the value of *SI*, the more severe contingency will be.

OVERVIEW OF DIFFERENTIAL EVOLUTION

Differential evolution (DE) defined as simple, and population set based direct search algorithm. It is a high performance optimisation algorithm and easy to understand and implement. It was first proposed by Storn and Price (Storn & Price, 1997). The optimisation steps are similar to the Genetic Algorithm. However unlike GA, which relys on crossover operation, DE algorithm initially employs the mutation (differential) operation, crossover and selection process to guide the search of a solution toward the prospective solution within a search region. Like other evolutionary algorithms, DE works with population set of candidate solutions known as individuals that randomly generate and improve iteratively by implementing mutation, crossover and selection operations (Singh & Srivastava, 2014). The DE generates a population set of real valued individual vectors $X_{i,G}$ which called target vector as below:

$$\ldots.\ X_{i,G} = X_{j,i,G} \qquad i = 1, \ldots. NP, \qquad G = 0,1, \ldots G_{max}\ , \qquad j = 1, \ldots \ldots. D \tag{7}$$

Each individual vector has a population index *i*, its range between 1 and *NP*, where *NP* represents the population size. The parameters in the vectors are indexed by *j*, its range between 1 and *D* where *D* represents the number of variables that need to be optimised. The basic stages of DE algorithm are depicted as following:

Initialisation

The optimisation process of DE algorithm begins by generating a population set of *NP D* dimentional real valued vectors at $G = 0$. Each parameter vector is as a candidate for solution to the optimisation process. The initial vector values are selected randomly and limited to lower and upper parameter bounds i.e. [X_L,X_H]. Where X_L = [X_1,*L*, X_2,*L*,......., X_D,*L*] and X_H =[X_1,*H*, X_2,*H*,.........,*XD*,*H*], represent the lower and upper limits for the search region for each individual vector respectively. The initial individual vector can be expressed as:

$$X_{j,i}(0) = X_L + rand\ (X_H\ X_L) \tag{8}$$

where *rand* is a random number which is selected between 0 and 1.

Mutation

In the mutation stage, DE algorithm generates a new candidate solution called a mutant (donor) vector from the initial population by selecting randomly three distinct vectors from the target vector. The mutant vector is created by adding a weighted difference between two of the selected vectors to the third vector from the current generation. These randomly selected vectors are different from the target vector and chosen from the range 1 to NP. A mutant vector $V_{j,i,G}$ is expressed as:

$$V_{j,i,G} = X_{r1,G} + F\left(X_{r2,G} - X_{r3,G}\right) \tag{9}$$

where $r_1 \neq r_2 \neq r_3$ ={1,....... *NP*} randomly generated indices. X_{r1},*G*, X_{r2},*G*, and X_{r3},*G* are randomly chosen vectors from the initial population set. *F* represents a mutation factor and selected within the range [0,1].

Crossover

In this step, the mutant vector $V_{j,i,G}$ and the target vector $X_{j,i,G}$ are swapped in order to form the trial vector $U_{j,i,G}$ using an operation named as crossover in order to increase the diversity of a population. This trial vector can be generated by:

$$U_{j,i,G} = \begin{cases} V_{j,i,G} & if \ \ (rand \leq CR \ or \ j = j_{rand}) \\ X_{j,i,G} & otherwise \end{cases} \tag{10}$$

where CR is the crossover factor which controls the diversity of a population and assists the algorithm to escape from the local optimum. Its range between 0 and 1. $j_{rand} \in [1,2,\ldots..D]$, represents an index which is randomly chosen to ensure that $U_{j,i,G}$ gets at least one element from the mutant vector.

In order to avoid the violation of the vector limits and to ensure the vector values lie within the boundary limits after the recombination, a penalty function is applied. The new vector value which violates the constraints is replaced by a random value as:

$$U_{j,i,G} = X_{j,i,L} + rand\left(X_{j,i,H} - X_{j,i,L}\right) \tag{11}$$

Selection

In order to keep the population size fixed, a selection operation is performed to determine which one of the target vectors or the mutant vectors will survive to be in the next generation i.e. ($G = G+1$). The selection operation can be expressed as:

$$X_{i,G+1} = \begin{cases} U_{i,G} & if \ J(U_{i,G}) < J(X_{i,G}) \\ X_{i,G} & otherwise \end{cases} \tag{12}$$

where $J(X)$ denotes the fitness function to be minimised. Thus, if the fitness value of a trial vector is lower, then it swaps the individual vector along with its corresponding fitness of the target vector through the next generation, else the target value is kept to the population to be survive in the next generation. Therefore, the population set either gets better or remains constant from the fitness function point of view, but never declines. These steps are repeated over each iteration until a maximum number of generations (iterations) *Gmax* is met.

RESULTS AND DISCUSSIONS

System contingency analysis

The validation of the proposed DE based SPCS has been examined on IEEE 30 bus system. The algorithms are performed using Matlab and executed in Intel core i3 CPU 2.2 GHz, 2 GB RAM PC. The test system data regarding line parameters, generation limits and base case load are adopted and taken from (Alsac & Stott, 1974). Full a.c power flow (e.g. Newton –

Raphson) method has been applied to determine the variables related to each bus of the power system which comprise four values: voltage magnitude, its phase angle, and real and reactive power flows. The variables are related to each line: active and reactive power flows as well as line losses. In a power system, transmission line overloading may take place due to different reasons comprising line outage. Therefore, N-1 contingency analysis has been conducted under normal demand conditions in order to identify the harmful disturbances during system operation. For each case, pre-and post contingency line flows are obtained by solving the power flow equations to determine which transmission lines get overloaded due to a specific single line outage. From the contingency analysis, line outage 1-2, 1-3, 3-4, 2-5 resulted in overloading some other lines in the system under base and increased load by 10% at all buses conditions.

The Proposed DE Algorithm

For a secure system operation, the power flows in transmission lines should not override its allowable limits under normal and contingency conditions. Thus, corrective actions should be taken to relieve line overloads. The main objective of this study is to mitigate line overloading by applying generation rescheduling strategy during a system contingency. Optimum generation rescheduling is obtained using DE algorithm.

Generated active power of the system generators are taken as the control variables of the proposed algorithm. Initially, a set of P_G values are randomly created by DE algorithm within the generation limits such that equation (3) is satisfied for the lower and upper limits. Hence, DE algorithm runs these generated values in the fitness function algorithm to get the values of SI in order to evaluate the problem which needs to be solved. Consequently, the algorithm utilises the mutation and crossover operations in order to get a better and minimum fitness value as much as possible due to its strategy. In this study, the magnitudes of *F* and *CR* are taken as 0.8 and 0.5 respectively that give best results after many trials. The fitness function of this work is the load flow algorithm to get the line flow and evaluate the severity index. Minimum severity index is considered as the objective function for the proposed algorithm. The optimal active power generation as a corrective action plan is shown in Table 1 for the simulated cases in addition to system losses for each simulated case.

The algorithms were performed for a maximum number of 50 iterations and was run for 10 independent runs. The generation rescheduling values are taken as average from the independent runs. Figure 1 illustrates the variation of the fitness function convergence of DE algorithm runs for the considered base load contingencies and its values are also taken as the average. It is clear from Figure 1 that the DE algorithm converges rapidly and focuses on finding the convenient solutions to the specific issue. The fitness value goes down to its minimum value close to zero. Simulated line outage cases along with the overloaded lines details are tabulated in Table 2 before and after generation rescheduling. The values of *SI* are also evaluated for each scenario before rescheduling and the final values of S*I* after rescheduling are also given in the last column.

Table 1
Control variables setting of IEEE 30-bus test system

		Active power generation values (MW)						
Case study	Line out of service	PG1	PG2	PG3	PG4	PG5	PG6	Power Losses (MW)
Base load	1-2	124.87	46.12	41.53	30.97	20.19	32.97	12.82
	1-3	128.65	42.75	39.81	31.18	20.41	29.18	8.30
	3-4	129.07	42.62	35.31	30.81	21.02	32.61	7.92
	2-5	149.59	40.37	32.69	24.46	21.13	28.97	13.32
Base load	1-2	124.87	46.12	41.53	30.97	20.19	32.97	12.82
	1-3	128.65	42.75	39.81	31.18	20.41	29.18	8.30
	3-4	129.07	42.62	35.31	30.81	21.02	32.61	7.92
	2-5	149.59	40.37	32.69	24.46	21.13	28.97	13.32
Increased load by 10%	1-2	126.78	65.17	46.70	31.71	21.97	33.50	14.06
at all buses	3-4	133.14	55.34	45.62	32.25	20.77	36.46	11.83

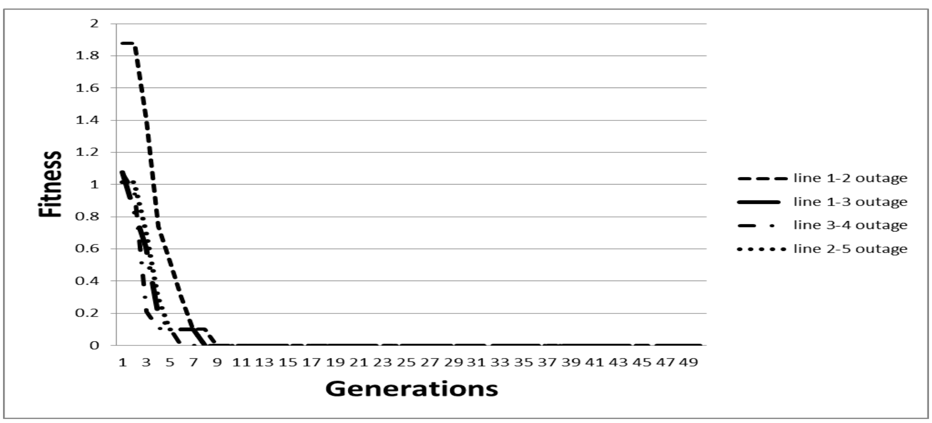

Figure 1. Fitness convergence of the proposed DE algorithm

Table 2
Simulated line outage details before and after generation rescheduling

Case study	Line outage	Overloaded lines	Line limit (MVA)	Before rescheduling		After rescheduling	
				Line flow (MVA)	SI	Line flow (MVA)	SI
Base load	1-2	1-3	130	307.803	16.265	123.144	0
		2-4	65	65.592		24.384	
		3-4	130	279.121		116.283	
		4-6	90	174.058		73.506	
		6-8	32	36.362		13.152	
	1-3	1-2	130	273.019	9.279	128.068	0
		2-4	65	86.154		44.752	
		2-6	65	92.759		47.477	
		6-8	32	33.188		7.040	
	3-4	1-2	130	270.07	9.076	126.559	0
		2-4	65	84.916		42.758	
		2-6	65	91.805		46.112	
		6-8	32	32.928		8.085	
	2-5	1-2	130	164.467	10.885	85.544	0
		2-4	65	74.604		43.368	
		2-6	65	102.858		59.528	
		4-6	90	124.097		71.591	
		5-7	70	110.189		69.689	
		6-8	32	33.317		12.509	
Increased load by 10% at all buses	1-2	1-3	130	369.586	22.580	124.888	0
		2-4	65	77.239		21.141	
		3-4	130	321.795		117.563	
		4-6	90	201.235		76.224	
		6-8	32	44.791		9.732	
	3-4	1-2	130	305.287	11.518	127.499	0
		2-4	65	93.888		47.139	
		2-6	65	101.556		50.865	
		6-8	32	38.874		5.228	

CONCLUSION

In this paper, an SPCS scheme for transmission line overloading alleviation has been presented based on the Differential Evolution (DE) algorithm. The proposed technique effeciently mitigates the line overloads based on the corrective action through the generation rescheduling philosophy. Contingency conditions due to unexpected single line outage under base and increased load are considered in this study. In order to reveal the efficiency of the performed approach, IEEE 30-bus system was used for the simulation cases. The results show that DE algorithm completely mitigates the line overloading issues in addition to fast fitness convergence.

ACKNOWLEDGEMENT

The authors would like to acknowledge the financial support from Universiti Putra Malaysia (UPM) under the Geran Putra IPB scheme with the project no. GP-IPB/2013/941210.

REFERENCES

Alsac, O., & Stott, B. (1974). Optimal load flow with steady-state security. *Power Apparatus and Systems, IEEE Transactions on, PAS-93*(3), 745-751.

Awais, M., Basit, A., Adnan, R., Khan, Z. A., Qasim, U., Shafique, T., & Javaid, N. (2015). Overload Management in Transmission System Using Particle Swarm Optimization. *Procedia Computer Science, 52*, 858-865.

Balaraman, S., & Kamaraj, N. (2012). Cascade BPN based transmission line overload prediction and preventive action by generation rescheduling. *Neurocomputing, 94*, 1-12.

Dutta, S., & Singh, S. (2008). Optimal rescheduling of generators for congestion management based on particle swarm optimization. *IEEE Transactions on Power Systems, 23*(4), 1560-1569.

Hagh, M. T., & Galvani, S. (2010). *A multi objective genetic algorithm for weighted load shedding*. Paper presented at the 18th Iranian Conference on Electrical Engineering (ICEE), 2010.

Pandiarajan, K., & Babulal, C. (2014). Transmission line management using hybrid differential evolution with particle swarm optimization. *Journal of Electrical Systems, 10*(1), 21-35.

Seyedi, H., & Sanaye-Pasand, M. (2009). Design of new load shedding special protection schemes for a double area power system. *American Journal of Applied Sciences, 6*(2), 317.

Sharma, S., & Srivastava, L. (2008). Prediction of transmission line overloading using intelligent technique. *Applied Soft Computing, 8*(1), 626-633.

Singh, H., & Srivastava, L. (2014). Modified differential evolution algorithm for multi-objective VAR management. *and Energy Systems, 55*, 731-740.

Storn, R., & Price, K. (1997). Differential evolution–a simple and efficient heuristic for global optimization over continuous spaces. *Journal of Global Optimization, 11*(4), 341-359.

Vinnakota, V. R., Yao, M. Z., & Atanackovic, D. (2008). *Modelling issues of system protection schemes in energy management systems*. Paper presented at the Electric Power Conference, 2008. EPEC 2008. IEEE Canada.