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Optimal Placement of SVC Incorporating Installation Cost

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Abstract

As the FACTS controllers are an inequitable part of power system due to their fast and very flexible control. With the enhancement of FACTS technology, their role in the marginal cost determination should be considered taking their cost function into account. The aim of this paper is to compare the optimal performance of static VAR compensator (SVC) in voltage stability enhancement problem. During last decade, FACTS devices are broadly used for maximizing the margin of voltage stability and loadability of existing power system transmission networks. To get the optimal system, cost analysis might be necessary. In the cost analysis of SVC, authors analyzed the installation cost of SVC devices in USD, the cost of SVC in USD/KVAR and the average value of installation cost for given systems. Here, the voltage stability enhancement problem is solved applying Gravitational Search algorithm incorporating SVC. The following conditions are investigated with the incorporation of SVC: the role of SVC for improving the voltage profile, loss minimization and the approximate analysis on cost recovery and payback period with SVC in voltage stability enhancement problem. With this motivation, the location of SVC is finalized through weak bus identification methods. Voltage stability indices namely Fast Voltage Stability Index (FVSI) is utilized to identify weak buses in the systems. For calculation of the Size of SVC, an optimization routine Gravitational Search Algorithm (GSA) is established. The main purpose of optimization is to minimize the FVSI. The proposed approach has been tested on three standard IEEE bus systems with different loading scenarios.

General Terms*: Flexible AC Transmission System (FACTS), Marginal Cost, Voltage Stability Assessment, Static VAR Compensators.*

Keywords*: Fast Voltage Stability Index (FVSI), Gravitational Search Algorithm (GSA) and IEEE test bus systems*

1. Introduction

The electricity companies over the globe are transforming their electricity busyness into the competitive environment for technical innovations, lower rates, better choice, and better operation of the power system. In this scenario, transmission price of real and reactive power has become important issue for economic operation of power system. With the growing interest in determining the costs of ancillary services needed to maintain the quality of supply, the spot price for reactive power has also gained great importance. Many researchers have proposed models for determining spot pricing of real and reactive power. In present time, electric power networks are mightily facing the problem of voltage collapse and the voltage stability is becoming a limiting factor in the modern power systems due to the various changes in network variables. This has necessitated to

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employment the techniques for analyzed and determined the critical or weak point of system voltage stability. Voltage stability is defined as the ability of the power system to maintain acceptable & constant level of voltage at all buses in the system under normal conditions and after being subjected to the disturbance [1]. Therefore, voltage stability analysis is necessary to identify the critical buses in a power system *i.e.*, buses which are closed to their voltage instability and to help the planning engineers and operators to take appropriate actions to avoid and overcome the problem of voltage collapse [1, 2]. Claudia Reis et. al. [3] presented a comparative analysis of the performance of static voltage collapse indices. The voltage stability margin analyzed by using P-V and Q-V curves and L-index by Kessel et. al. [4], V/Vo index, was proposed by N. D. Hatziargyriou [5], Line stability index Lmn and VCPI was proposed by M.Moghavemmi *et al.* [6], Line stability index FVSI was proposed by I. Musirin et. al. [7, 8], Line stability index LQP was proposed by A. Mohamed et. al. [9], Krishna Nandlal et. al. [10] developed a voltage stability assessment MATLAB toolbox for marginal and analytical assessment of voltage stability. Z.J.Lim et. al. [11] and M.V.Suganyadevi et. al. [12] discussed various voltage stability indices namely Lnm, FVSI, LQP, LP and NLSI. The values of FVSI indicated the voltage stability condition in the power system and it used to rank the line contingency. Ibrahim B.M. Taha [13] and Md. M.Biswas [14] discussed the best locations of shunt SVCs for voltage stability enhancement. Mark Ndubuka [15] used the SVC for improvement of voltage stability and PSCAD/ EMTDC used to carry out simulations of the system. Bekri O.L. [16] used Continuation Power Flow for the study of voltage stability assessment with appropriate representation of SVC and TCSC. Chaparro E.R. [17] discussed the coordinated tuning of a set of Stativ Var Compensators using Evolutionary Algorithms. J. Vara Prasad [18] discussed the enhancement of Critical loading margin (CLM) using SVCs and CLM derived from Repeated Power Flow (RPF). Chang C.S. [19] discussed a scheme of hybrid optimization using parallel simulated annealing and a lagrange multiplier for optimal SVC planning. B.T. Ooi [20] used SVC in long distance radial transmission system for damping improvement. Hemat Barot and Lake singh [21] discussed the global scenario of SVCs in Ontario, Canada. Prechanon Kumkratug [22] gives the mathematical model of power system with SVC in long transmission lines. Many researches have been carried out for optimal costing of reactive power. El-Keib *et al.* [23] proposed decoupled OPF approach for reactive power cost minimizing. Chatopadhyaya *et al.* [24] discussed the cost of reactive power investment equipments to be included in an objective function. Dandachi *et al.* [25] calculated reactive power cost using linear and quadratic cost function of reactive cost of generator. Hao *et al.* [26] discussed methods for reactive power cost calculations and emphasized the use of reactive power topologies. Lamont *et al*., [27] proposed opportunity cost concept based on generator's capability curve. Gill *et al* [28] proposed a cost of generation of reactive power as a function of active power losses of generator. Muchai *et al*.[29] gives the summary of algorithms for the determination of reactive power price.

This paper focused on the optimal placement of SVC devices, for enhance the voltage profile and minimizing the real power losses. SVC is a shunt FACTS device which is designed to maintain the voltage profile in a power system under normal as well as contingency conditions. In practical power systems, all buses have different sensitivity to the power system security and stability. If SVC devices are located at more sensitive buses, it will positively improve the voltage profile stability.

In the view of literature survey, following research objectives are formed for this paper.

(a) To present the mathematical frame work of FVSI, to identify the weak buses in networks and calculate the same for three standard IEEE networks (14, 30 and 118 bus).
(b) To formulate an optimization routine with the aim of minimization of FVSI and solve this routine by GSA. Further, the optimization routine will suggest the size of SVC on identified weak locations.

(c) Further analyzed the installation cost of SVC devices in USD, the cost of SVC in USD/KVAR and the average value of installation cost for given systems.
(d) Finally discussed about the profile of minimization in losses and voltage after using SVCs, for IEEE 14, 30 and 118 test bus systems with different loading scenarios.

Rest part of the paper is organized as follows in section 2 mathematical frame work of FVSI is presented. In section 3, brief details of GSA are incorporated. In section 4 simulation results are presented, last but not the least in section 5 conclusion and future scope of the work is presented.

2. FVSI Formulation

The FVSI is derived from the voltage quadratic equation at the receiving bus on a two-bus system. Since "s" as the sending bus and "r" as the receiving end bus, since δ is normally very small & negligible, then, *$\delta \approx 0$, $R\sin\delta \approx 0$ and $X\cos\delta \approx X$.* Taking the symbols "*s"* as the sending bus and "*r"* as the receiving bus, FVSI can be calculated [3, 7].

$$FVSI_{sr} = \frac{4Z^2 Q_r}{V_s^2 X} \tag{1}$$

The result for bus ranking is based on maximum loadability using FVSI. The bus ranking can be performed by sorting the maximum loadability in ascending order. The smallest maximum loadability will be ranked the highest implying the weakest bus in the system.

3. Optimization Problem

In this paper, a stability indicator namely FVSI is employed for weak bus identification. At high reactive loading the value of FVSI becomes high. The system is on the verge of collapse. The application of SVCs on weak buses is a corrective action in this condition. The choice of size of SVC is calculated by GSA for IEEE 14, 30, and 118 bus systems.

Minimization of FVSI:

$$J = \min\left[FVSI\right] = \min\left[\frac{4Z^2 Q_r}{V_s^2 X}\right] \tag{2}$$

Equality Constraints:

$$P_{gi} - P_{di} = V_i \sum_{j \in N_i} V_j \left(G_{ij}\cos\theta_{ij} + B_{ij}\sin\theta_{ij}\right) \; i \in N_0 \tag{3}$$

$$Q_{gi} - Q_{di} = V_i \sum_{j \in N_i} V_j \left(G_{ij}\sin\theta_{ij} - B_{ij}\cos\theta_{ij}\right) \; i \in N_{PQ} \tag{4}$$

Inequality Constraints:

Generator Constraints:

$$V_i^{\min} \le V_i \le V_i^{\max} \quad i \in N_B \tag{5}$$

$$Q_{Gi}^{\min} \le Q_{Gi} \le Q_{Gi}^{\max} \quad i \in N_G \tag{6}$$

Transformer Constraints:

$$T_k^{\min} \le T_k \le T_k^{\max} \quad k \in N_T \tag{7}$$

Shunt VAR Compensator Constraints:

$$Q_{Ci}^{\min} \le Q_{Ci} \le Q_{Ci}^{\max} \quad i \in N_C \tag{8}$$

Security Constraints:

$$S_I \le S_I^{\max} \quad i \in N_I \tag{9}$$

3.1. Gravitational Search Algorithm

Rashedi *et al.* developed a new meta-heuristic algorithm called GSA in year 2009 [30]. An analogy between Newton's gravitational laws with the optimization is presented in the algorithm. The algorithm says that every particle attracts towards each other and force exerted between two objects (agents) is proportional to the mass of the objects and inversely proportional to square of the distance between them. Force causes a global movement of all objects towards the objects with heavier mass. The agent which has higher fitness values, has heavier mass. GSA proposes four prepositions of a gravitational mass: its position, gravitational mass (active and passive) and inertial mass. Solution is gives by the position of mass and fitness of a function represented by the masses.

For Minimization:

$$worst(t) = \max_{j=(1...m)} fit_j(t) \tag{10}$$

$$best(t) = \min_{j=(1...m)} fit_j(t) \tag{11}$$

For Maximization:

$$best(t) = \max_{j=(1...m)} fit_j(t) \tag{12}$$

$$worst(t) = \min_{j=(1...m)} fit_j(t) \tag{13}$$

4. Results and Discussion

A computer software programme has been developed in the MATLAB 2013^R environment to perform the simulations and run on a Pentium IV CPU, 2.69 GHz, and 1.84 GB RAM computer. To demonstrate the effectiveness of the proposed technique, an IEEE 14 bus test system, IEEE 30 bus test system and a typical IEEE 118 bus test system have been used. The IEEE 14 Bus system represents a portion of the American Electric Power System which is located in the Midwestern US as of February, 1962. Basically this 14 bus system has 14 buses, 5 generators and 9 load buses. The IEEE 30 Bus system represents a portion of the American Electric Power System (in the Midwestern US) as of December, 1961. Basically this 30 bus system has 30 buses, 6 generators and 24 load buses. The IEEE 118 has the 118 buses, 51 generators and 67 load buses [31, 32].

4.1. Static VAR Compensators (SVCs)

Static VAR compensators (SVCs) are simply shunt connected static device which are generate inductive or capacitive reactive power and measured in the form of volt ampere reactive (VAr). The term static is used to indicate that, SVCs have no rotating components, unlike synchronous compensators. It is based on power electronic devices. The SVC consists of a Static VAr Generator (SVG), which can derive lagging (inductive) and/or leading (capacitive) reactive currents. The basic structure of a SVC is shown in Figure 1.

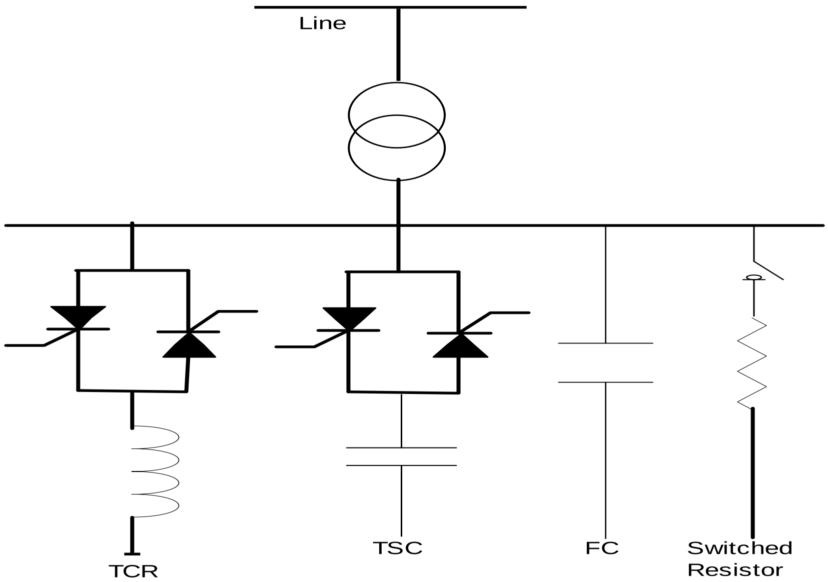

Figure 1. Basic Structure of A SVC

Static VAR compensators (SVCs) have been extensively used in electric power systems for reactive power compensation. The main objectives of installing SVCs is such as increasing the operation efficiency and further ensuring certain security level and improving the quality of service. SVC planning can be formulated with the help of optimization problem.

Each proposed SVC reinforcement scheme should be formulated into a multi objective optimization problem and assessed by how much it has contributed to [19][33-36]. Figure 2 shows the benefits of FACTS devices for different applications and found that in case of voltage stability and control, SVC devices are versatile to give better results with smooth and flexible control.

Some benefits are listed of utilizing SVC devices:

(a) Environmental Benefits with flexible controls.
(b) Gives the better utilization of assets of existing transmission system.
(c) Using SVCs the reliability and availability of transmission system is increased.
(d) Reduced loop flows and increased the dynamic and transient grid stability.
(e) Increased quality of supply for sensitive industries.

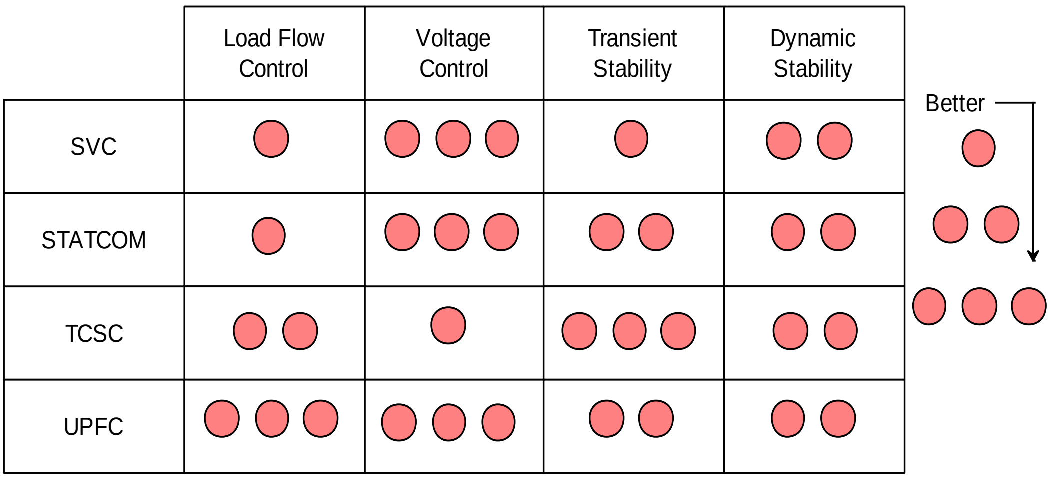

Figure 2. Benefits of FACTS devices for Different Applications

4.1.1. Cost Model of SVCs

The cost of installation of SVC is given by [37]:

$$IC = C_{SVC} * S * 1000 \quad (14)$$

Where Installation Cost of SVC devices is in USD and C_{SVC} is the cost of SVC in USD/KVAR.

The cost function of SVC has been taken from [38] as follows:

$$C_{SVC} = 0.0003S^2 - 0.3051S + 127.38 USD/KVAR \quad (15)$$

Where $S = Q_2 - Q_1$ = Operating Range of SVC in MVAR (16)

The average value of installation cost for the five years is given by following equation:

$$C_1(f) = \frac{C_{Total}}{8760*5} USD/Hr \quad (17)$$

Where C_{Total} is the total installation cost of SVC devices in USD.

4.1.1.1. Case study on IEEE-14 Bus System

Table 1. The Best Optimal Size of SVCs for IEEE 14 Test Bus System by GSA

S.No.	Bus No.	Optimal Size of SVC	Cost of SVC in USD/Kvar	Installation Cost of SVC in USD
1	14	0.11 p.u.	124.06	1364660
2	12	0.12 p.u.	123.762	1485144
3	11	0.11 p.u.	124.06	1364660
4	10	0.10 p.u.	124.359	1243590
Total Cost			**496.241USD/Kvar**	**5458054 USD**
Average value of Installation cost (for 5 yrs)			**124.6131 USD/Hr**	

Table 2. Effect of SVC Installation for Loss Minimization for IEEE 14 Test Bus Systems

Loading Factor λ	Pre-SVC		Post-SVC by GSA	
	MW	**Mvar**	**MW**	**Mvar**
1.1	16.969	21.446	16.671	18.632
1.33333	27.171	64.164	26.206	57.843
1.56667	39.844	115.278	39.047	110.81
1.8	55.885	179.495	54.937	174.82
2.03333	74.84	254.765	73.491	248.36
2.26667	98.003	346.503	96.133	337.84
2.5	126.279	458.292	123.71	446.58
2.73333	161.045	595.577	157.486	579.55
2.96667	204.574	767.413	199.504	744.8
3.2	261.211	991.176	253.506	957.14

Table 1 shows the size of SVCs and according to size, the cost of SVC devices is calculated using [32-33] in USD for IEEE 14 test bus system. Table 2 shows the effect of SVC installation for loss minimization for IEEE 14 test bus system. Table 3 shows the difference in losses, without and with SVC *i.e*. saving in energy and capital cost mightily decided by using the data of differential loss.

Table 3. Effect of SVC Installation on Capital Saving for IEEE 14 Test Bus Systems

Losses at Pre-SVC	**261.211 MW**
Losses at Post-SVC by GSA	253.506 MW
Difference in Losses by GSA	7.705 MW

[1 USD=66.66 INR]

Total Capital Saving for GSA (For 1 Year) = Unit cost (INR) * Total Energy Saving in 1 year (In KWHr) = 6.30*7.705 *8760*1000 = 425223540 INR = 6378990.999 USD

Total Cost of SVCs for GSA = 5458054 USD

Total Capital Saving for GSA (For 1 Year) = 6378990.999 USD

Cost Recovery and Payback Period: Cost of SVCs are recovered by energy savings, within a year

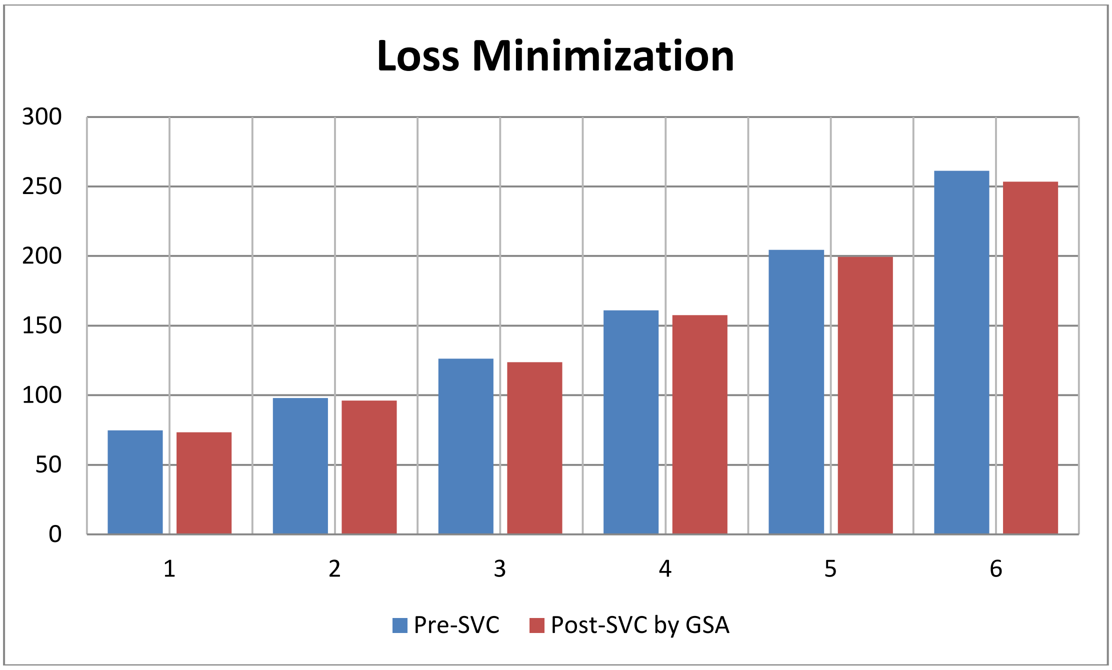

Figure 3. Loss Minimization Using SVC for IEEE 14 Bus Test System

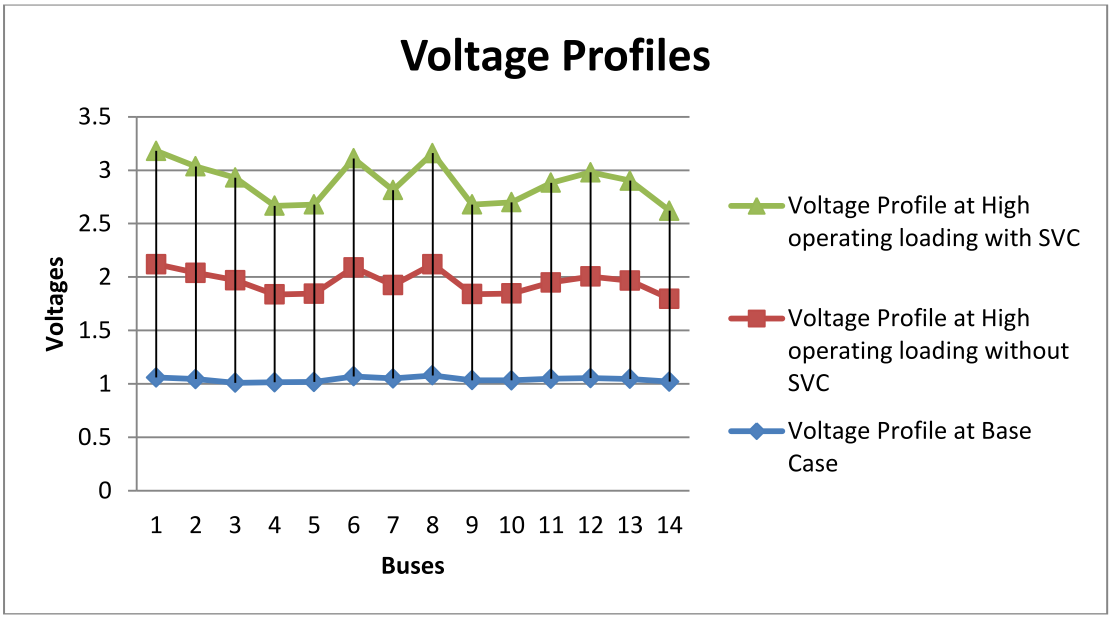

Figure 4. Voltage Profiles for 14 Test Bus Systems by GSA

Figure 3 shows the profile of loss minimization for IEEE 14 test bus system, with and without installation of SVC devices and concluded that post SVC losses are lesser than pre SVC losses. Figure 4 shows improving voltage profile after using SVCs for IEEE 14 test bus system. At high operating loadings, the post SVC profile of voltage is better than pre SVC profile of voltage. Further calculate the cost of SVCs, total cost of SVCs and average installation cost for 5 years. For IEEE 14 buses system the cost recovery and payback period is one year for given conditions.

4.1.1.2. Case study on IEEE-30 Bus System

Table 4. The Best Optimal Size of SVCS for IEEE 30 Test Bus System By GSA

S.No.	Bus No.	Optimal Size of SVC	Cost of SVC in USD/Kvar	Installation Cost of SVC in
1	26	0.11 p.u.	124.06	1364660
2	30	0.10 p.u.	124.359	1243590
3	29	0.10 p.u.	124.359	1243590
4	20	0.13 p.u.	123.464	1605032
5	18	0.12 p.u.	123.762	1485144
	Total Cost		**620.0044** USD/Kvar	**6942016 USD**
Average value of Installation cost (for 5 yrs)			**158.4935 USD/Hr**	

Table 4 shows the size of SVCs and according to size, the cost of SVC devices is calculated using [32-33] in USD for IEEE 30 test bus system. Table 5 shows the effect of SVC installation for loss minimization for IEEE 30 test bus system. Table 6 shows the difference in losses, without and with SVC *i.e*. saving in energy and capital cost mightily decided by using the data of differential loss.

Table 5. Effect of SVC Installation for Loss Minimization for IEEE 30 Test Bus Systems

Loading Factor λ	Pre-SVC		Post-SVC by GSA	
	MW	Mvar	MW	Mvar
1.1	22.018	40.078	22.523	39.93
1.27778	31.904	80.846	31.691	76.342
1.45556	43.691	128.593	42.867	120.36
1.63333	58.344	187.007	56.493	174.58
1.81111	74.914	251.883	73.136	239.68
1.98889	94.547	328.524	92.002	312.12
2.16667	117.939	419.87	114.192	397.34
2.34444	146.012	529.642	140.2	497.16
2.52222	180.357	664.355	171.104	615.78
2.7	224.992	840.687	208.288	758.6

Table 6. Effect of SVC Installation on Capital Saving for IEEE 30 Test Bus Systems

Losses at Pre-SVC	**224.992 MW**
Losses at Post-SVC by GSA	208.288 MW
Difference in Losses by GSA	16.704 MW

[1 USD=66.66 INR]

Total Capital Saving for GSA (For 1 Year) = Unit cost (INR) * Total Energy Saving in 1 year (In KWHr) = 6.30*16.704 *8760*1000 = 921860352 INR = 13829288.21 USD

Total Cost of SVCs for GSA = 6942016 USD

Total Capital Saving for GSA (For 1 Year) = 13829288.21 USD

Cost Recovery and Payback Period: Cost of SVCs are recovered by energy savings, within a year

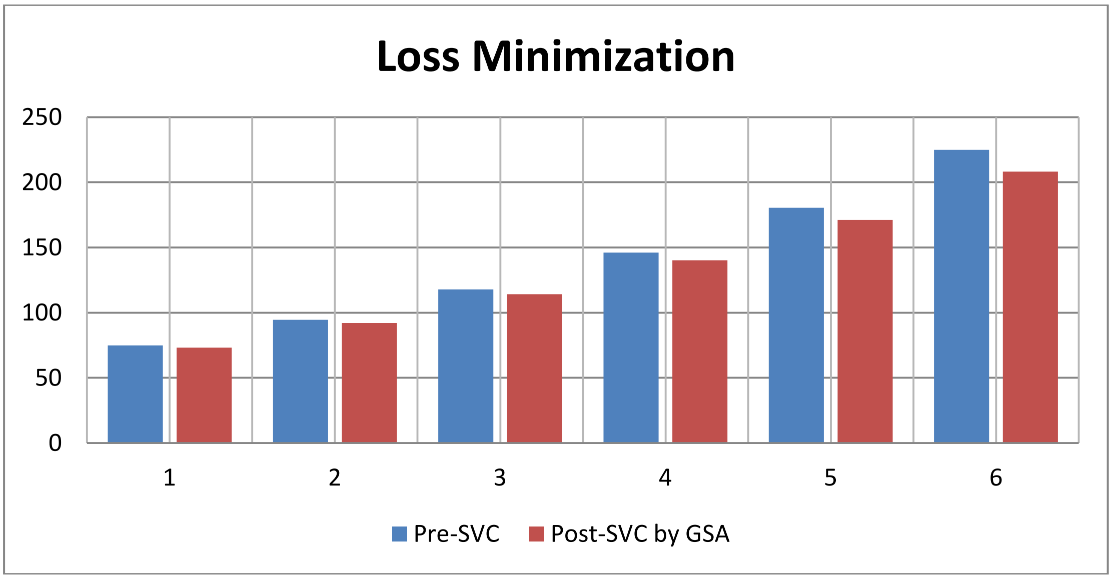

Figure 5. Loss Minimization using SVC for IEEE 30 Bus Test System

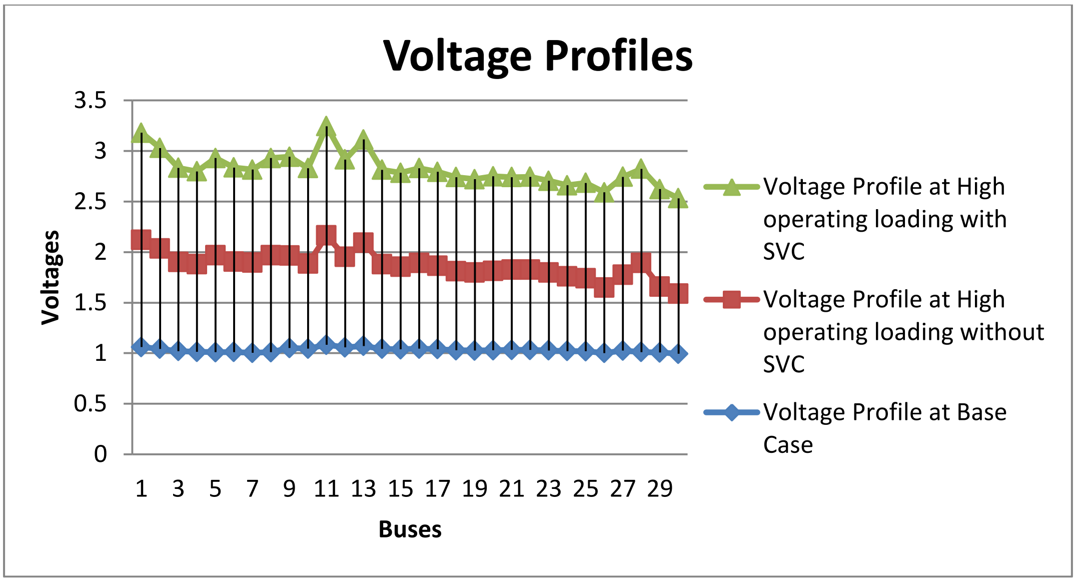

Figure 6. Voltage Profiles for 30 Test Bus Systems by GSA

Figure 5 shows the profile of loss minimization, with and without installation of SVC devices for IEEE 30 test bus system and concluded that the account of loss minimization is higher for post SVC contingency. Figure 6 shows that at high operating loadings, the post SVC profile of voltage is better than pre SVC profile of voltage. Further calculate the cost of SVCs, total cost of SVCs and average installation cost for 5 years. For IEEE 30 buses system the cost recovery and payback period is one year for given conditions.

4.1.1.3. Case Study on IEEE-118 Bus System

Table 7. The Best Optimal Size of SVCs for IEEE 118 Test Bus Systems by GSA

S.No.	Bus No.	Optimal Size of SVC	Cost of SVC in USD/Kvar	Installation Cost of SVC
1	117	0.80 p.u.	104.892	8391360 USD
2	43	0.83 p.u.	104.1234	8642242.20
3	22	0.79 p.u.	105.1494	8306802.60
4	20	0.77 p.u.	105.666	8136282 USD
5	86	0.77 p.u.	105.666	8136282 USD
6	53	0.73 p.u.	106.7064	7789567.20
7	44	0.69 p.u.	110.4234	7619214.60
8	21	0.68 p.u.	108.0204	7345387.20
9	101	0.72 p.u.	151.968	10941696
10	33	0.76 p.u.	105.9252	8050315.20
	Total Cost		**1108.5402 USD/Kvar**	**83359149 USD**
Average value of Installation t cost (for 5			**1903.1769 USD/Hr**	

Table 8. Effect of SVC Installation for Loss Minimization for IEEE 118 Test Bus Systems

Loading Factor Λ	Pre-Svc		Post-Svc By Gsa	
	MW	Mvar	MW	Mvar
1.1	136.438	-533.74	143.296	-521.2
1.2675	197.695	-179.97	202.563	-175.4
1.435	322.083	560.285	321.946	533.59
1.6025	535.276	1858.29	529.297	1791.3
1.77	875.468	3937.26	863.38	3837.3

Table 7 shows the size of SVCs with the cost of SVC devices is calculated using [32-33] in USD for IEEE 118 test bus system. Table 8 shows the effect of SVC installation for loss minimization for IEEE 118 test bus system. Table 9 shows the difference in losses, without and with SVC *i.e.* saving in energy and capital cost mightily decided by using the data of differential loss.

Table 9. Effect of SVC Installation on Capital Saving for IEEE 118 Test Bus Systems

Losses at Pre-SVC	**875.468 MW**
Losses at Post-SVC by GSA	863.38 MW
Difference in Losses by GSA	12.088 MW

[1 USD=66.66 INR]

Total Capital Saving for GSA (For 1 Year) = Unit cost (INR) * Total Energy Saving in 1 year (In KWHr) = 6.30*12.088 *8760*1000 = 667112544 INR = 10007688.93 USD

Total Cost of SVCs for GSA = 83359149 USD

Total Capital Saving for GSA (For 1 Year) = 10007688.93 USD

Cost Recovery and Payback Period: Cost of SVCs are recovered by energy savings, within 8.3 years

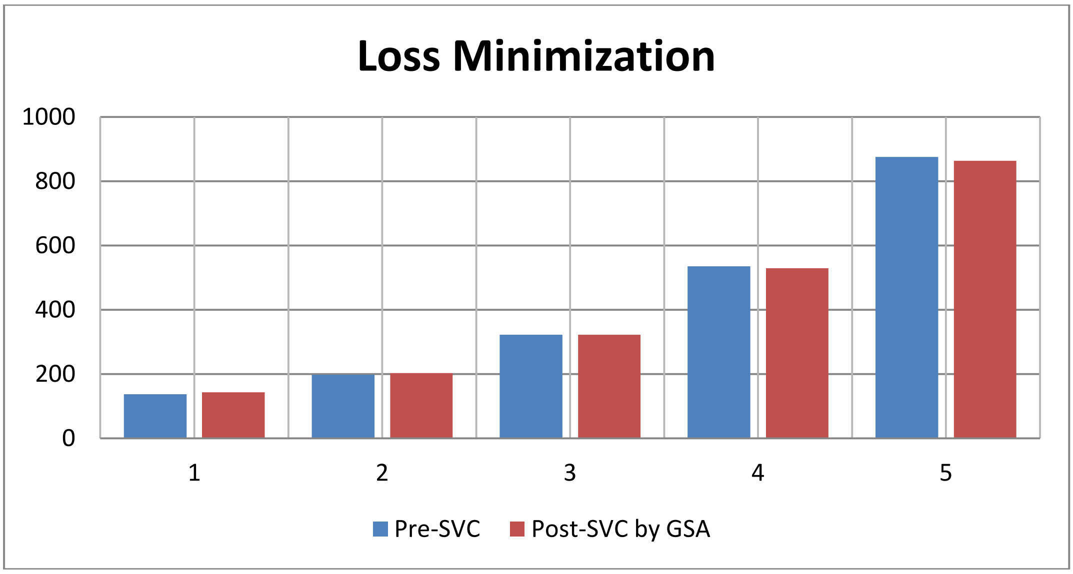

Figure 7. Loss Minimization using SVC for IEEE 118 Bus Test System

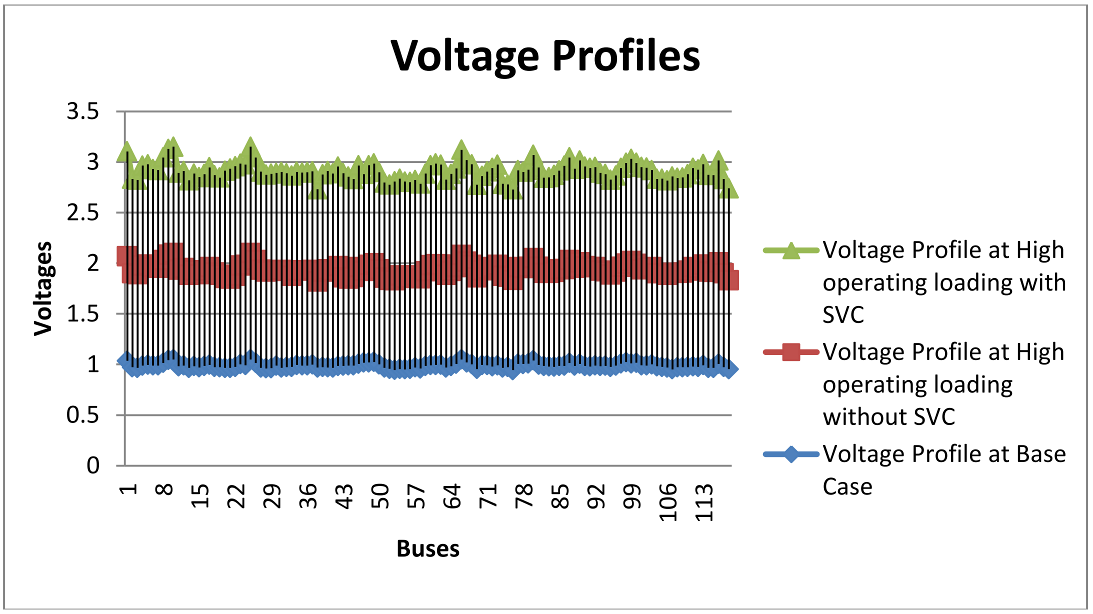

Figure 8. Voltage Profiles for 118 Test Bus Systems by GSA

Figure 7 and 8 shows the profile of minimization in losses and voltage after using SVCs. For IEEE 118 buses system the cost recovery and payback period is 8.3 years for given conditions.

5. Conclusions

In this work, cost of SVC has been obtained taking SVCs cost model for reactive support into system account. SVC devices with its cost model have been incorporated in this paper to find the impact of SVC on loss minimization and voltage profile of the system. The following conclusions can be expressed as:

(a) Although the investment cost of SVC devices are costly but maintenance costs are low since the SVC devices have no moving parts and repairs are minimal.
(b) The voltage profile of the system is improved using the SVCs on weaker buses *i.e.* the overall voltage stability of the system is also improved by using FACTS.
(c) Optimal Placement of SVCs is also minimized the total line losses.
(d) Cost of SVCs recovered by energy savings, within one year in the case of IEEE-14 and 30 buses, but in case of IEEE-118 buses system limit extend up to 8.3 years *i.e.* cost recovery and payback period depends on size of transmission networks.
(e) With SVC, the reactive power cost reduces at all buses due to its better reactive support nature.

It is observed that reactive power cost component is an important element to be considered for determination of installation cost and overall cost transmission. The FACTS devices can be remunerated based on the cost model and component obtained for their reactive support in the transmission system.

For future work, these things can be considered while calculating the benefit.

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Nomenclature

R Resistance of the line
X Reactance of the line
Z Impedance of the line
V_1, V_2 Voltage at sending bus and receiving bus respectively
Q_2 Reactive Power at receiving bus
δ Voltage Angle
"s" , "r" Symbol for sending and receiving side respectively
V_G Generator Voltage Vector except Slack Bus
T_k Transformer Tap Vector
Q_c Shunt Capacitor/Inductor Vector
Q_G Generator Reactive Power Vector
P_{Gi} Injective Active Power at Bus i
P_{Di} Demanded Active Power at Bus I
V_i Voltage at Bus i
Q_{Gi} Injective Reactive Power at Bus I
Q_{Di} Demanded Reactive Power at Bus i
N-R Newton Raphson
FVSI Fast Voltage Stability Index

References

[1] P. Kundur, "*Power System Stability and Control", Mc.Graw-Hill, ISBN-13:9780070635159, NewYork, USA, (***1994***).*
[2] P. Nagendra, "An innovative technique to evaluate network equivalent for voltage stability assessment in a widespread sub-grid system", *Electrical Power and Energy Systems, ELSEVIER, vol. 33,* ***(2011)****, pp. 737–744.*
[3] R. Claudia, "A Comparison of Voltage Stability Indices", IEEE MELECON 2006, Benalmadena (Malaga), Spain, **(2006)**.
[4] P. Kessel and H. Glavitsch, "Estimating the voltage stability of a power system", IEEE Transactions on Power Delivery, vol.PWRD-1, no.3, **(1986)**, pp. 346- 353.
[5] D. Hatziargyriou and T. Van Cutsem, "Indices for predicting voltage collapse including dynamic phenomena", technical report TF-38-02-11, CIGRE, **(1994)**.
[6] M. Moghavvemi, "New method for indicating voltage stability in power system" Proceedings of IEEE International Conference on Power Engineering, Singapore, IPEC, **(1997)**, pp. 223-227.
[7] M. Ismail, "On-Line Voltage Stability Based Contingency Ranking Using Fast Voltage Stability Index (FVSI)", International conference on "IEEE/PES Transmission and Distribution Conference and Exhibition, Asia Pacific. vol. 2, **(2002)**, pp.1118 – 1123.
[8]M. Ismail, "Novel Fast Voltage Stability Index (FVSI) for Voltage Stability Analysis in Power Transmission System", IEEE Student Conference on Research and Developing Proceeding, **(2002)**, pp. 265 - 268.
[9] A. Mohamed, G. B. Jasmon and S. Yusoff, "A static voltage collapse indicator using line stability factors", Journal of Industrial Technology, vol. 7, no. 1, **(1989)**, pp. 73-85.
[10] N. Krishna, "Assessment of Voltage Stability of a Small Island Network using a Developed MATLAB Toolbox", IEEE Transmission & Distribution Conference and Exposition-Latin America IEEE, **(2014)**.
[11] Z. J. Lim, "Evaluation of the Effectiveness of Voltage Stability Indices on Different Loadings", IEEE International power engineering and optimization conference, Melaka, Malaysia, (**2012**).
[12] M.V. Suganyadevi, "Estimating of Loadability Margin of a Power System by comparing Voltage Stability Indices", International conference on "control, automation, communication and energy conservation, **(2009)**.
[13] Ibrahim B.M.Taha, "Best locations of shunt SVCs for steady state voltage stability enhancement", IEEE 978-1-4799-8598-2, **(2015)**.
[14] Md. M. Biswas, "Voltage level improving by using static VAR compensator (SVC)", Global Journal of researches in engineering, vol. 11, Issue 5, Version 1.0, **(2011)**, ISSN: 0975-5861.

[15] M. Ndubuka, “Voltage Stability Improvement using Static Var Compensator in Power Systems”, Leonardo Journal of Sciences, ISSN 1583-0233, Issue 14, **(2009)**, pp. 167-172.

[16] O.L. Beki, “Optimal location of SVC and TCSC for Voltage Stability Assessment”, IEEE The 4th International Power Engineering and Optimization Conference**,** Shah Alam, Selangor, MALAYSIA, **(PEOCO 2010)**.

[17] E.R. Chaparro, “Coordinated tuning of a set of Static Var Compensators using Evolutionary Algorithms”, IEEE Trondheim PowerTech, 978-1-4244-8417-1/11, **(2011)**.

[18] J. Vara Prasad, “Optimal Allocation of FACTS Controllers for Critical Loading Margin Enhancement”, IEEE International Conference on Power, Energy and Control, 978-1-4673-6030-2/13, **(ICPEC-2013)**.

[19] C.S. Chang, “Optimal multi objective SVC planning for voltage stability enhancement”, *IEEE Proceedings on Generation, Transmission and Distribution*, vol. 145, no.2, **(1999)**.

[20] B.T. Ooi, “Co-Ordination of Static Var Compensators with Long Distance Radial Transmission System for Damping Improvement”, IEEE Power Engineering Review, **(1984)**, pp-265-274.

[21] H. Barot, “Operational experience withstatic Var compensators in Ontario, Canada”, IEEE 978-1-4799-6415-4/14, **(2014)**.

[22] P. Kumkratug, “The Mathematical Model of Power System with Static Var Compensator in Long Transmission Line”, American Journal of Applied Sciences, ISSN 1546-9239, vol. 9, no. 6, **(2012)**, pp. 846-850.

[23] A. A. El-Keib and X. Ma, “Calculating the short-run marginal costs of active and reactive power production”, IEEE Trans. on Power Systems, vol. 12, no. 2, **(1997)**, pp. 559-565.

[24] D. Chattopadhyaya, K. Bhattacharya and J. Parikh, “Optimal reactive power planning and its spot pricing: An integrated approach”, IEEE Trans. on Power Systems, vol. 10, no. 4, **(1995)**, pp. 2014-2019.

[25] N. H. Dandachi, M. Rawlins, O. Alsac, M. Paris and B. Stott, “OPF for reactive power transmission pricing on the NGC system”, IEEE Trans. on Power Systems, vol. 11, no. 1, **(1996)**, pp. 226-232.

[26] S. Hao and A. Pepalexopolous, “A reactive power pricing and management”, IEEE Trans. on Power Systems, vol. 12, no. 1, **(1997)**, pp. 95-104.

[27] J. W. Lamont and J. Fu, “Cost analysis of reactive power support”, IEEE Trans. on Power Systems, vol. 14, no. 3, , **(1999)** pp. 890- 898.

[28] J. B. Gill, T. G. S. Roman, J. J. A. Rioa and P. S. Martin, “Reactive power pricing: A conceptual framework for remuneration and charging procedures”, IEEE Trans. on Power Systems, vol. 15, no. 2, **(2000)**, pp. 483-489.

[29] M. Muchayi and M. E. El-Hawary, “A summary of algorithms in reactive power pricing”, Electric Power and System Research, vol. 21, **(1999)**, pp. 119-124.

30 E. Rashedi, H. Nezamabadi-pour and S. Saryazdi, “GSA: A Gravitational Search Algorithm”, Information Science, vol. 179, **(2009)**, pp. 2232– 2248.

[31] Power system Test Archive-UWEE, University of Washington, < http://www.ee.washington.edu/research/pstca>.

[32] www.mathworks.com.

[33] M. Amroune, “Static Voltage Stability Margin Enhancement Using SVC and TCSC”, World Academy of Science, Engineering and Technology” International Journal of Electrical, Computer, Energetic, Electronic and Communication Engineering, vol. 7, no.10, **(2013)**.

[34] P. Nagendra, “Voltage stability assessment of a power system incorporating FACTS controllers using unique network equivalent”, Ain Shams Engineering Journal 5, **(2014)**, pp. 103–111.

[35] A. Kumar, “Locational marginal prices with SVC in Indian electricity market”, International Journal of Engineering, Science and Technology, vol. 3, no. 3, **(2011)**, pp. 9-24.

[36] A. Singh, “Placement of SVC for Multi-objective Function using RCGA”, International Journal of Computer Applications, vol. 120, no.11, **(2015)**, pp. 0975 – 8887.

[37] M. Saravanan, “Application of PSO Technique for Optimal Location of FACTS Devices Considering System Loadability and Cost of Installation”, *Power Engineering Conference,* vol. 21, **(2015)**, pp.716 - 721.

[38] L.J. Cai and I. Erlich, “Optimal Choice and Allocation of FACTS Devices using Genetic Algorithms”, Proceedings on Twelfth Intelligent Systems Application to Power Systems Conference, **(2003)**, pp. 1–6.

