Artificial Neural Network Application for Voltage Control and Power Flow control in Power Systems with UPFC

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Abstract— **Voltage control and stability are important aspects in the day to day operation of modern stressed power system networks. Unified power flow controller (UPFC) is an important FACTS device, which can simultaneously control the voltage at a bus and the active and reactive power flow through the transmission line to which it is connected. The variables of the UPFC must be controlled in accordance with system load conditions for stable operation of the power system. Artificial neural network (ANN) is an important tool which gives acceptable solution in real time. In this paper a back propagation feed forward artificial neural network is developed for evaluating the output variables of UPFC for different loading conditions of a 24 bus EHV Indian power system.**

Keywords*— *Back propagation neural network; Series voltage controller; Shunt voltage controller; Voltage stability.

I.INTRODUCTION

UPFC is an important FACTS device which can control the real and reactive power flow through a transmission line. It can also control the voltage at a bus by injecting reactive power of appropriate value. Unified power flow controller has two voltage source inverters coupled through a common DC link. These converters are connected to the system with intermediate coupling transformers. The schematic diagram of UPFC is shown in figure 1. One converter is inserted in series with the transmission line (VSC2) and the other converter is shunt connected to the bus (VSC1). In order to study the effect of UPFC on power system, it should be modeledt appropriately. One commonly used model is voltage source model [1], in which the UPFC is modeled as two voltage sources one connected in series and the other connected in shunt.

Artificial neural networks provide approximate but acceptable solutions using a network of simple processing units operating in parallel. In this paper a multilayer feed forward back propagation neural network is developed to find the output variables of series converter and shunt converter of the UPFC for different loading conditions of the power system.

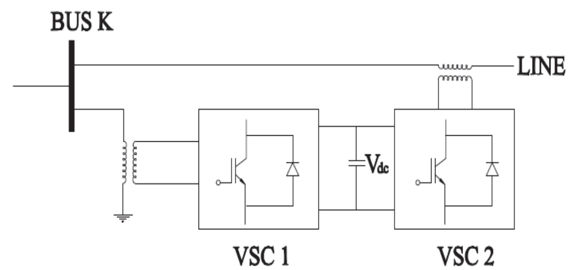

Fig.1 schematic diagram of UPFC

II. OPERATING PRINCIPLE AND MODELING OF UPFC

The two voltage source converters of the UPFC, connected through a D.C link can be modeled as two voltage sources, one connected in series and the other in shunt as shown in fig.2.The shunt converter of the UPFC is connected to bus k and the series converter is connected in series with the transmission line connected between bus k and bus m. The voltage magnitude of the series voltage source E_s and the angle of the series voltage source δ_s are controllable. The voltage angle δ_s can be varied between the limits 0 and 2π. The voltage magnitude (Es) can vary between its minimum and maximum limits. Similarly the voltage magnitude of the shunt voltage source E_p and the angle of the shunt voltage source δ_p are also controllable. The voltage angle δ_p can be varied between the limits 0 and 2π. The voltage magnitude E_p can vary between its lower and upper limits. The power flow in the transmission line k-m can be controlled by controlling the voltage and angle of the series voltage source. The magnitude of the bus k voltage

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can be controlled by controlling the output of the shunt source.

The presence of UPFC introduces four additional variables such as magnitude of shunt voltage source E_p, angle of shunt voltage source δ_p, magnitude of series voltage source E_s and angle of series voltage source δ_s, which are to be solved with other load flow variables. The power flow equations of other buses in the system are not affected by the presence of UPFC except for buses k and m.

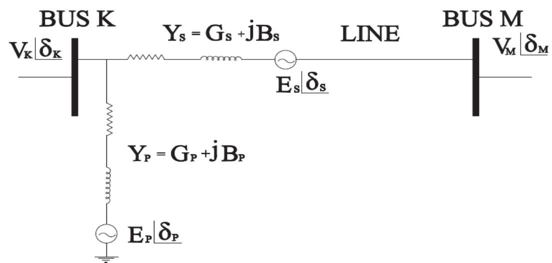

Fig.2 voltage source model of UPFC

The real and reactive power flow in the line k-m from bus k towards m can be expressed as

$$P_{km}=V_k^2(G_p+G_s)-|V_k||E_p||Y_p|\cos(\delta_k-\delta_p-\theta_p)+|V_k||E_s||Y_s|\cos(\delta_k-\delta_s-\theta_s)-|V_k||V_m||Y_s|\cos(\delta_k-\delta_m-\theta_s) \quad (1)$$

$$Q_{km}=-V_k^2(B_p+B_s)+|V_k||E_p||Y_p|\sin(\delta_k-\delta_p-\theta_p)+|V_k||E_s||Y_s|\sin(\delta_k-\delta_s-\theta_s)-|V_k||V_m||Y_s|\sin(\delta_k-\delta_m-\theta_s) \quad (2)$$

Assuming lossless converters the active power supplied to the shunt converter P_{sh} equals to the active power demand by the series converter P_{se}.

$$P_{sh}+P_{se}=0 \quad (3)$$

Where

$$P_{sh}=-G_p|E_p|^2+|V_k||E_p||Y_p|\cos(\delta_p-\delta_k-\theta_p) \quad (4)$$

$$P_{se}=G_s|E_s|^2+|E_s||V_k||Y_s|\cos(\delta_s-\delta_k-\theta_s)-|E_s||V_m||Y_s|\cos(\delta_s-\delta_m-\theta_s) \quad (5)$$

Where θ_s is angle of Y_s and θ_p is angle of Y_p

The shunt controller output is adjusted to maintain the voltage magnitude bus k. And the series controller output is adjusted to maintain specified amount of complex power flow in the transmission line connected between bus k and bus m. The three additional equations (1) (2) and (3) are linearized along with other static load flow equations corresponding to the remaining buses. The static power flow equations corresponding to the buses where UPFC is connected are also modified. These linearized equations are solved using Newton Raphson algorithm.

A 24 bus EHV Indian power system is considered for this work. The one line diagram of the 24 bus power system is shown is figure 3. For this 24 bus system load flow analysis is performed and voltage stability is evaluated using L-index [2], to find the location of UPFC. It is found that the maximum value of L-index is at bus 24, indicating that bus 24 is the weakest bus as for as voltage stability is concerned. Bus 13 is found to be the next weakest bus. So the shunt converter of UPFC is connected to bus 24 and the series converter of the UPFC is connected in the line between bus 24 and bus 13.

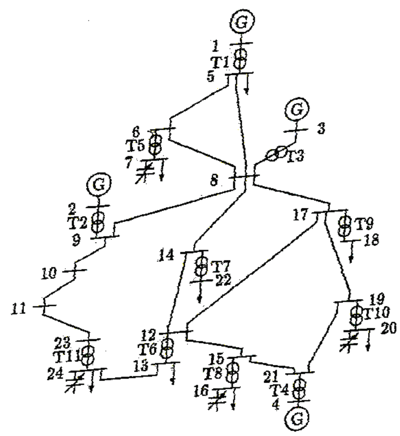

Fig.3 Single line diagram of 24 bus EHV System

III. ARTIFICIAL NEURAL NETWORK ARCHITECTURE

ANNs are composed of simple processing units operating in parallel. It is composed of a large number of interconnected processing elements called neurons that inter connected and tied together with weighted connections. A trained the back propagation neural network is able to provide accurate recommendations in short duration of time making it suitable for real time applications in Energy control centers.

Two back propagation neural networks (BPNN) are developed and trained, one BPNN for the shunt converter and the other for the series converter. The networks are developed using MATLAB neural network toolbox. The load multiplier, the voltage magnitude at bus 24, the active and reactive power flow in the transmission line connected between bus 24 and bus 13 are taken as inputs. The voltage magnitude of the shunt converter and the angle of the shunt converter voltage are considered as the outputs in one BPNN.

In the second BPNN the voltage magnitude of the series converter and the angle of series converter voltage are considered as outputs. The neural networks developed have an input layer with 4 nodes, an output layer with 2 nodes and 4 hidden layers.

A Data for training ANN

The training data is obtained for various values of load multiplier, the voltage of bus 24, and the power flow through line 24-13. The load multiplier (Lm) is varied from 0.9 pu to 1.05 pu. The bus voltage magnitude of bus 24 (V_{24}) is varied from 0.95 pu to 1.05 pu with a incremental step of 0.02 pu. The real power flow in the transmission line (Ps) is varied from 0.9 to 1.0 pu in steps of 0.05 pu. The reactive power flow (Qs) in the line is varied from 0.05 to 0.1 pu in steps of 0.01 pu. Load flow analysis is carried out for various combinations of these input vectors, to evaluate the series and shunt converter outputs. Levenberg-Marquardt training algorithm is used for training the neural networks. Table 1 shows the training data for load multiplier of 1.0 and the voltage of bus 24 as 1.01 pu.

Table 1: Training data for load multiplier of 1.0 and the voltage at bus 24 is 1.01 pu.

P	Q	Voltage (E_s)	Angle (δ_s)	Voltage (E_p)	Angle (δ_p)
0.9	0.05	0.2273	-116.7931	1.0133	-39.6030
	0.06	0.2273	-116.9905	1.0134	-39.6000
	0.07	0.2273	-117.1876	1.0135	-39.5971
	0.08	0.2273	-117.3844	1.0136	-39.5941
	0.09	0.2274	-117.5947	1.0137	-39.5909
	0.10	0.2274	-117.7894	1.0138	-39.5880
0.95	0.05	0.2419	-117.5577	1.0134	-40.2174
	0.06	0.2419	-117.7427	1.0135	-40.2143
	0.07	0.2419	-117.9413	1.0136	-40.2109
	0.08	0.2420	-118.1243	1.0137	-40.2079
	0.09	0.2420	-118.3070	1.0138	-40.2050
	0.10	0.2420	-118.4895	1.0139	-40.2020
1.00	0.05	0.2566	-118.2560	1.0134	-40.8359
	0.06	0.2566	-118.4425	1.0135	-40.8324
	0.07	0.2566	-118.6149	1.0136	-40.8293
	0.08	0.2567	-118.7870	1.0137	-40.8263
	0.09	0.2567	-118.9589	1.0138	-40.8232
	0.10	0.2567	-119.1380	1.0139	-40.8199

B. Validation of Back Propagation Neural networks

For the validation of the developed back propagation networks two different load conditions are presented. Table 2 shows the recommendations provided by back propagation neural networks and the conventional Newton Rapson method, for different input vector combinations.

Table 2:Validation of Back Propagation Neural Network

Input vector	Recommendation by BPNN	Recommendation by conventional NRLF method
L_m = 0.95 V_{24}= 1.00 P_s = 0.9 Q_s = 0.05	E_s = 0.2429 δ_s = -121.6733 E_p = 0.9988 δ_p = -37.0417	E_s = 0.2364 δ_s = -121.7176 E_p = 1.0041 δ_p = -36.86
L_m = 1.00 V_{24}= 1.00 P_s = 0.9 Q_s = 0.06	E_s = 0.2266 δ_s = -116.5683 E_p = 1.0126 δ_p = -39.6258	E_s = 0.2273 δ_s = -16.9905 E_p = 1.0136 δ_p = -39.600
L_m = 1.05 V_{24} = 0.99 P_s = 0.95 Q_s = 0.06	E_s = 0.2423 δ_s = -119.4846 E_p = 0.9941 δ_p = -43.8370	E_s = 0.2402 δ_s = -119.5660 E_p = 0.9949 δ_p = -43.9884
L_m = 0.95 V_{24} = 1.02 P_s = 0.92 Q_s = 0.10	E_s = 0.2373 δ_s = -118.6882 E_p = 1.0252 δ_p = -36.5948	E_s = 0.2364 δ_s = -117.9576 E_p = 1.0224 δ_p = -36.5739
L_m = 1.00 V_{24}= 0.96 P_s = 0.9 Q_s = 0.06	E_s = 0.2513 δ_s = -128.9900 E_p = 0.9612 δ_p = -41.0107	E_s = 0.2436 δ_s = -129.4913 E_p = 0.9622 δ_p = -41.0107

It can be seen from table 2 that the recommendations provided by conventional method (Newton Raphson load flow analysis) and the recommendations of BPNN are comparable. The maximum error value, in the magnitude of voltage of series converter is 0.0077 pu, when the load multiplier is 1.00, voltage magnitude of bus 24 is 0.96 pu and the value of complex power flow in the line connected between bus 13 and 24 is 0.9+j0.06 pu. The maximum error value in the voltage magnitude of shunt converter is 0.0053, when the load multiplier is 0.95, voltage to be maintained at bus 24 is 1.00 pu and the power flow in the transmission line connected between bus 13 and 24 is 0.9+j0.05 pu.

Fig 4.a to fig 4.d shows the recommendations of the developed back propagation neural network and the NRLF method, for different load factors, when the voltage magnitude of bus 24 is 0.98pu and the power flow in the transmission line connected between bus 13 and 24 is 0.95+j0.1 pu.

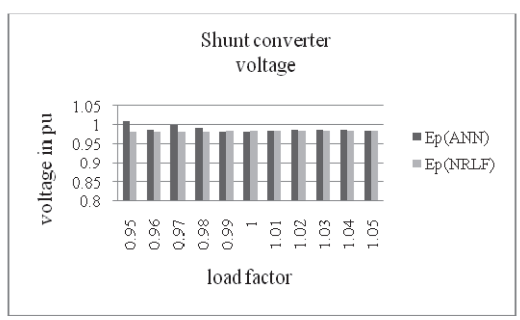

Fig 4.a Recommendations for shunt converter voltage

It can be observed from figure 4.a that the maximum error in the recommendation of shunt converter voltage by the developed back propagation neural network is 0.0271 pu when the load factor is 0.95. The recommendation of the shunt converter voltage by the developed back propagation neural network is same as the conventional NRLF method when the load factor is 1.05.

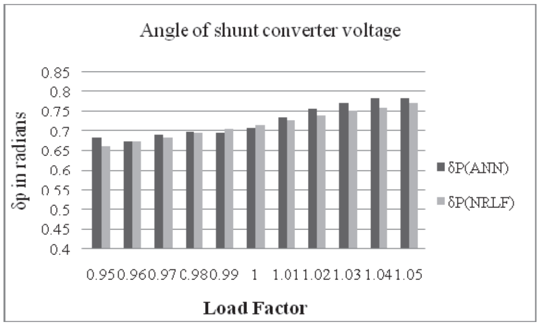

Fig 4.b Recommendations for angle of shunt converter voltage

It can be observed from figure 4.b that the maximum error in the recommendation of angle of shunt converter voltage by the developed back propagation neural network is 0.0217 radian when the load factor is 1.03. The minimum error in the recommendation of the angle of shunt converter voltage by the developed back propagation neural network is 0.0016 radian when the load factor is 0.98.

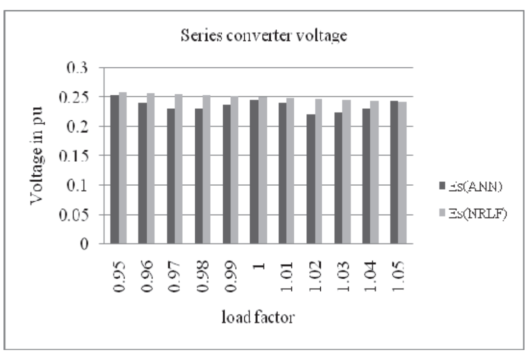

Fig 4.c Recommendations for series converter voltage

It can be observed from figure 4.c that the maximum error in the recommendation of series converter voltage by the developed back propagation neural network is 0.0267 pu when the load factor is 1.02. The minimum error recommendation of the series converter voltage by the developed back propagation neural network is 0.0017 pu when the load factor is 1.05.

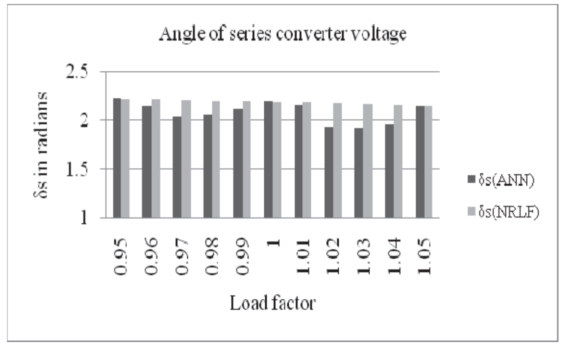

Fig 4.d Recommendations for angle of series converter voltage

It can be observed from figure 4.d that the maximum error in the recommendation of angle of series converter voltage by the developed back propagation neural network is 0.0247 radian when the load factor is 1.02. The minimum error recommendation of the angle of series converter voltage by the developed back propagation neural network is 0.0007 radian when the load factor is 1.05.

IV.CONCLUSION

A prototype back propagation ANN for evaluating the output variables of an UPFC have been developed. The recommendations of the ANNs shows acceptable solutions for a EHV Indian power system considered for analysis. Hence the Artificial neural networks developed can be used by operators of Energy control centers as a decision support aid tool, to decide the control settings of the UPFC under varying loading conditions.

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VIII. BIOGRAPHIES

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