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Reactive power loss control in power flow controller using Adaptive learning

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Abstract: Recently Voltage stability issues have gained significant attention, due to voltage instability incidents. Voltage instability is the progressive and uncontrollable fall or rise of the voltage at some buses of the system which affects mainly reactive power increment. Voltage stability issues include the reactive power loss compensation techniques. In this paper a hybrid model of decision making based on two algorithms namely Swarm Optimization and Genetic Algorithm based implementation is proposed. The optimization problem is defined by obtaining the optimal locations of the Var compensators and to minimize the total reactive power loss in a power system network. The simulation observation illustrates an improvement in relative loss compensation in comparison to existing models.

Keywords: Power flow controller, swarm optimization, genetic algorithm, adaptive learning.

I. INTRODUCTION

One of the major problems in transmission lines that may associate with a stressed system is the voltage instability or collapse. Instability of the voltage can affect the performance of a power system. The main cause of voltage instability is insufficient reactive power supply. Reactive power can be dispatched effectively to maintain acceptable voltage levels. Maintaining viable voltage levels are very important to avoid voltage collapse. Static VAR Compensator (SVC) as the reactive resource uses power electronics to control its reactive power output to regulate bus voltage. To minimize the reactive power loss, location and placement of reactive power improvement devices is a major task.

Reactive power compensation in transmission systems also improves the stability of the ac system by increasing the maximum active power that can be transmitted. It also helps to maintain a substantially flat voltage profile at all levels of power transmission, it improves HVDC (High Voltage Direct Current) conversion terminal performance, increases transmission efficiency, controls steady-state and temporary over voltages [4], and can avoid disastrous blackouts [5], [6]. Series and shunt VAR compensation are used to modify the natural electrical characteristics of ac power systems. Series compensation modifies the transmission or distribution system parameters, while shunt compensation changes the equivalent impedance of the load [1], [7]. In both cases, the reactive power that flows through the system can be effectively controlled improving the performance of the overall ac power system. Traditionally, rotating synchronous condensers, fixed or mechanically switched capacitors or inductors have been used for reactive power compensation. However, in recent years, static VAR compensators employing thyristor switched capacitors and thyristor controlled reactors to provide or absorb the required reactive power have been developed [7], [8], [9]. Also, the use of self-commutated PWM converters with an appropriate control scheme permits the implementation of static compensators capable of generating or absorbing reactive current components with a time response faster than the fundamental power network cycle. Based on the use of reliable high-speed power electronics, powerful analytical tools, advanced control and microcomputer technologies, Flexible AC Transmission Systems (FACTS) have been developed and represent a new concept for the operation of power transmission systems. In these systems, the use of static VAR compensators with fast response times play an important role, allowing to increase the amount of apparent power transfer through an existing line, close to its thermal capacity, without compromising its stability limits. These opportunities arise through the ability of special static VAR compensators to adjust the interrelated parameters that govern the operation of transmission systems, including shunt impedance, current, voltage, phase angle and the damping of oscillations.

In this paper particle swarm combined with genetic algorithm VAR compensator is proposed. The Swarm optimization (SWO) based method is used to find the location of series capacitors to be implanted to minimize the total reactive power loss in a power system network. The established indicator is used for the voltage stability assessment and also to find the change in reactive power loss.

The remaining paper is organized as follows: Section II reviews the basic model of representation of a transmission line and VAR compensator. The illustration about the proposed combination of SWO and genetic algorithm is presented in Section III. The performance evaluation of the proposed method presented in Section IV which gives the effectiveness under consideration of reactive power compensation. The conclusions of this paper are made in section V.

II. SYSTEM MODEL

Transmission Line

A Transmission Line is a device designed to guide electrical energy from one point to another. The transmission line has a single purpose for both the

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transmitter and the antenna. The purpose is to transfer the energy output of the transmitter to the antenna with the least possible power loss. Transmission lines can be defined in terms of its impedance. The ratio of voltage to current (E_{in}/I_{in}) at the input end is known as the input impedance (Z_{in}). This is the impedance presented to the transmitter by the transmission line and its load, the antenna. The ratio of voltage to current at the output (E_{out}/I_{out}) end is known as the output impedance (Z_{out}). This is the impedance presented to the load by the transmission line and its source. If an infinitely long transmission line could be used, the ratio of voltage to current at any point on that transmission line would be some particular value of impedance. This impedance is known as the characteristic impedance. A simple transmission line connected between bus-*i* and bus-*j* can be represented by its lumped π equivalent parameters [5] as shown below.

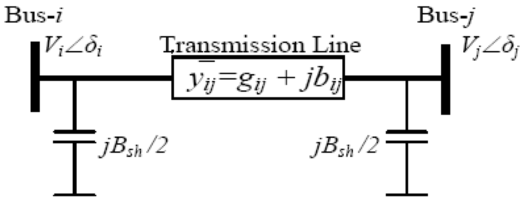


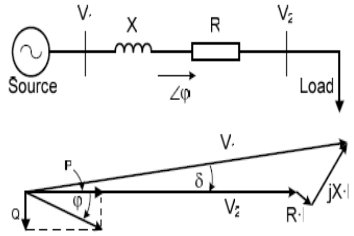
Fig. 1. Static representation of transmission line

Power Flow Compensation Principles

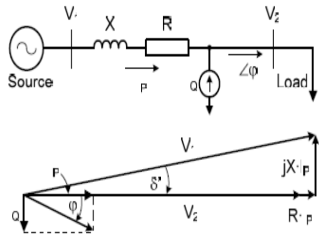
VAR compensation is defined as the management of reactive power to improve the performance of ac power systems. The concept of VAR compensation embraces a wide and diverse field of both system and customer problems, especially related with power quality issues, since most of power quality problems can be attenuated or solved with an adequate control of reactive power [1]. In general, the problem of reactive power compensation is viewed from two aspects: load compensation and voltage support. In load compensation the objectives are to increase the value of the system power factor, to balance the real power drawn from the ac supply, compensate voltage regulation and to eliminate current harmonic components produced by large and fluctuating nonlinear loads [2], [3]. Voltage support is generally required to reduce voltage fluctuation at a given terminal of a transmission line.

In a linear circuit, the reactive power is defined as the ac component of the instantaneous power, with a frequency equal to 100 / 120 Hz in a 50 or 60 Hz system. The reactive power generated by the ac power source is stored in a capacitor or a reactor during a quarter of a cycle, and in the next quarter cycle is sent back to the power source. In other words, the reactive power oscillates between the ac source and the capacitor or reactor, and also between them, at a frequency equals to two times the rated value (50 or 60 Hz). For this reason it can be compensated using VAR generators, avoiding its circulation between the load (inductive or capacitive) and the source, and therefore improving voltage stability of the power system. Reactive power compensation can be implemented with VAR generators connected in parallel or in series.

Shunt Compensation



(a)



(b)

Fig. 2.Principles of shunt compensation in a radial ac system

a) Without reactive compensation

b) Shunt compensation with a current source

Fig. 2 shows the principles and theoretical effects of shunt reactive power compensation in a basic ac system, which comprises a source V1, a power line and a typical inductive load. Fig. 2.a) shows the system without compensation, and its associated phasor diagram In the phasor diagram, the phase angle of the current has been related to the load side, which means that the active current IP is in phase with the load voltage V2. Since the load is assumed inductive, it requires reactive power for proper operation and hence the source must supply it, increasing the current from the generator and through power lines. If reactive power is supplied near the load, the line current can be reduced or minimized, reducing power losses and improving voltage regulation at the load terminals. This can be done in three ways: a) with a capacitor, b) with a voltage source, or c) with a current source. In Fig. 2.b), a current source device is being used to compensate the reactive component of the load current (IQ). As a result, the system voltage regulation is improved and the reactive current component from the source is reduced or almost eliminated. If the load needs leading compensation, then an inductor would be required. Also a current source or a voltage source can be used for inductive shunt compensation. The main advantages of using voltage or current source VAR generators (instead of inductors or capacitors) is that the reactive power generated is independent of the voltage at the point of connection.

Series Compensation

VAR compensation can also be of the series type. Typical series compensation systems use capacitors to decrease the equivalent reactance of a power line at rated frequency. The connection of a series capacitor generates reactive power that, in a self-regulated manner, balances a fraction of the line's transfer reactance. The result improves functionality of the power transmission system through:

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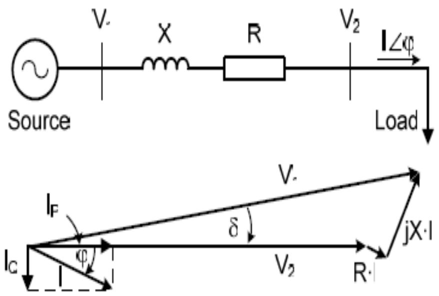
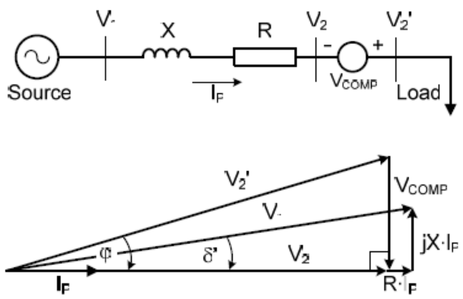
(i) Increased angular stability of the power corridor,
(ii) Improved voltage stability of the corridor,
(iii) Optimized power sharing between parallel circuits.

Like shunt compensation, series compensation may also be implemented with current or voltage source devices, as shown in Fig. 3-a) shows the same power system of Fig. 2.4-a), also with the reference angle in V2, and Fig. 3-b) the results obtained with the series compensation through a voltage source, which has been adjusted again to have unity power factor operation at V2. However, the compensation strategy is different when compared with shunt compensation. In this case, voltage VCOMP has been added between the line and the load to change the angle of V2', which is now the voltage at the load side. With the appropriate magnitude adjustment of VCOMP, unity power factor can again be reached at V2. As can be seen from the phasor diagram of Fig. 2.4-b), VCOMP generates a voltage with opposite direction to the voltage drop in the line inductance because it lags the current IP.



(a)



(b)

Fig. 3 Principles of series compensation.
a) The same system of Fig. 2.4-a) without compensation.
b) Series compensation with a voltage source.

As was already mentioned, series compensation with capacitors is the most common strategy. Series Capacitor are installed in series with a transmission line as shown in Fig. 4, which means that all the equipment must be installed on a platform that is fully insulated for the system voltage (both the terminals are at the line voltage). On this platform, the main capacitor is located together with over voltage protection circuits. The over voltage protection is a key design factor as the capacitor bank has to withstand the throughput fault current, even at a severe nearby fault. The primary over voltage protection typically involves non-linear metal-oxide varistors, a spark gap and a fast bypass switch. Secondary protection is achieved with ground mounted electronics acting on signals from optical current transducers in the high voltage circuit.

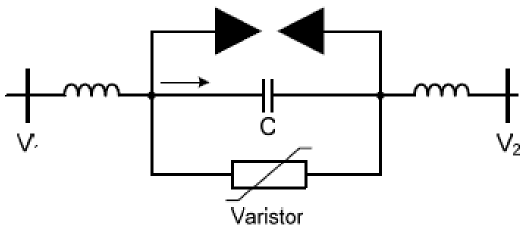


Fig. .4 Series Capacitor Compensator and associated protection system.

Independent of the source type or system configuration, different requirements have to be taken into consideration for a successful operation of VAR generators. Some of these requirements are simplicity, controllability, dynamics, cost, reliability and harmonic distortion. The following sections describe different solutions used for VAR generation with their associated principles of operation and compensation characteristics.

To minimize the real and reactive losses for economic considerations. This can be illustrated by the following simple set of equations

$$I^2 = I.I^* = \left[\frac{P - jQ}{V^*}\right]\left[\frac{P + jQ}{V}\right] = \frac{P^2 + Q^2}{V^2}$$

$$P_{loss} = I^2 R = \frac{P^2 + Q^2}{V^2} R$$

$$Q_{loss} = I^2 X = \frac{P^2 + Q^2}{V^2} X$$

From the above equation it is clear that by controlling the factor X the bus voltage profile automatically improved. Faster recovery of the magnitudes of the over voltage and under voltage can be achieved by minimizing the temporary voltage drop.

III. PROPOSED SYSTEM

The swarm optimizations and genetic algorithm (GA) is well known optimization algorithm in engineering application. In this paper a hybrid model of swarm optimization and genetic algorithm have been implemented considering its simplicity, less memory requirements to obtain the optimal locations of the VAR compensators.

a) Swarm Optimization

Since its introduction, SWO has been successfully applied to optimize various continuous nonlinear functions. To minimize the series reactive power loss in the system the transmission lines, where the RPL is maximum, are to be located and hence, series compensation is to be applied in these lines to minimize the losses. Mathematically,

$$Q_{loss} = \left[V_i^2 + V_j^2 - 2V_i V_j \cos(\delta_i - \delta_j)\right] X_L \Big/ (X_L^2 + R_L^2)$$

XL is the variable in this case. Usually, a practical upper limit, lesser than 1, is chosen for the degree of compensation. This is because for Kse=1, the effective line reactance would become zero, so the smallest disturbance in the relative rotor angles of the terminal synchronous machines would result in the flow of large

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currents. Moreover, the circuit would become series resonant at the fundamental frequency, and it would be difficult to control transient voltages and currents during disturbances. The practical upper limit chosen in this case is 70% i.e. upper limit for XL is chosen as [1-(70/100)]* XL= 0.3 XL. A lower limit for compensation is also chosen as 10% i.e. 0.9 XL. Hence, XL is varied from 0.3 XL to 0.9 XL.

Step1 The population size and the stopping criterion are chosen (number of iterations).

Step 2 Each particle is randomly initialized, considering all the constraints. The iteration count is initialized. The constraint in this case is that the value of compensation has to be maintained between 10% to 70% i.e. within 0.3 Xl to 0.9 Xl.

Step 3 If constraints are satisfied, the original reactance of the line is replaced with the changed reactance and power flow is conducted at each step. The change in voltages and other system parameters are updated accordingly.

Step 4 The objective function is calculated and closeness of particles to the objective function is noted.

Step 5 Pbest and Gbest are updated as:-

$$P_{best}(t+1) = \begin{cases} P_{best}(t) & if \quad P(t+1) > P_{best}(t) \\ P_i(t+1) & if \quad P(t+1) < P_{best}(t) \end{cases}$$

$$G_{best}(t+1) = \begin{cases} G_{best}(t) & if\ P_{best}(t+1) > G_{best}(t) \\ P_{best}(t+1) & if\ P_{best}(t+1) < G_{best}(t) \end{cases}$$

Step 6 The constraints are checked again. If satisfied, move to step 7.

Step 7 The end criterion is checked. If satisfied, move to step 12.
Else move to step 8.

Step 8 Particle velocity is updated for N-1 dimensions

$$V_{ij}^t = W \times V_{ij}^t + C_1 \times r_1 \times (P_{bestij}^{t-1} - X_{ij}^{t-1}) + C_2 \times r_2 \times (G_{bestij}^{t-1} - X_{ij}^{t-1})$$

$$i = 1,2....N_D\ ,\ j = 1,2...........N_{par}$$

$$V_{\min} \le V \le V_{\max}$$

$$V_{\max} = \frac{(X_{\max} - X_{\min})}{N_D}$$

$$V_{\min} = -V_{\max}$$

Step9 Particle position is updated for the above N-1 dimensions according to:-

$$X_{ij}^t = X_{ij}^{t-1} + V_{ij}^t$$

$$X_{\min} < X < X_{\max}$$

Step 10 The position of the Nth dimension is now adjusted by satisfying its constraints.

Step 11 The iteration count is incremented and step 4 is repeated for modified values.
Step 12 END.

b) convergence algorithm

Since its introduction, GA has been successfully applied to optimize various continuous nonlinear functions. The objective (as stated above) is to minimize the series reactive power loss in the system. To do so, reactive power loss in each and every line is calculated and the lines having maximum reactive power loss are selected and hence, series compensation is applied in these lines to minimize the losses. The objective function is:-

$$Q_{loss} = \left[V_i^2 + V_j^2 - 2V_iV_j\cos(\delta_i - \delta_j)\right] X_L \Big/ (X_L^2 + R_L^2)$$

XL is the variable in this case, Random values of XL are generated within the prescribed limits and the value which results in minimum value of the objective function is selected. The practical upper limit chosen in this case is 70% i.e. upper limit for XL is chosen as [1-(70/100)]* XL= 0.3 XL. A lower limit for compensation is also chosen as 10% i.e. 0.9 XL. Hence, XL is varied from 0.3 XL to 0.9 XL.

Step 1 The constraint limits for the reactance of the line is set between 10% and 70%.

Step 2 Random values of X are generated between limits

$$X_{new}(w,t,1) = X_{\min} + Y(t,1) \times \left(\left(X_{\max} - X_{\min}\right)/((2^{\wedge}1) - 1\right)$$

Step 3 the values are converted to decimal- 8 bit

Step 4 the values of generated reactances are put into the objective function

Step 5 the fitness evaluation is done for the various reactance values

```
fmax (w, 1) = max (fx (w, 1))
fmin(w,1) = min(fx(w,1)
for i=1:z
ft(i,1) = (fmax(w,1) - fmin(w,1)) - fx(w,1);
end
ftb = mean (ft);
for i=1:z
rl (i, 1) = ft (i, 1)/ftb;
end
end
```

Step 6 The best fit is calculated

Step 7 Selection based on the roulette wheel concept is done, the values providing the best fit being given a higher percentage on the wheel area so that values providing a better fit have higher probability of producing an offspring.

Step 8 Crossover is performed on strings using midpoint crossover. Crossover provides incorporation of extra characteristics in the off springs produced.

Step 9 Mutation is done if consecutive iteration values are the same

Step 10 The new reactance's that satisfy the objective of minimization of reactive power loss and the corresponding losses are tabulated.

To verify the effectiveness of the proposed approach, simulation is performed. Series capacitors were employed

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Vol. 2, Issue 3, March 2014

in the system which changes the effective reactance of the line. The effect of this compensation on the system was analyzed with the various values of degree of compensation and is presented in the following section.

IV. RESULTS OBSERVATION

This section gives the complete illustration about the performance evaluation of the proposed method. The values represented in the below table gives the voltage levels in the IEEE 13 bus lines with compensation and with out compensation.

IEEE-13 Bus system:
Line diagram:

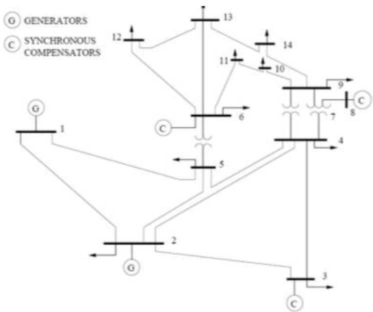

Figure 5: IEEE-13 Bus system line diagram

Figure illustrates the line diagram for a 13 Bus distributed network considered for simulation perspective. The generator, line and bus parameter used for the network is as outlined below.

Line parameters used of IEEE-13-Bus system:
Generator data parameter:

Generator bus no.	1	2	3	4	5
MVA	615	60	60	25	25
x_l (p.u.)	0.2396	0.00	0.00	0.134	0.134
r_a (p.u.)	0.00	0.0031	0.0031	0.0014	0.0041
x_d (p.u.)	0.8979	1.05	1.05	1.25	1.25
x'_d (p.u.)	0.2995	0.1850	0.1850	0.232	0.232
x''_d (p.u.)	0.23	0.13	0.13	0.12	0.12
T'_{do}	7.4	6.1	6.1	4.75	4.75
T''_{do}	0.03	0.04	0.04	0.06	0.06
x_q (p.u.)	0.646	0.98	0.98	1.22	1.22
x'_q (p.u.)	0.646	0.36	0.36	0.715	0.715
x''_q (p.u.)	0.4	0.13	0.13	0.12	0.12
T'_{qo}	0.00	0.3	0.3	1.5	1.5
T''_{qo}	0.033	0.099	0.099	0.21	0.21
H	5.148	6.54	6.54	5.06	5.06
D	2	2	2	2	2

Bus data parameter:

Bus No.	P Generated (p.u.)	Q Generated (p.u.)	P Load (p.u.)	Q Load (p.u.)	Bus Type*	Q Generated max.(p.u.)	Q Generated min.(p.u.)
1	2.32	0.00	0.00	0.00	2	10.0	-10.0
2	0.4	-0.424	0.2170	0.1270	1	0.5	-0.4
3	0.00	0.00	0.9420	0.1900	2	0.4	0.00
4	0.00	0.00	0.4780	0.00	3	0.00	0.00
5	0.00	0.00	0.0760	0.0160	3	0.00	0.00
6	0.00	0.00	0.1120	0.0750	2	0.24	-0.06
7	0.00	0.00	0.00	0.00	3	0.00	0.00
8	0.00	0.00	0.00	0.00	2	0.24	-0.06
9	0.00	0.00	0.2950	0.1660	3	0.00	0.00
10	0.00	0.00	0.0900	0.0580	3	0.00	0.00
11	0.00	0.00	0.0350	0.0180	3	0.00	0.00
12	0.00	0.00	0.0610	0.0160	3	0.00	0.00
13	0.00	0.00	0.1350	0.0580	3	0.00	0.00
14	0.00	0.00	0.1490	0.0500	3	0.00	0.00

Line Data parameter:

From Bus	To Bus	Resistance (p.u.)	Reactance (p.u)	Line charging (p.u.)	tap ratio
1	2	0.01938	0.05917	0.0528	1
1	5	0.05403	0.22304	0.0492	1
2	3	0.04699	0.19797	0.0438	1
2	4	0.05811	0.17632	0.0374	1
2	5	0.05695	0.17388	0.034	1
3	4	0.06701	0.17103	0.0346	1
4	5	0.01335	0.04211	0.0128	1
4	7	0.00	0.20912	0.00	0.978
4	9	0.00	0.55618	0.00	0.969
5	6	0.00	0.25202	0.00	0.932
6	11	0.09498	0.1989	0.00	1
6	12	0.12291	0.25581	0.00	1
6	13	0.06615	0.13027	0.00	1
7	8	0.00	0.17615	0.00	1
7	9	0.00	0.11001	0.00	1
9	10	0.03181	0.08450	0.00	1
9	14	0.12711	0.27038	0.00	1
10	11	0.08205	0.19207	0.00	1
12	13	0.22092	0.19988	0.00	1
13	14	0.17093	0.34802	0.00	1

A load flow analysis is carried out using Newton raphson method on the 13 Bus systems and the Reactive power loss on the transmission line is computed. The analysis is carried out with the placement of controlling device on bus 1-2, 1-5 and 2-3 lines. The reactive power loss is observed to be reduced in case of WNC-UPFC as compared to conventional approach.

Table I: Observed reactive power loss for developed model

From-Bus	To-Bus	RPL (GA)	RPL(SO)	RPL(Hybrid model)	Xl	Xc	% compensation
1.0000	2.0000	12.9630	5.7350	4.8280	0.0592	0.0292	49.2986
1.0000	5.0000	11.6430	7.1320	6.7740	0.2230	0.1092	48.9778
2.0000	3.0000	9.5990	6.8760	6.6640	0.1980	0.0638	32.2120
2.0000	4.0000	5.0870	3.7500	2.7500	0.1763	0.0550	31.2046
2.0000	5.0000	2.8210	2.1810	1.1810	0.1739	0.0439	25.2358
3.0000	4.0000	0.9630	0.1910	0.1910	0.1710	0.0414	24.2238
4.0000	5.0000	1.4940	1.4470	1.4170	0.0421	0.0089	21.1589
4.0000	7.0000	1.6310	1.5830	1.6520	0.2091	0.0420	20.0937
4.0000	9.0000	1.2770	1.2560	1.2281	0.5562	0.1108	19.9180
5.0000	6.0000	5.1520	5.2470	5.2470	0.2520	0.0497	19.7286
6.0000	11.0000	0.2650	0.2690	0.2690	0.1989	0.0382	19.2056
6.0000	12.0000	0.1670	0.1670	0.1680	0.2558	0.0491	19.1978
6.0000	13.0000	0.4940	0.4860	0.4960	0.1303	0.0245	18.7841
7.0000	8.0000	1.1110	1.1460	1.1460	0.1762	0.0255	14.4479
7.0000	9.0000	0.9579	1.0730	1.0500	0.1100	0.0155	14.0987

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9.0000	10.0000	0.0159	0.0280	0.0200	0.0845	0.0113	13.3728
9.0000	14.0000	0.1906	0.2140	0.2020	0.2704	0.0354	13.0853
10.0000	11.0000	0.1181	0.1340	0.1330	0.1921	0.0037	1.9108
12.0000	13.0000	0.0099	0.0100	0.0100	0.1999	0.0036	1.7911
13.0000	14.0000	0.2124	0.2220	0.2220	0.3480	0.0062	1.7873

The graphical representation for the proposed method in the regard of real power versus voltage is represented using below figure.

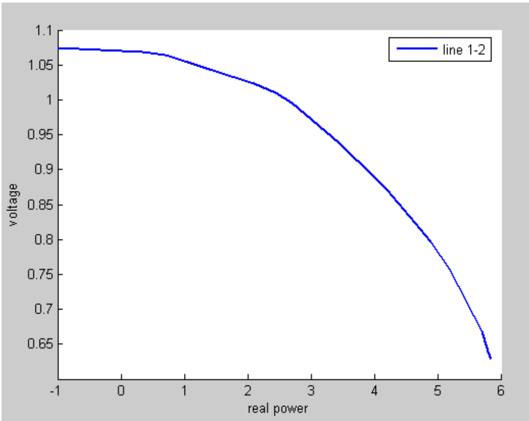

Fig 6: Real power versus voltage rating for the IEEE bus 1-2

Similarly the graphical representation for the proposed method in the regard of real power versus voltage is represented using below figure.

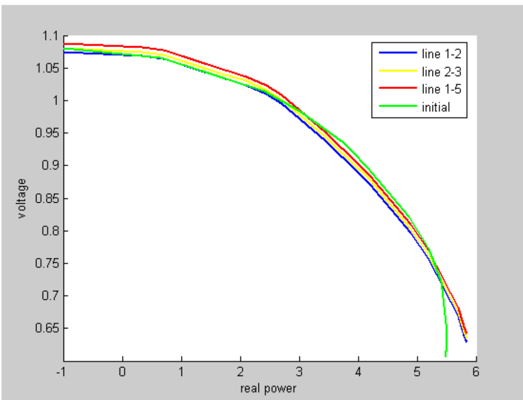

Fig 7: Real power versus voltage rating for the various lines in IEEE bus

V. CONCLUSION

In this paper the series reactive power loss minimization is achieved through the series compensation method. The exact location and the degree of compensation for the series capacitor to be installed in the transmission line were found out. The algorithm developed and the indicator dQloss/dKs shows the exact line for the employment of series capacitor. This reduces the effective reactance of the line and helps reduce the reactive power loss in turn providing high degree of stability to the system. Compensation in the form of series capacitors also increases the power transfer capability of the line.

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