VOL. 10, NO. 22, DECEMBER 2015 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

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COMPUTATIONAL INTELLIGENCE TECHNIQUE FOR STATIC VAR COMPENSATOR (SVC) INSTALLATION CONSIDERING MULTI-CONTINGENCIES (*N-m*)

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ABSTRACT
This paper discusses about a new approach based on Evolutionary Programming (EP) optimization technique for installation Static VAR Compensator (SVC) considering multi-contingencies *(N-m)* which occurred in the power system. The proposed technique determines the optimum sizing in order to reduce the total transmission loss in the system and this would be the objective function of the transmission system network. In addition, Static Voltage stability Index (*SVSI*) was used as tool to indicate the location that to be installed into the system. A computer program was written in MATLAB. The design program tested on IEEE 30 Bus-RTS. Finally, comparative studies made between EP and Artificial Immune System (AIS).

Keywords: optimal reactive power dispatch, evolutionary programming, static voltage stability index, power loss minimization, voltage stability, multi-contingencies (*N-m*), static var compensator.

INTRODUCTION
The Optimal Reactive Power dispatch (ORPD) is playing a major role in today's power system network. During contingency, the operating generators fail to operate and cause shortages of reactive power supply by the generators. The reactive power shortage can cause the voltage profile becomes unstable and give impact to the transmission reliability. Voltage stability is one of the important aspects to uphold a secure power system operation network [1].

Therefore, an efficient voltage stability analysis technique is required in order to perform the voltage stability study accurately with less computational burden. Studies have shown that voltage stability can be improved by means of real and reactive power rescheduling in a power system [1] [2]. Basically, real and reactive power scheduling would be controlled by reactive power dispatch, compensating capacitor placement, transformer tap changer setting and installation of FACTS devices.

Hence, to overcome the inadequacy of reactive power new optimization technique based FACTS devices has been used due to its capability to change the network parameters with a rapid response [3]. The objective function that used for optimization of SVC is minimizing power loss in the system. The process involves several equations and constraint specifically equality constraint and inequality constraint. The equality constraints are the nodal power balance equations, whereas the inequality constraints are the limits of all control or state variables.

Besides that, there are different types of FACTS devices which have been used to install in power system in order to reduce the total transmission loss in the system. It is Static VAR Compensator (SVC), Thyristor Controlled Series Compensator (TCSC) and Unified Power Flow Controller (UPFC). The TCSC would be used to change line reactance and SVC can be utilized to control the reactive power at the bus. Consequently, UPFC is the most and versatile device, which controls the line reactance [4].

However, the ORPD problem can be solved using Classical method and intelligent method. Present days, intelligent method most likely used to solve ORPD problem, namely Artificial Neural Networks (ANN), Fuzzy Logic, Evolutionary Programming (EP) and Particle Swarm Optimization (PSO). Evolutionary Computations are one of the Artificial Intelligence method. In addition, EP was one of the Evolutionary Computation methods that used in the optimization process.

In an electrical power system network, there are always disturbances related to contingencies. The elements that usually involve in those contingencies are generator, transmission line and transformer. The occurrence of the contingency should prevent otherwise it can interrupt power system. The line outage contingencies may cause violations on bus limit, transmission line overloads and lead to system instability while generator outage contingencies may caused by failure of generator that can lead to system instability.

Hence, this paper presents about Computational Intelligence technique for Facts device installation considering multi-contingencies (*N-m*). The suggested technique determines the optimum sizing of SVC that has been selected to install into the power system in order to minimize transmission power losses. The mathematical programming was written in MATLAB and tested on IEEE 30 Bus-RTS and. Finally, the proposed techniques were tested with Artificial Immune System (AIS) for different loading factor.

MATHEMATICAL MODELLING OF SVC
The SVC is an important component that capable of giving a fast-acting reactive support in the power system network. In addition, the SVC also can be operated

VOL. 10, NO. 22, DECEMBER 2015 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

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as both inductive and capacitive compensation which can control bus voltage by absorbing or injecting reactive power. The mathematical modelling of SVC is shown in Figure-1 [5].

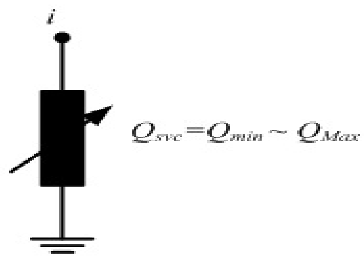

Figure-1. SVC model.

Hence, SVC is modelled as ideal reactive power injections to perform the steady-state condition at bus *i*. The absorbed or injected power at bus *i* in the system is represented by Q_{svc}. The constraint limit of SVC was shown below in Equation. (1).

$$Q_{\min} \le Q_{SVC} \le Q_{\max}$$
$$-200MVAr \le Q_{SVC} \le 200MVAr \qquad (1)$$

FACTS DEVICE INSTALLATION

The FACTS device installed on the weak buses and heavily loaded areas in order to reduce the stress condition in the system. The locations of FACTS devices indicated using the Static Voltage Stability Index (*SVSI*) technique that operates at same operating conditions in the power system network. When the load flow program was run, stability indices are calculated and the system identified the line with the highest *SVSI* for the installation of FACTS device. Finally Evolutionary Programming (EP) optimization technique was used to identify the optimal size of the FACTS devices namely SVC. The mathematical equation of *SVSI* is shown in Equation. (2).

$$SVSI_{ji} = \frac{2\sqrt{\left(X_{ji}^2 + R_{ji}^2\right)\left(P_{ji}^2 + Q_{ji}^2\right)}}{\left| \left|V_i\right|^2 - 2X_{ji}Q_{ji} - 2R_{ji}P_{ji} \right|} \qquad (2)$$

where

R_{ji} = line resistance
X_{ji} = reactance
P_{ij} = real power at the receiving end
Q_{ij} = reactive power at the receiving end

V_{ij} = sending end voltage

FACTS DEVICES INSTALLATIONS COST

The installation cost of FACTS Device namely SVC are formulated below in Equation. (3), [6].

$$IC = C_{FACTS} \times S \times 1000 \qquad (3)$$

The sums of the installation cost of SVC where it can calculate using cost function are stated below in Equation. (4) and Equation. (5).

$$C_{SVC} = 0.0003S^2 - 0.3051S + 127.38 (US\$ / KVAr) \qquad (4)$$

$$S = \left|Q_2 - Q_1\right| \qquad (5)$$

Where

IC = Installation cost in US$
C_{FACTS} = cost of FACTS devices in US$/KVAr
S = operating range of FACTS devices in MVAr
Q_1 = Reactive power flow in the branch before FACTS installation
Q_2 = Reactive power flow in the branch after

PROBLEM FORMULATION

The objective function which was discussed in this paper is minimized of active power loss subjected to set of equality and inequality constraint.

Minimization of active power loss

Generators have maximum and minimum output powers and reactive powers, which add inequality constraints. Furthermore, to maintain the quality of electrical service and system security, bus voltages usually have a maximum and minimum magnitudes. These limits again require the addition of inequality constraints [7]. The mathematical formulas of the objective function are stated below in Equation. (6).

$$\min f_p = \sum_{k \in N_E} P_{k_{Loss}}\left(V, \theta\right)$$
$$= \sum_{\substack{k \in N_E \\ k=(i,j)}} g_k \left(V_i^2 + V_j^2 - 2V_iV_j \cos\theta_{ij}\right) \qquad (6)$$

Subjected to:

$$h_{Qi} = Q_{Gi} - Q_{Di} - V_i \sum_{j \in N_i} V_j \left(G_{ij} \sin\theta_{ij} - B_{ij} \cos\theta_{ij}\right) = 0, i \in N_{PQ}$$
$$V_{i\,min} \le V_i \le V_{i\,max}\ ,\ i \in N_B \qquad (7)$$

Equality constraint of active and reactive power loss are shown in Equation. (8).

$$Q_i - Q_{Gi} + Q_{Di} = 0$$
$$Q_i = Q_{Gi} - Q_{Di} - V_i \sum_{j \in N_i} V_j \left(G_{ij} \sin\theta_{ij} - B_{ij} \cos\theta_{ij}\right) = 0,\ \ i \in N_{PQ} \qquad (8)$$

$$P_i - P_{Gi} + P_{Di} = 0$$
$$P_i = P_{Gi} - P_{Di} - V_i \sum_{j \in N_i} V_j \left(G_{ij} \cos\theta_{ij} - B_{ij} \sin\theta_{ij}\right) = 0,\ \ i \in N_{B-1}$$

Inequality constraints of generator power reactive capability limits, generator power active capability limits, and voltage constraints are shown below in Equation. (9).

VOL. 10, NO. 22, DECEMBER 2015 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

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$$Q_{Gi_{\min}} \le Q_{Gi} \le Q_{Gi_{\max}} \quad i \in N_G$$
$$Q_{ci_{\min}} \le Q_{ci} \le Q_{ci_{\max}} \quad i \in N_c \tag{9}$$
$$P_{Gi_{\min}} \le P_{Gi} \le P_{Gi_{\max}}, \quad i \in Slackbus$$
$$V_{i_{\min}} \le V_i \le V_{i_{\max}} \quad i \in N_B$$

Where,

g_k	=	conductance of branch k
n_s	=	Slack bus number
N_{PQ}	=	PQ bus number
N_{PV}	=	PV bus number
N_B	=	total number of buses
N_{B-1}		total buses excluding slack bus
N_c	=	possible reactive power source installation buses number
N_E	=	branch number
N_i	=	numbers of buses adjacent to bus i including bus i
θ_{ij}	=	voltage angle different between bus i and bus j (rad)
Q_i	=	the reactive power on the sending
Q_j	=	reactive power on the receiving buses
Q_G	=	the generated reactive power
V_i	=	voltage magnitude at the sending buses
V_j	=	voltage magnitude at the receiving buses
G_{ij}	=	Conductance between bus i and bus j
B_{ij}	=	Subceptance between bus i and bus j
P_v	=	total active power loss in the system

The mathematical equation of objective function can be generalized as shown in Equation. (10) and Equation. (11).

$$f_p = \sum_{k \in N_E} P_{k_{Loss}}(V,\theta) + \sum_{k \in NVPQ_{\lim}} \lambda_{Vi}\left(V_i - V_i^{\lim}\right)^2 + \sum_{k \in NQg_{\lim}} \lambda_{Qg\lim}\left(Q_{gi} + Q_{gi}^{\lim}\right)^2 \tag{10}$$

Subject to

$$Q_{Gi} - Q_{Di} - V_i \sum_{k \in N_E} V_j \left(G_{ij} \sin\theta_{ij} - B_{ij}\cos\theta_{ij}\right) = 0, \quad i \in N_{PQ} \tag{11}$$

$$P_{Gi} - P_{Di} - V_i \sum_{k \in N_E} V_j \left(G_{ij}\cos\theta_{ij} - B_{ij}\sin\theta_{ij}\right) = 0, \quad i \in N_{B-1}$$

Where

λ_{Vi}	=	penalty factor which can increase the optimization procedure
$N_{VPQ_{\lim}}$	=	number of *PQ* bus at which the voltage violates the limits
$N_{Qg_{\lim}}$	=	Denotes the number of buses at which the reactive power generation violates the limits.

The limits of voltage and reactive power generation are shown below in Equation. (12).

$$V_i^{\lim} = \begin{cases} V_i^{\min} & \text{if } V_i < V_i^{\min} \\ V_i^{\max} & \text{if } V_i < V_i^{\max} \end{cases} \tag{12}$$
$$Q_{g_i}^{\lim} = \begin{cases} Q_{g_i}^{\min} & \text{if } Q_{gi} < Q_{g_i}^{\min} \\ Q_{gi}^{\max} & \text{if } Q_{gi} < Q_{gi}^{\max} \end{cases}$$

METHODOLOGY

This segment presents necessary information concerning the development and mathematical problem formulation for EP technique.

Application of EP in FACTS installation

EP was used to optimize the FACTS devices namely, SVC in order to improve transmission loss in the system. EP involved few steps. It is initialization, mutation, combination and selection. Transmission loss minimization was chosen as the objective function for the optimization process. The general flow chart for the implementation of the EP optimization technique is shown in Figure-2.

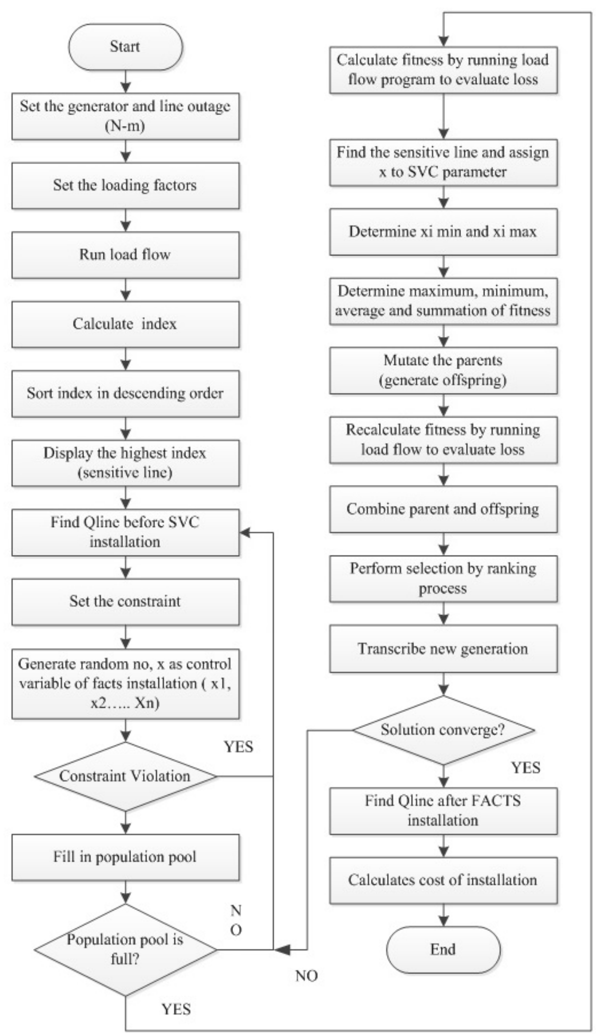

Figure-2. Flowchart for optimization of FACTS using EP.

RESULT AND DISCUSSION

The results are divided in two sub parts. The first part presents the results of FACTS optimization with transmission loss minimization while the second part presents the results of comparative studies between the EP and AIS. The test was conducted on IEEE 30-Bus RTS for different loading factor in order to observe the impact of the transmission loss, voltage profile and installation cost of the loaded bus. The parameters of N-m for IEEE 30-bus RTS system are generator buses 11, 13 and lines 1, 4, 8, 9, 7.

SVC in the IEEE 30-Bus RTS

The test was conducted on the weak bus and secure bus namely bus 26 and bus 14 are respectively. Table-1 and Table-2 tabulate the effect of loading factor variation, λ to transmission losses, voltage profile and installation cost for Bus 26 and bus 14 respectively. In addition, there are five locations of SVCs installation in the network are also recognized by using *SVSI* technique and shown in Table-3. There were two constraints assigned before the CSVC is optimized namely *total loss* $\leq$ *loss_set* and V_m *(bus)* $\leq$ *V_set.*

Table-1. Results for CSVC when bus 26 was reactively loaded: IEEE 30-bus RTS.

λ factor	Analysis CSVC	Transmission loss (MW)	ΔLoss (%)	V_m (p.u)	Cost (US$)
1.0	Pre	82.74	33.3	0.8235	44,091.35
	Post	55.20		0.8459	
1.5	Pre	87.26	29.8	0.7584	53,998.39
	Post	61.22		0.9489	
2.0	Pre	95.94	38.1	0.6671	70,055.27
	Post	59.42		1.1093	
2.3	Pre	111.38	46.8	0.5571	97,227.54
	Post	59.22		1.0789	

Table-2. Results for CSVC when bus 14 was reactively loaded: IEEE 30-bus RTS.

λ	Analysis CSVC	*SVSI* (p.u.)	Transmission loss (MW)	ΔLoss (%)	V_m (p.u)	Cost (US$)
1.0	Pre	0.5977	82.48	33.6	0.8882	44,414.33
	Post	0.586	54.75		1.0957	
2.0	Pre	0.6232	88.77	36.4	0.8355	56,737.81
	Post	0.5792	56.44		1.0546	
3.0	Pre	0.6647	99.91	43.0	0.7673	77,954.69
	Post	0.5637	56.97		0.8174	
3.7	Pre	0.7371	121.19	50.2	0.6849	118,165.25
	Post	0.4413	60.39		1.033	

Table-3. SVC sizing and location when bus 26 and bus 14 were reactively loaded: IEEE 30-bus RTS.

Test Bus	λ	Location (Line No.)	Sizing (MVAr)
26	2.3	1	-42.902
		31	-21.285
		2	-9.789
		5	-44.989
		37	-88.403
14	3.7	1	-163.829
		2	178.775
		5	-170.770
		37	0.115
		12	-46.468

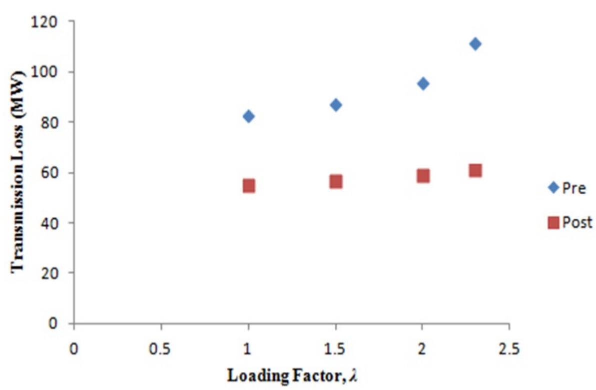

Figure-3. Transmission loss for pre and post at different loading factor, λ when Bus-26 relatively loaded.

VOL. 10, NO. 22, DECEMBER 2015 ISSN 1819-6608
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Table-4. Comparison results for SVC between EP and AIS when bus 26 was loaded: IEEE 30-bus RTS.

λ	Pre-CSVC		Post-SVC							
			EP				AIS			
	Voltage (V)	Loss (MW)	Voltage (V)	Loss (MW)	△Loss (%)	Cost (US$)	Voltage (V)	Loss (MW)	△Loss (%)	Cost (US$)
2.0	0.8235	82.74	0.8459	55.20	33.3	44,091.35	0.8235	63.29	23.5	39,393.91
2.5	0.7584	87.26	0.9489	61.22	29.8	53,998.39	1.0246	71.55	18.0	48,614.89
3.0	0.6671	95.94	1.1093	59.42	38.1	70,055.27	1.3022	69.29	27.8	66,863.44
3.2	0.5571	111.38	1.0789	59.22	46.8	97,227.54	1.2586	67.59	39.3	90,629.36

Table-5. Comparison results for SVC between EP and AIS when bus 14 was loaded: IEEE 30-bus RTS.

λ	Pre-CSVC		Post-SVC							
			EP				AIS			
	Voltage (V)	Loss (MW)	Voltage (V)	Loss (MW)	△Loss (%)	Cost (US$)	Voltage (V)	Loss (MW)	△Loss (%)	Cost (US$)
1.0	0.8882	82.48	1.0957	54.75	33.6	44,414.33	0.9394	70.16	14.9	31,359.95
2.0	0.8355	88.77	1.0546	56.44	36.4	56,737.81	1.1381	64.94	26.8	26,453.66
3.0	0.7673	99.91	0.8174	56.97	43.0	77,954.69	1.103	64.40	35.5	50,206.81
3.7	0.6849	121.19	1.033	60.39	50.2	118,165.25	1.3611	90.26	25.5	117,614.22

Table-1 shows the results for SVC when bus 26 reactively loaded. Based on Table-1, the transmissions loss value decreases respect to loading factor, λ. Furthermore, at λ = 2.3, the transmission loss is reduced from 111.38 MW to 59.2 MW. The percentage in reduction of loss after the installation of SVC is 46.8%. Additionally, the voltage profiles also enhanced from 0.5571 p.u. to 1.0789 p.u. after the implementation of CSVC. The cost of SVC installation is US$ 97,227.54. The above description was clearly shown in Figure-3.

Table-2 shows the results for CSVC when bus 14 was reactively loaded. When loading factor augmented up to 3.7, then the transmission losses as well as increased the voltage profile value reduced at the loaded bus. At λ = 3.7 the transmission losses was decreased from 121.19 MW to 60.39 MW. The reduction of losses in percentage is 50.2 %. Furthermore, after the implementation of CSVS the voltage value has been improved for all loading factors. Hence, installations of the CSVCs in the system can assist to minimize the losses and improve the voltage profile. The cost of SVC installation is US$ 118,165.25. The results for other λ values are indicated in the same table.

Besides that, Table-3 shows SVC sizing and location when bus 26 and bus 14 were reactively loaded. The suggested technique determines the optimum sizing of SVC which should be installed into the system in order to improve transmission losses in the system for bus 26 as well as bus 14.

Comparison of SVC in the IEEE 30-bus RTS

Table-4 shows the comparison results for SVC between EP and AIS when bus 26 was loaded. The analysis shown that, EP gives better results compared to AIS in terms of transmission losses reduction. However, AIS outperformed EP in term of voltage profile and installation cost. For instance, at loading factor, λ = 3.2 , EP has reduced the transmission loss from 111.38 MW to 59.22 MW where loss in reduction is 46.89% as compared to AIS which only managed to reduce to 67.59 MW which implies 39.3% . In contrast, AIS has enhanced the voltage profile from 0.5571 p.u. to 1.2586 p.u. but for the EP, voltage profile has only been increased to 1.0789 p.u.. Furthermore, the installation cost of five SVC devices equal to US$ 90, 629.36 for AIS while for EP is US$ 97, 227.54 which is higher than AIS.

Table-5 shows comparison results for SVC between EP and AIS when bus 14 was loaded. It is noticed that EP gives better result compared to AIS in terms of transmission losses only. For an example, at loading factor, λ = 3.2, the total transmission loss value of EP reduced from 111.38 MW to 59.22 MW while AIS only manages to drop to 67.59 MW only. Hence, AIS outperformed EP in terms of the voltage profile with the improvement from 0.6849 p.u. to 1.3611 p.u. as compared to EP which is only able to increase the voltage up to 1.033 p.u..The installation cost of SVC for AIS technique is US$ 117, 614.22 that is lesser compared to EP where US$ 118, 165.2.

CONCLUSIONS

This paper has presented the application of evolutionary programming optimization technique implemented for FACTS in order to minimize the total transmission losses in a system under *(N-m)* contingencies. From the analysis, the author concluded that optimization technique using EP gives better result compare to AIS.

Furthermore, FACTS devices, namely, SVC have been installed into the system in order to minimize transmission power system loss which act as objective function.

REFERENCES

[1] D. T. Bansilal and K. Parthasarathy. 1996. Optimal Reactive power algorithm for voltage stability improvement. Journal of Electrical Power and Energy Systems. Vol. 18, No. 7, pp. 461-468.

[2] A. S. Quintela and C. A. Castro. 2002. Improved branched- based voltage stability proximity indices. In: IEEE Large Power Engineering Systems Conference On Power Engineering. pp. 115 – 119.

[3] I. Musirin. 2003. New technique for voltage stability assessment and improvement in power system. Ph.D thesis. University Teknologi Mara. pp. 23-25.

[4] D. J. Gotham and G. T. Heydt. 1998. Power flow control and power flow studies for systems with FACTS devices. In: IEEE Transaction on Power Systems. No. 13. pp. 60 – 65.

[5] M. Saravanan and S. M. R. Slochanal. 2005. Location of FACTS devices considering system loadability and cost of installation. In: Power Engineering Conference (21). pp. 716 -721.

[6] L. L. Lai and J. T. Ma. 1997. Application of evolutionary programming to reactive power planning Comparison with Nonlinear Programming Approach. In: IEEE Conference (12). pp. 198.