COMPLEX NEURAL NETWORK APPROACH TO OPTIMAL LOCATION OF FACTS DEVICES FOR TRANSFER CAPABILITY ENHANCEMENT

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ABSTRACT

This paper concentrates on enhancement of total transfer capability incorporating FACTS devices. Repeated power flow program is used to determine the voltage constrained total transfer capability (TTC). The effect of change in reactance of the line on the transfer capability and reactive power loss is studied. In recent years Complex valued Artificial Neural Networks (ANNs) are becoming popular for solving problems involving complex data. As the transfer capability, real and reactive power loss depends on the line parameters a novel method for computing transfer capability and total real and reactive power loss is proposed in this paper using complex valued neural network.

Keywords: FACTS devices, TCSC, transfer capability enhancement, complex valued neural networks.

INTRODUCTION

Power system load growth is increasing at a faster rate as compared to the increase in transmission capability. In the last decade the increase in transmission capacity is approximately 50% of the increased generation capacity. The various reasons for the short fall are difficulty in getting right of way and permits due to property devaluation, electromagnetic field effects on health, impact on land use, ecological systems and construction and maintenance. The other important reason is lack of investors for the proposed transmission projects. All the above factors and the rapid growth of the load lead to congestion of lines. The performance of the system can be improved without rescheduling or topological changes by incorporating FACTS devices [1-2]. Several methods are proposed for this purpose. Wu G., Yokoyama A., He J., Yu Y., suggested the allocation and control of FACTS devices for stability improvement [3]. Preedavinchit P, Srivastava S.C., presented an approach for reactive power dispatch [4]. Optimal flow with FACTS devices is discussed in references [5, 6]. In reference [7] economic dispatch method is used for finding out the optimal location of FACTS device. As series compensation is most effective way of enhancing power transfer capability in this paper a method to determine the optimal location of Thyristor Controlled Series Capacitors (TCSC) using complex valued neural network is proposed. This approach is based on determining the actual line transfer capability (real and reactive flows) and total power loss (real and reactive power loss) by introducing TCSC in each line for a voltage constrained power system.

TRANSFER CAPABILITY, CONSTRAINTS

For planning and operation of a power system determination of transfer capability is very important. For a secured system transfers should not exceed the transfer capability limits. One of the most common approaches for transfer capability calculations is the continuation power flow (CPF) [8, 9].

Power transfer capability of a power system indicates that how much inter area power transfer can be increased without any security violations [10]. For a bulk power system exact computation of the transfer capability provides vital information for planning and secured operation.
The main constraints which limit the transfer capability are:

- Thermal related
- Voltage related and
- Operation related.

Thermal related constraints may cause overheating of conductor thereby decreasing its life span. The line sag also increases with temperature which may cause conductor to ground clearance violation and loss of mechanical strength.

Voltage related constraints cause the voltage dip or swell problems which may in turn cause insulation failure, interference with adjacent communication lines, inadequate operation and damage of equipment.

FACTS DEVICES

With the advent of flexible ac transmission system (FACTS) devices power utilities all over the world are able to improve the system stability limit, control the power flow, improve the transmission system security and provide strategic benefits for better utilization of the existing power system. The operation of FACTS devices is based on power electronic controllers. These devices are also used to enhance transfer capability and to minimize the total power loss of a system thereby improving the system efficiency. In a competitive electric power system the most important aspect is better utilization of existing lines in the context of growing demand and outgrowth of energy trading markets. In the context of restructuring the existing power systems FACTS devices have assumed an importance since they can expand the usage potential of transmission systems by controlling power flows in the network. FACTS devices are operated in a manner so as to ensure that the contractual requirements are fulfilled as far as possible by minimizing line congestion.

The concept of FACTS devices was first proposed by Hingorani [11]. The power system can be operated in a more secured, flexible and sophisticated way with the help of FACTS devices. In present deregulated environment the operation of power system need much more sophisticated means of power control which can be met by the incorporation of FACTS devices.

STATIC MODELING OF TCSC

Thyristor controlled series capacitors (TCSC) are connected in series with transmission lines. It is equivalent to a controllable reactance inserted in a line to compensate the effect of the line inductance. The net transfer reactance is reduced and leads to an increase in power transfer capability. The voltage profile as also improved due to the insertion of series capacitance in the line.

The transmission line model with a TCSC connected between the two buses i and j is shown in Figure-1. Equivalent pi model is used to represent the transmission line. TCSC can be considered as a static reactance of magnitude equivalent to *-jX*$_c$. The controllable reactance *Xc* is directly used as control variable to be implemented in power flow equation.

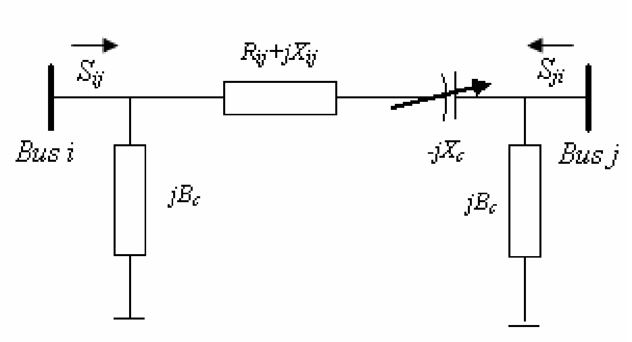

Figure-1. Transmission line model with TCSC.

The following equations are used to model TCSC.
Let the voltages at bus *i* and bus *j* are represented by $V_i\angle\delta_i$ and $V_j\angle\delta_j$
The complex power from bus *i* to *j* is

$$S^*_{ij} = P_{ij} - Q_{ij} = V_i^* I_{ij\,i} \tag{1}$$

$$= V_i^*\left[(V_i - V_j)Y_{ij} + V_i(jB_c)\right] \tag{2}$$

$$= V_i^*\left[[G_{ij} + j(B_{ij} + B_c)] - V_i^* V_j (G_{ij} + jB_{ij})\right] \tag{3}$$

Where

$$G_{ij} + jB_{ij} = 1\Big/(R_L + jX_L - jX_C) \tag{4}$$

From the above equations the real and reactive power equations can be written as

$$P_{ij} = V_i^2 G_{ij} - V_i V_j G_{ij}\cos(\delta_i - \delta_j)$$

$$- V_i V_j B_{ij}\sin(\delta_i - \delta_j) \tag{5}$$

$$Q_{ij} = -V_i^2 (B_{ij} + B_c) - V_i V_j G_{ij}\sin(\delta_i - \delta_j)$$

$$+ V_i V_j B_{ij}\cos(\delta_i - \delta_j) \tag{6}$$

Similarly the real and reactive powers from bus j to i can also be represented replacing V_i by V_j.
The real and reactive power losses in a line are represented by equations (7) and (8).

$$P_L = P_{ij} + P_{ji} \tag{7}$$

$$Q_L = Q_{ij} + Q_{ji} \tag{8}$$

LOCATION OF FACTS DEVICES

The objectives for device placement may be one of the following:

a) Reduction in the real power loss of a particular line
b) Reduction in the total system real power loss
c) Reduction in the total system reactive power loss
d) Maximum relief of congestion in the system

For the first three objectives, methods based on the sensitivity approach may be used. If the objective of FACTS device placement is to provide maximum relief of congestion, the devices may be placed in the most congested lines or, alternatively, in locations determined by trial-and-error.

COMPLEX VALUED NEURAL NETWORK

In recent years, complex-valued neural networks have widened the scope of application to the problems where the input and output are in complex form such as load flow analysis, contingency analysis. As inputs to CVNNs are in complex form generalization algorithms are modified to manipulate complex valued data. Complex back propagation algorithm can be applied to multilayered neural networks whose weights, threshold values, inputs and outputs all are complex numbers.

Complex version of back propagation (CVBP) algorithm made its first appearance when Widrow, Mc Cool and Ball [12] announced their complex least mean squares (LMS) algorithm. Hirose [13] studied the dynamics of CVNN which was later applied to the problem of reconstructing vectors. An extensive study of CVBP was reported by Nitta [14]. L. Chan, A.T.P. So and L.L. Lai [15] published the first paper on applications of complex artificial neural networks to load flow analysis. Complex valued neural network requires half the number of inputs used by the conventional real valued neural network. Furthermore the average learning speed of complex back propagation algorithm is several times faster than that of real valued back propagation.

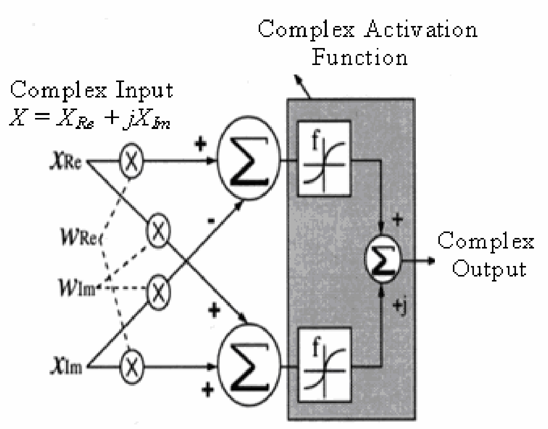

Figure-2. Complex valued neural network.

Internal potential of hidden neuron j:

$$u_j = \sum_{i=1}^{I} (w_{ji} x_i) + \theta_j = \mathrm{Re}[u_j] + i\,\mathrm{Im}[u_j] \qquad (9)$$

Output of hidden neuron j:

$$z_j = \phi(u_j) = \frac{1}{1+e^{-\mathrm{Re}[u_j]}} + i\frac{1}{1+e^{-\mathrm{Im}[u_j]}} = \mathrm{Re}[z_j] + i\,\mathrm{Im}[z_j] \qquad (10)$$

Internal potential of output neuron k:

$$s_k = \sum_{j=1}^{m} (v_{kj} z_j) + \gamma_k = \mathrm{Re}[s_k] + i\,\mathrm{Im}[s_k] \qquad (11)$$

Output of output neuron k:

$$o_k = \phi(s_k) = \frac{1}{1+e^{-\mathrm{Re}[s_k]}} + i\frac{1}{1+e^{-\mathrm{Im}[s_k]}} = \mathrm{Re}[y_k] + i\,\mathrm{Im}[y_k] \qquad (12)$$

Error

$$E_k = 0.5\sqrt{\sum_{k=1}^{l} (\mathrm{Re}[y_k] - \mathrm{Re}[d_k])^2 + (\mathrm{Im}[y_k] - \mathrm{Im}[d_k])^2} \qquad (13)$$

With the help of this error E_k we derive the gradient of E with respect to both the real and imaginary part of the complex weights of input layer and output layer $\partial E/\partial w$ and $\partial E/\partial v$ respectively.

During training the network cost function E is minimized by recursively altering the weight coefficient based on gradient descent algorithm, given by equation (15),

$$w_{ji}(p+1) = w_{ji}(p) + \Delta w_{ji}(p) = w_{ji}(p) - \eta \nabla_{w_{ji}} E_{p\left|w_{ji} - w_{ji(p)}\right|} \qquad (15)$$

Where 'p' is the number of iterations and 'η' is the learning rate constant.

RESULTS AND DISCUSSIONS

The proposed method is applied to a 14 bus system shown in Figure-3. It consists of 20 lines and 5 generators. Only 15 lines are considered for location of TCSC. The effect of TCSC in a particular line is considered as change in line reactance component. Voltage constrained total transfer capability and total power loss are obtained by repeated power flow method.

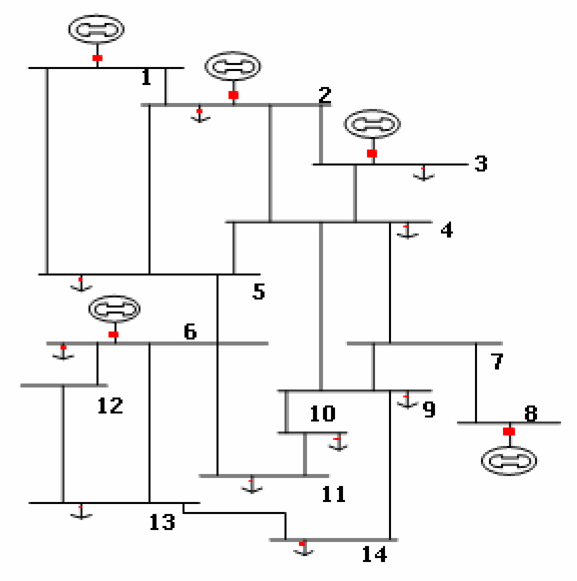

Figure-3. 14-Bus system.

Training patterns for the proposed complex valued neural network are obtained by varying the line reactance from 20% to 80 % in steps of random values and the effect on each line is studied. The network takes the line admittance in complex form as input; the outputs are line flow and total power loss in complex form. Complex back propagation algorithm is used to train the network. The number of iterations required is 5000 with an error of 0.01. The variation of error with respect to number of iterations is shown in Figure-4.

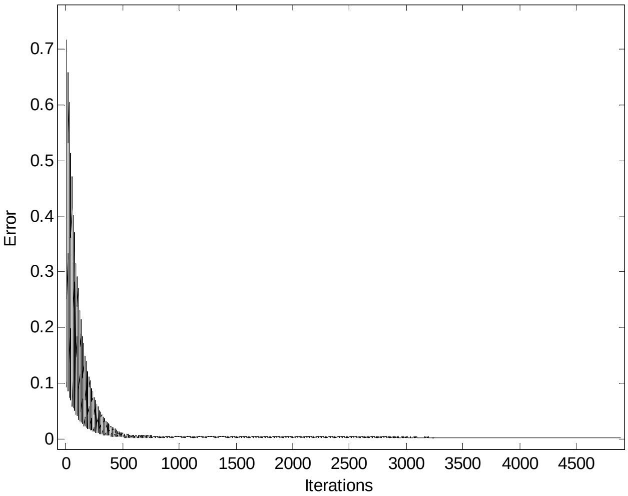

Figure-4. Variation of error with number of iterations.

Figure-5 represents the effect of controlling line reactance incorporating TCSC on total reactive power loss of the system.

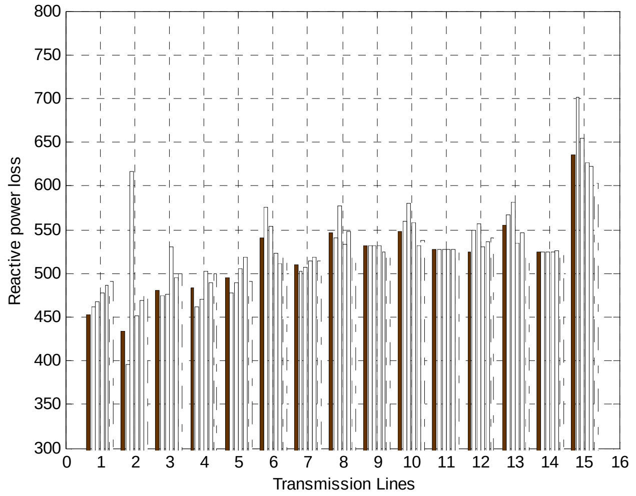

Figure-5. Reactive power loss with TCSC in each line.

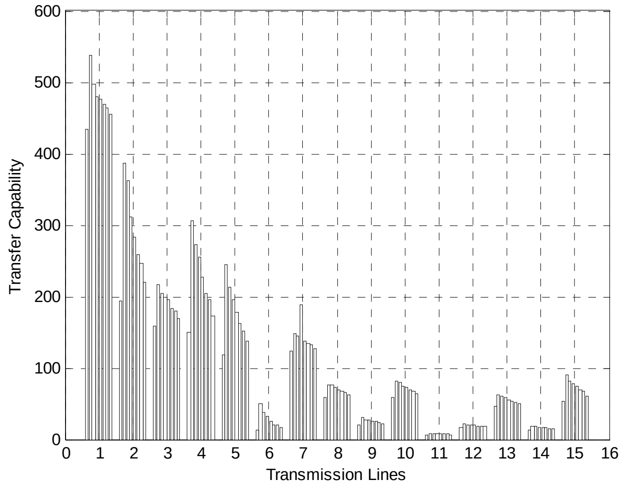

Figure-6. Transfer capability variations of each line.

The proposed network is tested for different values of line reactance incorporating the effect of TCSC as shown in Tables [1 to 4].

Table-1. Transfer capability of line 1-5 and total loss.

	Line 1-5 with 55% reactance	
	CVNN output (p.u)	**Desired output** (p.u)
Line flow	0.2654 + 0.0522i	0.2710 + 0.0600i
Total loss	0.1404 + 0.4839i	0.1397 + 0.4800i

Table-2. Transfer capability of line 2-3 and total loss.

	Line 2-3 with 70% reactance	
	CVNN output (p.u)	**Desired output** (p.u)
Line flow	0.1831 - 0.0739i	0.1790 - 0.0690i
Total loss	0.1410 + 0.4987i	0.1390 + 0.5030i

Table-3. Transfer capability of line 2-4 and total loss.

	Line 2-4 with 55% reactance	
	CVNN output (p.u)	**Desired output** (p.u)
Line flow	0.2120 + 0.0872i	0.2140 + 0.0900i
Total loss	0.1473 + 0.4910i	0.1430 + 0.4800i

Table-4. Transfer capability of line 2-5 and total loss.

	Line 2-5 with 55% reactance	
	CVNN output (p.u)	**Desired output** (p.u)
Line flow	0.1699 + 0.0733i	0.1700 + 0.0750i
Total loss	0.1454 + 0.5017i	0.1460 + 0.5120i

It is observed that there is a negligible change in reactive power loss at lines 9, 11 and 15. The minimum reactive power loss is 396 MVAR with 20% reactance on line 1-5 where as the base case reactive power loss is 528MVAR. The variation of transfer capability of the lines with change in reactance due to the incorporation of TCSC is shown in Figure-6. It is observed that the enhancement of transfer capability of lines 9, 11, 12 and 14 is very small. Considering the reactive power loss the optimal location of TCSC is in line 1-5.

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