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Hybrid Optimization Methods for Analyzing the performance of Advanced FACTS Device in Transmission System

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Abstract — The multiplicity of transactions frequently leads to the conditions where the operating zone will not remain secure in the field of emerging electric power systems. In the system of power security advancement, the highly Flexible AC transmission systems (FACTs) controllers will play a prime role. But because of large scale capital investment it is required to locate the FACTs controllers in the power system in optimum condition. Due to the flexibility nature of these controllers, with fast control characteristics they may regulate both active and reactive power flow control cum adaptive to voltage magnitude control very effectively. Regulation in line flow and maintenance of voltages at different locations of the bus are achieved by keeping of such devices in suitable location. In this paper optimization methods GA-PSO and DA-PSO are proposed for finding the optimum location and firing angle of SVC. In that, the location of the device is optimized by GA or DA and the optimized firing angle is done with PSO. Because of the two different Optimizing techniques are used to solve single objective function, it is called Hybridization. The proposed optimization is an effective method for finding the optimal location of SVC device and also increasing voltage profile and reducing the power system losses in the line. The Hybrid GA-PSO, GA-DA and DA-PSO methods are tested on IEEE 57 bus test systems and simulation results are presented.

Keywords --- Power *system, Transmission system, FACTS, SVC, Firing Angle, Hybrid GA-PSO, GA-DA and DA-PSO*

1 INTRODUCTION

In the deregulated power industry the capability of transmission lines is becoming the major bottleneck of transmission of power. The competition of electricity may aggravate loadability of some power transmission lines. The open transmission lines must be utilized more resourcefully to meet the load demands in a power system and to convince the stability and reliability criterion. The principle of the transmission network is to pool power plants and load centers for providing the load at a needed reliability with more efficiency at a minor cost. Some efficient controls with the aid of FACTS (Flexible AC Transmission Systems) devices are to be used to above problems for technically smart solutions. N.G. Hingorani[1] first introduced the formation of FACTS as a total network control philosophy from the electric power research institute (EPRI) in the USA in 1988 even though before that the power electronic controlled devices had been used in the transmission network for many years.

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The application of FACTS in electric power System is mainly applicable for the power flow control, stability improvement, voltage profile management, power factor correction and loss minimization. The majority popular devices of the FACTS are thyristor Controlled Series Capacitors (TCSC) and Static VAR Compensators (SVC). The major functionality of the SVC is to control the voltage at a chosen bus by regulating the reactive power injection at the desired location. For proper operation and utilization of loads it is important to maintain the rated voltage levels.

In this paper, the optimal location for placement of FACTS device has been formulated as a problem, and is solved using a new Hybrid Optimization algorithm called the Hybrid GA – PSO, GA-DA and DA - PSO Algorithm. The Hybrid Optimization Algorithm is used for finding out the optimal location of advanced static VAR compensator (SVC) devices, to achieve more improved voltages and minimum transmission line losses and in the system.

Many concepts were proposed by many authors regarding placement and sizing of SVC. The equations in polar form related to real and reactive power flow are represented by Hadi Saadat for two bus systems using Newton Raphson method with the help of a Jacobean matrix [1]. The initiation and development of FACTS devices from power electronics devices is referred by Hingorani N.G et.al. The improved stability, increased security, with the more heightened capability for power transferring and mitigated operation and transmission investment costs can be attained by using SVC's

[2]. The combination of mechanically controlled and thyristor controlled shunt capacitors and reactors are named as SVC [3]-[4]. With reference to [5]-[6] papers, the combination of either thyristor controlled reactor & fixed capacitor or thyristor controlled reactor & thyristor switched capacitor is considered as the most popular model of SVC's. The novel firing angle model for Static VAR Compensator (SVC) FACTS devices is also designed as new SVC model [7]-[9]. As on development in the power electronic construction, the variable reactance reactive power compensator is placed instead of fixed capacitor and reactor reactive compensator. In multi machine power systems, Kumar G.R et.al discussed in brief regarding FACTS controllers with respect to of load flow analysis from various operational conditions [10]. B.Venkateswara rao et.al highlighted the Power System Stability management by introducing Static VAR Compensator in the system network [11]. The performance of the power system has been improved by Sahoo et.al by developing the basic modelling of the FACTS [12].Zhang, X.P et.al mentioned Newton Raphson algorithm and Newton Raphson strong convergence characteristics with the help of Jacobian Matrix for power flow analysis [13]. The optimal placement of FACTS devices controls the power flows and losses in transmission losses has been detailed by Gotham.D.J and G.T Heydt to assure the power systems security and safety [14]. Povh.D justified the better modelling concepts of the transmission network in power systems with the inclusion of the FACTS devices [15]. The network's maximum power capability was tested by Ache et.al, using computer programming for the FACTS devices with various techniques [16].The multiplicity combinations of compensators and their stillness was proposed by Radman.G and R.S Raje [17]. Stagg.G.W et.al stated the multiple load flow analysis with preliminary perceptions of the power systems [18]. Tong Zhu and Gamg Haung conceptualised the FACTS devices installation to the buses which were suitable [19]. P.Kessal and H. Glavitsch recommended the installation of FACTS devices in transmission network raised capacity of transmission networks [20]. L. Jebaraj et al conferred that the transmission system with the FACTS devices action has been assessed with limited voltage stability for progressed levels of voltage and mitigated losses [21]. The optimal location of SVC with scheduled parameters Reza Sirjani et al explains the optimal placement and parameter settings of SVC FACTS devices [22]. M. L. Soni et al detailed the load demand, capacitor banks function etc with respect to SVC in a optimal way [23]. The optimal placement and setting of SVC's parameters by using genetic algorithm concepts [24]-[27].The PSO concept for proper location and sizing of SVC device are analyzed [28]-[31]. The advancement in the techniques has been extended by S.Meerjaali as a novel technique named Dragon fly algorithm [32].

2. POWER FLOW ANALYSIS

The analysis of power flow [33] is very vital to the design of power system. This is essential to plan, operate schedule and exchange power among various utilizes. The fundamental principle for the analysis of power flows is to know both magnitude and phase angle of voltage at every bus and to find real and reactive power flow in a transmission line. Power flow analysis is a prominence tool which contains numerical analysis applied to the power system.

Thus it is also helpful to know the best locations, best size, optimal capacity of proposed power generating stations, substations as well as new transmission lines. The load flow is a vital and essential subject in the studies of power system. It too helps to estimate losses of the lines for different conditions of power flow. It will help for the analysis of the effect of temporary loss of generating station or transmission on power flow.

Around a base point $(\theta(0),V(0))$, ΔP and ΔQ are the power mismatch equations as well expanded and therefore the following relationship is expressed through power flow Newton–Raphson algorithm.

$$\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = \begin{bmatrix} \frac{\partial P}{\partial \theta} & \frac{\partial P}{\partial V}V \\ \frac{\partial Q}{\partial \theta} & \frac{\partial Q}{\partial V}V \end{bmatrix} \begin{bmatrix} \Delta \theta \\ \frac{\Delta V}{V} \end{bmatrix} \quad (1)$$

Where

ΔP is the active power mismatches at the bus

ΔQ is the reactive power mismatches at the bus

$\frac{\partial P}{\partial \theta}$ is the real power change at the bus with respect to angles

$\frac{\partial P}{\partial V}V$ is the real power change at the bus with respect to change in voltage magnitude

$\frac{\partial Q}{\partial \theta}$ is the reactive power change at the bus with respect to angle

$\frac{\partial Q}{\partial V}V$ is the reactive power change at the bus with respect to change in Voltage magnitude

Δ V is the bus voltage change

$\Delta\theta$ is the bus angle change

3 SHUNT COMPENSATION

When the demand of reactive power grows in busses, then the bus voltage will be rightly controlled with the help of connecting capacitor banks in parallel to a lagging load [34]. For decreasing the magnitude of the source current that is necessary to supply load. The capacitor banks will provide part or full reactive power of load. As a result, the voltage drop in between sending end and load end gets minimized. Improvement in power factor and enhancement in active power output are takes place from source.

The capacitor banks could be connected permanently to the system or might be varied through ON or OFF switches of parallely connected capacitors manually or electronically depending upon load demanding conditions.

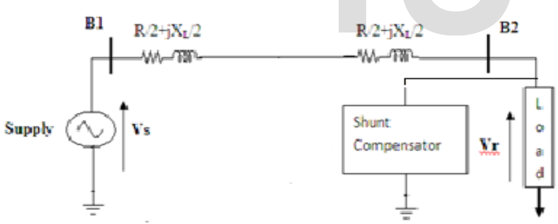

Fig.1 single line diagram of shunt compensation

In practical, shunt compensation schemes the power factor may be lifted from say 0,75 lagging up to 0.9. it would be rare and generally uneconomic to provide sufficient compensation to bring the power factor up into the range 0.95 to 1.

Advantages

a) No inherent Ferro resonance risk. b) Capacitor do not carry line fault current c) Reduced line currents

Disadvantages

a) Automatic regulation is only possible with expensive control gear b) Switchgear and control equipment generally equipped c) Voltage and VAR changes in discrete steps. d) Inability to respond to rapid load fluctuations. e) Risk of over current damage from load generated harmonics

3.1 Operation of the SVC (Firing Angle Power Flow Model)

SVC [36] comprising with a group of shunt-connected capacitors and reactors banks with fast control action by means of thyristor switching, the SVC will be looked from the operational point of view as a variable shunt reactance which adjusts automatically in response to the varying system operative conditions. The SVC draws either capacitive or inductive current from the network depending on the nature of the equivalent SVCs reactance, i.e., capacitive or inductive. Suitable control of this equivalent reactance allows voltage magnitude regulation at the SVC point of connection. SVCs realize their main operating Characteristic at the price of generating harmonic currents and filters, engaged with this kind of devices. The most accepted configuration for continuously controlled SVC's is the combination of either fix capacitor and thyristor controlled reactor or thyristor switched capacitor and thyristor controlled reactor.

The objective of SVC is to inject reactive power [37] to a bus or absorbs reactive power from the bus where it is connected in order to regulate voltage magnitude of the bus at the point of connection.

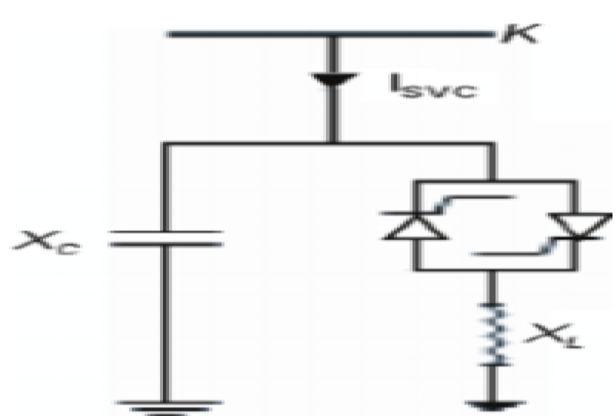

Fig.2 The Firing angle model of SVC

When thyristors are fired, the total reactance of the TCR is X_{Leq}, at fundamental frequency, is given by [5] ,

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$$X_{Leq} = X_L . \frac{\pi}{2(\pi-\alpha)+\sin(2\alpha)} \quad (2)$$

Where α is the thyristor's firing angle.

The SVC effective reactance X_{eq} is determined by the parallel combination of X_C and X_{Leq},

$$X_{eq} = \frac{X_C . X_L}{\frac{X_C}{\pi}.(2(\pi-\alpha)+\sin(2\alpha))-X_L} \quad (3)$$

In general, the transfer admittance equation for the variable shunt compensator is,

$$I_{svc}(i) = jB_{svc}V(i) \quad (4)$$

Where

The SVC equivalent susceptance is given by (3) whilst its profile, as function of firing angle,

$$B_{svc} = B_c - B_{TCR} = -\frac{1}{X_c X_L}(X_L - \frac{X_c}{\pi}[2(\pi-\alpha)+\sin 2\alpha]) \quad (5)$$

$$X_L = wL . X_C = \frac{1}{wC} \quad (6)$$

and the reactive power equation is,

$$Q_k = \frac{-V_k^2}{X_c X_L}\{X_L - \frac{X_c}{\pi}[2(\pi-\alpha_{svc})+\sin 2\alpha_{svc}]\} \quad (7)$$

4 HYBRID OPTIMIZATION

The different type of optimizing techniques which are used to solve the single objective function by sharing different parameters is called hybrid optimization. In this a paper hybrid optimizing techniques such as GA-PSO, GA-DA and DA-PSO are used to optimize the losses of the transmission system.

GA-PSO: In this optimization Genetic algorithm [19] is used to select the suitable location of the transmission network and PSO[20] is used to select the suitable firing angle of the internal power electronic device of the system. The parameters of the Genetic Algorithm are shown below

Population=10.
Generations=30
Crossover=0.9.
Mutation=0.03

The initialization vector is randomized with the bus numbers of the system. Compensation device like SVC is placed at bus number which generated at each iteration .By crossover and mutation the suitable location of the device is selected by optimizing the losses of the transmission network.
With Particle swarm Optimization technique the suitable firing angles of the internal power electronic device is selected by considering the following parameters.

No of Particles=30
Iterations=150
Wmax= 0.9
Wmin=0.4
C1=1.5
C2=1.5.

By using the GA-PSO algorithms the minimum losses are finding by optimal location of SVC with Optimal size.

GA-DA: In this optimization Genetic algorithm [19] is used to select the suitable location of the transmission network and DA [21] is used to select the suitable firing angle of the internal power electronic device of the system. The parameters of the Genetic Algorithm are shown below

Population=10.
Generations=30
Crossover=0.9.
Mutation=0.03

The initialization vector is randomized with the bus numbers of the system . Compensation device like SVC is placed at bus number which generated at each iteration .By crossover and mutation the suitable location of the device is selected by optimizing the losses of the transmission network.

Dragonfly algorithm (DA)[21] is used to find the optimal location of SVC by using the parameters of the DA which are mentioned below.

Number of searching Agents=40;
Iterations=500;

DA-PSO: In this hybrid optimization dragonfly algorithm (DA)[21] is used to find the optimal location of SVC by using the parameters of the DA which are mentioned below.

Number of searching Agents=40;
Iterations=500;

By considering the suitable line or branch from DA the particle swarm optimization is used to find the optimal value of the firing angle for reducing the losses of the system. The parameters which are mentioned in GA-PSO.

5 RESULTS

The proposed hybrid optimization techniques are implemented in different test cases which are IEEE 57 bus systems The single diagrams and the effect of voltage profile for each system by installing single and two SVCs with GA – PSO, GA-DA and DA-PSO are shown in the figures and Tabular columns respectively.

5.1 Test case 1: IEEE 57 bus system :

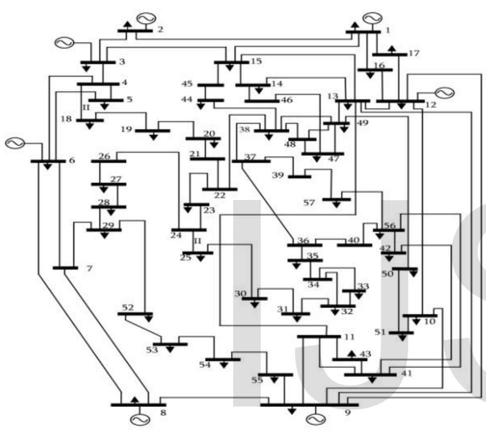

Fig. 3. Single line diagram IEEE 57 bus system.

5.2 Single SVC Placement

The placement of single SVC by using hybrid optimization technique such as GA - PSO and PSO - DA are implemented on IEEE 57 bus system. By placing single SVC at different locations of the transmission network the real and reactive power losses are reduced. With the reference of the table 2.The losses are greatly reduced by GA – PSO and GA-DA as compared to DA-PSO by placing the single SVC. The voltage profile, branch real and reactive power losses without placing of SVC and with the placing of single SVC are shown in the figure 7,8and 9 respectively.

GA-PSO: GA-PSO technique is implemented to IEEE 57 bus system and the results are tabulated as follows with the respective figures of change of voltage profiles.

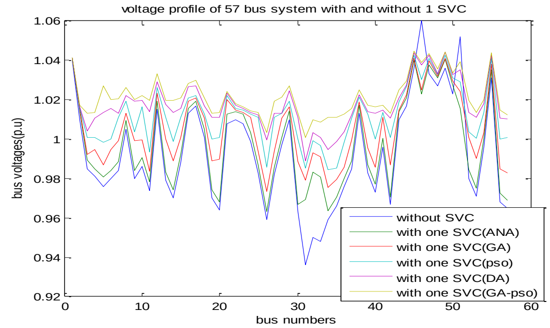

Fig. 4. Comparative Voltage profile of IEEE 57 bus with and without SVC

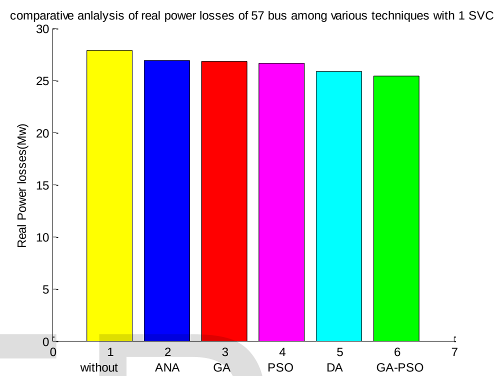

Fig. 5. Total Real power losses of IEEE 57 bus with and without SVC

GA-DA: GA-DA technique is implemented to IEEE 57 bus system and the results are tabulated as follows with the respective figures of change of voltage profiles.

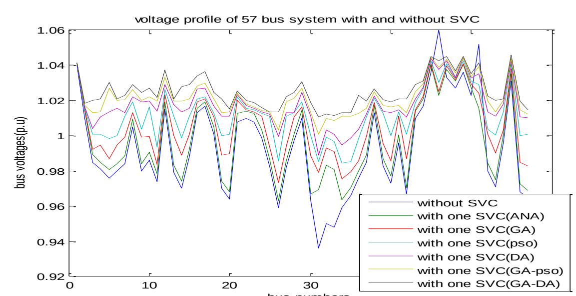

Fig. 6. Comparative Voltage profile of IEEE 57 bus with and without SVC

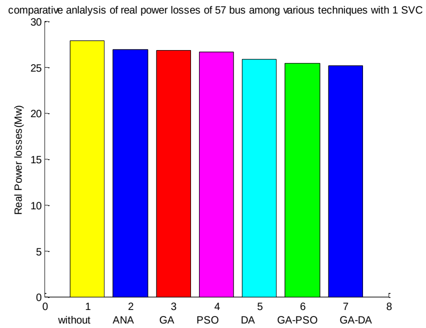

Fig. 7. Total Real power losses of IEEE 57 bus with and without SVC

DA-PSO: DA - PSO technique is implemented to IEEE 57 bus system and the results are tabulated as follows with the respective figures of change of voltage profiles.

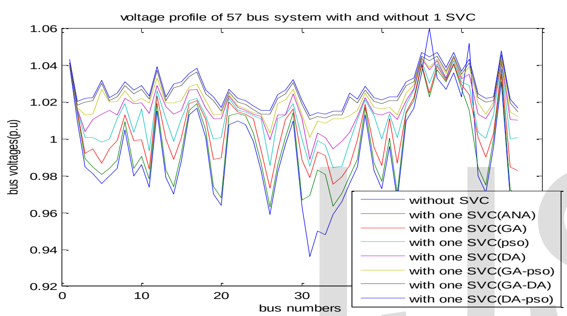

Fig. 8. Comparative Voltage profile of IEEE 57 bus with and without SVC

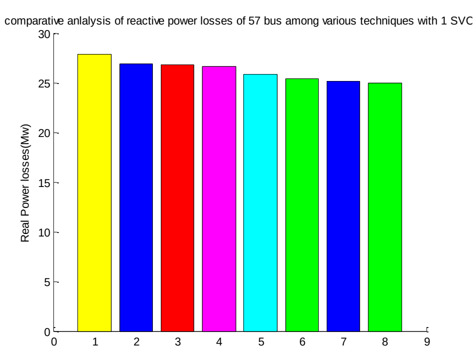

Fig. 9. Total Real power losses of IEEE 57 bus with and without SVC

5.3 Placement Two SVCs

With the inclusion of two SVC's in the IEEE 57 bus system then the power flows are further improved and losses further are reduced which is shown in the table 2. The voltage profile, total real and reactive power losses without placing of SVC and with the placing of two SVC's are shown in the figure 10,11,12,13,14 and 15 respectively.

GA-PSO: GA-PSO technique is implemented to IEEE 57 bus system and the results are tabulated as follows with the respective figures of change of voltage profiles

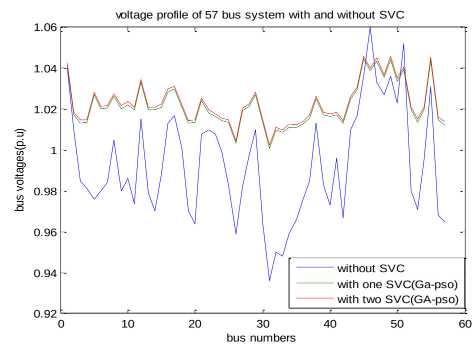

Fig..10. Comparative Voltage profile of IEEE 57 bus with and without two SVC's (GA-PSO)

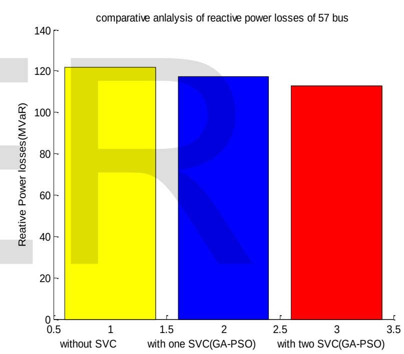

Fig. 11 Total Real power losses of IEEE 57 bus with and without two SVCs

GA-DA: GA-DA technique is implemented to IEEE 57 bus system and the results are tabulated as follows with the respective figures of change of voltage profiles, total real and reactive power losses

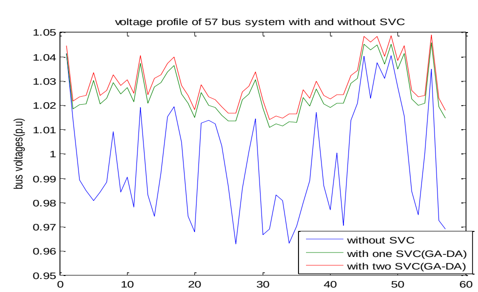

Fig..12. Comparative Voltage profile of IEEE 57 bus with and without two SVCs (GA-DA)

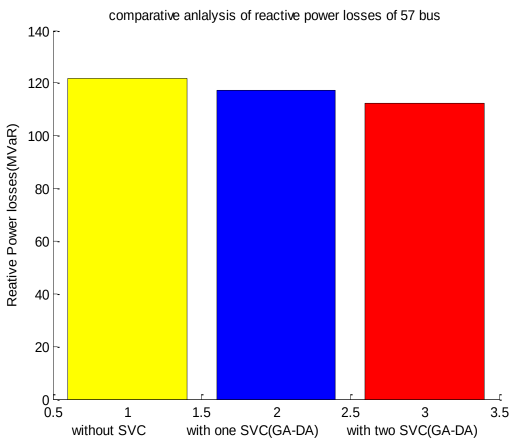

Fig. 13 Total Real power losses of IEEE 57 bus with and without two SVCs (GA-DA)

DA-PSO: DA - PSO technique is implemented to IEEE 57 bus system and the results are tabulated as follows with the respective figures of change of voltage profiles, total real and reactive power losses

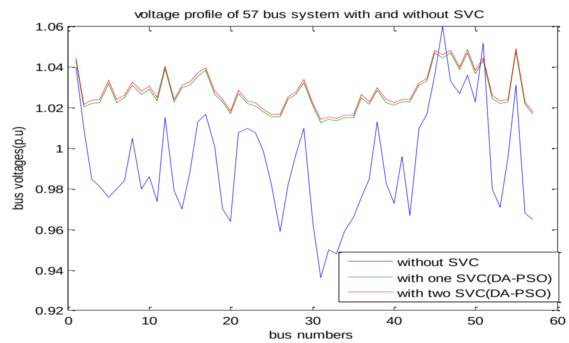

Fig. 14. Comparative Voltage profile of IEEE 57 bus with and without two SVCs (DA-PSO)

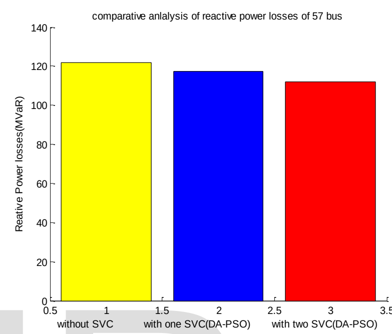

Fig. 15. Total Real power losses of IEEE 57 bus with and without two SVCs

Table 1: Comparative system parameters of IEEE 57 bus with and without SVC by using GA – PSO,GA-DA and DA-PSO

PARAMETERS	WITHOUT SVC	WITH SINGLE SVC(DA-PSO)	WITH TWO SVC(DA-PSO)	WITH SINGLE SVC(GA-DA)	WITH TWO SVC(GA-DA)	WITH SINGLE SVC(GA PSO)	WITH TWO SVC(GA - PSO)
MINIMUM VOLTAGE(P.U)	0.9360 & 31	1.0128 & 31	1.0142 & 31	1.0108 & 31	1.0142 & 31	1.0009 & 31	1.0023 & 31
MAXIMUM VOLTAGE(P.U)	1.06 & 46	1.0477 & 55	1.0491 & 55	1.0457 & 55	1.0491 & 55	1.0445 & 45	1.0459 & 45
REAL POWER LOSSES(MW)	27.864	24.923	24.116	25.123	24.532	25.368	24.604
REACTIVE POWER LOSSES(MVAR)	121.67	117.131	112.138	117.213	112.384	117.426	112.703
LOCATION OF SVC	----	52	42 & 48	34	36 & 42	48	41 & 44
SVC1 FIRING ANGLE(DEG)	----	128.7	135.7	129.5	130.8	146.27	134.9
SVC2 FIRING ANGLE(DEG)	----	----	127.8	----	126.8	----	142.8
SIZE OF	----	3.92	1.86	3.78	1.82	2.92	1.88

SVC1(MVAR)							
SIZE OF SVC2(MVAR)	----	----	2.95	----	2.91	----	2.75

From above table, the losses without SVC are 27.864MW and 121.67MVar. The voltage profile of the system improved by installing of the single SVC (DA-PSO) at 52nd bus. The losses are reduced to 24.923MW and 112.138 Mvar with SVC size of 3.92Mvar. The voltage profile further improved by installing two SVCs between the buses 42 and 48. The losses are further reduced to 24.116 MW and 112.138 Mvar.

6 CONCLUSION

To probe the performance of power transmission line in the presence of SVC device (single and double), the Hybrid Optimization i.e GA-PSO and DA-PSO are implemented on IEEE 57 bus system in the Novel Static VAR Compensator (SVC) model. To elaborate Novel model i.e firing angle models of SVC in this paper, Hybrid optimization algorithm has been proposed. Real and Reactive loses of power are less with SVC with the outcomes received for the above bus system using proposed method with and without SVC compared and observations. The received are highly supportive and reveal that SVC is the best effective shunt compensation device which will be able to considerably enhance the system voltage profile. For the analyzing the firing angle model of SVC the outcomes of GA - PSO and DA – PSO are compared with proposed method shown in table 1 & 2. From the tables, the Hybrid GA - PSO algorithms offers better voltage profile improvement and good reduction in transmission line power losses which can be concluded with that when single and double SVC's are kept in IEEE 57 bus system. The outcomes also reveal that Hybrid GA - PSO algorithm was the best optimization technique in comparison with Genetic algorithm (GA), the Particle Swarm Optimization (PSO) and Hybrid DA – PSO.

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