Power System Voltage Control using LP and Artificial Neural Network

A. Sina, A. Aeenmehr, H. Mohamadian

***Abstract*—**Optimization and control of reactive power distribution in the power systems leads to the better operation of the reactive power resources. Reactive power control reduces considerably the power losses and effective loads and improves the power factor of the power systems. Another important reason of the reactive power control is improving the voltage profile of the power system. In this paper, voltage and reactive power control using Neural Network techniques have been applied to the 33 shines-Tehran Electric Company. In this suggested ANN, the voltages of PQ shines have been considered as the input of the ANN. Also, the generators voltages, tap transformers and shunt compensators have been considered as the output of ANN. Results of this techniques have been compared with the Linear Programming. Minimization of the transmission line power losses has been considered as the objective function of the linear programming technique. The comparison of the results of the ANN technique with the LP shows that the ANN technique improves the precision and reduces the computation time. ANN technique also has a simple structure and this causes to use the operator experience.

***Keywords*—**voltage control, linear programming, artificial neural network, power systems

I. Introduction

IN a stable power system, the total loads and the power losses should be equal with the generated power. The variation of the reactive power will change the bus voltages. Thus keeping the voltage at a constant value is an important factor for the stability of the power system [6]. It is important to notice that load type and its variations are more major factors in the voltage and reactive power control. Three major methods are used to control the voltage in the power system.

1- Changing the set point of generator exciters.
2- Changing the tap of the transformers
3- Using the shunt compensators

In the first method, thermal limits of the generator windings are considered as a constraint to limit the generated and consumed reactive power of the generators.

A. Sina is membership ofDepartment of Electrical Engineering, Production Technology Research Institute branch of ACECR, Ahwaz, IRAN, (e-mail: Sina.Alireza@ gmail.com).

A. Aeenmehr, is membership of Department of Electrical Engineering, Production Technology Research Institute branch of ACECR, Ahwaz, IRAN, (e-mail: aaeinmehr@ gmail.com).

H. Mohammadianis membership of Department of Electrical Engineering, Production Technology Research Institute branch of ACECR, Ahwaz, IRAN, (e-mail: hm0918@ gmail.com).

Thus in the recent years, a lot of studies have been taken out for the modern reactive power and voltage control as a term for the improvement of the reliability and the stability in the power systems [2][3][12]. These methods have been introduced for solution of the reactive power and voltage control optimisation problem. To solve this problem, the mathematical optimisation methods have been used. Methods for reactive power and voltage control could be categorised into two major categories: methods based on the algorithmic methods and the methods based on the artificial intelligence. In this paper, the Linear Programming technique is selected as algorithmic method, and Artificial Neural Network technique is selected as an artificial intelligence method [1][11][13]. The data of the 33-shines of the Tehran Electric company have been used for the solution of the problem of the reactive power and voltage control by these two method and they have been compared with each other.

II. Linear Programming Method

Recently High speed, reliability and precision of the Linear Programming (LP), causes it to be used in the power system networks as a very effective and reliable method for the optimization problems. In this method, reactive power sources and transformer taps are as the control variables and bus voltages and the reactive power of the generators are as the related variables. Linear Programming problems are made using the sensitivity relations based on the Newton-Raphson power flows. The objective function is minimization of the power losses and improvement of the voltage profiles [9].

The relation between the control variables and the voltage buses are made using the load models and the transformer taps and Jacobean matrixes. This relation also define the relation between the variables and the reactive power connected to the busses

Minimize: $\Delta P_L = L^T \Delta V$

Subject to: $\Delta Q_{\min} \leq A.\Delta V \leq \Delta Q_{\max}$

ΔP_L : Variations of Transmission losses
L: Vector coefficients of objective function
ΔV : Vector variations of Shines Voltage
ΔQ : Vector variations of shines reactive power
A: Conditional functions Coefficients matrix

This method results in reduction of calculation time and memory space. Artificial Neural Networks extensively have been considered in the optimization problems [4][7].

David Rumelhart and James Mcland have revolutionized the ANN methods after the introduction of the Error Back Propagations based methods [7]. These methods are categorized as the dynamic methods processing on the experimental data, knowledge and the rules governing on their behavior, transform them to the network structure.

ANN with a parallel structure has a parallel and quick processing with the large data storage and non-linear mapping, as a great capability. After the network is trained by the initial cases, ANN could have a very good output for the practical inputs [7].

III. Case Study

In this paper, the case study is the 33-buses Tehran power company network. This network has 71 transmission lines, 13 generators (one as the reference and others as the PV buses) and 20 PQ buses.

The control variables are

a) bus voltages no. 1 to 13
b) reactive power sources at buses 4, 15 and 28
c) transformer taps of the lines 6-6, 7-9 and 4-8

Controlled variables are as following below

a) Voltages of shines numbers 1 to13
b) Reactive source of shines numbers 4, 15, and 28
c) Tap transformers of lines numbers 6-6, 9-7, 4-8

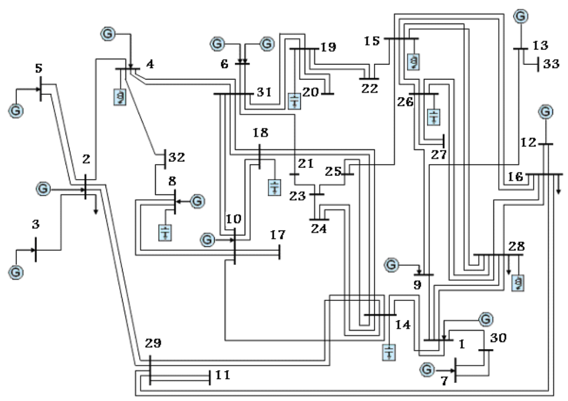

Fig. 1 Tehran power company network

A. Linear Programming Implementation

Bus 1 has been selected as the reference bus and buses 2, 3… m have been selected as the PV buses and buses m+1 …n have been selected as the PQ buses.

B. Equations and Constraints of Linear Programming Method

Equations and the constraints of the LP As it was mentioned in the section 2, system model and the objective function have been linearized using the elements of the Jacobean and the sensitivity Matrixes. The equations are as following:

$$\Delta P_L = \left[\underbrace{\frac{\partial P_L}{\partial V_1} \frac{\partial P_L}{\partial V_2} \cdots \frac{\partial P_L}{\partial V_m}}_{m} \underbrace{\frac{\partial P_L}{\partial Q_{m+x}}}_{nc} \underbrace{\frac{\partial P_L}{\partial t_{ij}}}_{nt} \right] \begin{bmatrix} \Delta V_1 \\ \Delta V_2 \\ . \\ . \\ . \\ \Delta V_m \\ \Delta Q_{m+x} \\ \Delta t_{ij} \end{bmatrix} : m \qquad (1)$$

In a practical system, there are some constraints on the control variables and the related variables.

$$\begin{aligned} &\Delta V_i^{\min} \langle \Delta V_i \langle \Delta V_i^{\max}, i = 1,2,\ldots m \\ &\Delta t_{ij}^{\min} \langle \Delta t_{ij} \langle \Delta t_{ij}^{\max} \\ &\Delta Q_{m+x}^{\min} \langle \Delta Q_{m+x} \langle \Delta Q_{m+x}^{\max} \\ &\Delta V_i^{\max} = V_i^{\max} - V_i, \Delta V_i^{\min} = V_i^{\min} - V \\ &\Delta t_{ij}^{\max} = t_{ij}^{\max} - t_{ij}, \Delta t_{ij}^{\min} = t_{ij}^{\min} - t_{ij\,i} \end{aligned} \qquad (2)$$

$$\begin{aligned} &\Delta Q_{m+x}^{\max} = Q_{m+x}^{\max} - Q_{m+x}, \Delta Q_{m+x}^{\min} = Q_{m+x}^{\min} - Q_{m+x} \\ &\Delta Q_{Gi}^{\min} \langle \Delta Q_{Gi} \langle \Delta Q_{Gi}^{\max}, i = 1,2,\ldots,m \\ &\Delta V_j^{\min} \langle \Delta V_j \langle \Delta V_j^{\max}, j = m+1,\ldots,n \\ &\Delta Q_{Gi}^{\max} = Q_{Gi}^{\max} - Q_{Gi}, \Delta Q_{Gi}^{\min} = Q_{Gi}^{\min} - Q_{Gi} \\ &\Delta V_{Lj}^{\min} = V_{Lj}^{\max} - V_{Lj}, \Delta V_{Lj}^{\min} = V_{Lj}^{\min} - V_{Lj} \end{aligned} \qquad (3)$$

Finally the LP problem for the controlling of the reactive power and the voltage are as following.

C. Objective Function

The objective is to minimize the power losses by some control variables, tap transformers and the reactive power sources. Equations and the constraints have been discussed in the section 2 and 2.1.4.

Minimize:

$$\Delta P_L = \left[\frac{\partial P_L}{\partial V_1} \cdots \frac{\partial P_L}{\partial V_m} \frac{\partial P_L}{\partial Q_{m+x}} \frac{\partial P_L}{\partial t_{ij}} \right] \begin{bmatrix} \Delta V_1 \\ \Delta V_2 \\ . \\ . \\ . \\ \Delta V_m \\ \Delta Q_{m+x} \\ \Delta t_{ij} \end{bmatrix} \tag{4}$$

Subject to:

$$\begin{bmatrix} \Delta Q_1^{\min} \\ . \\ \Delta Q_m^{\min} \\ \Delta V_{m+1}^{\min} \\ . \\ \Delta V_n^{\min} \\ \Delta V_i^{\min} \\ . \\ \Delta V_m^{\min} \\ \Delta Q_{m+x}^{\min} \\ \Delta t_{ij}^{\min} \end{bmatrix} \le \begin{bmatrix} S1 & S2 & S3 \\ . \\ . \\ . \\ . \\ .S4 & S5 & S6 \\ 1 \\ . & . \\ . & & . \\ . & & & . \\ . & & & & . \\ . & & & & & 1 \end{bmatrix} . \begin{bmatrix} \Delta V_1 \\ . \\ . \\ \Delta V_m \\ \Delta Q_{m+x} \\ \Delta t_{ij} \end{bmatrix} \le \begin{bmatrix} \Delta Q_1^{\max} \\ . \\ \Delta Q_m^{\max} \\ \Delta V_{m+1}^{\max} \\ . \\ \Delta V_n^{\max} \\ \Delta V_i^{\max} \\ . \\ \Delta V_m^{\max} \\ \Delta Q_{m+x}^{\max} \\ \Delta t_{ij}^{\max} \end{bmatrix}$$

D.Implementation of the ANN on Network

As it is seen in the Fig. 2, the ANN has three layers with 23 neurons in the input layer, 19 neurons in the output layer and 8 neurons in the middle layer.

Back Error Propagation methods have been used in the training technique. The output neurons are consisted of 13 neurons as the generators, 3 neurons for the transformers with a variable taps and 3 neurons as the reactive power sources. The number of input neurons are 23 as the same as the number of the PQ buses. The numbers of the middle neurons have been selected due to the different structures tested.

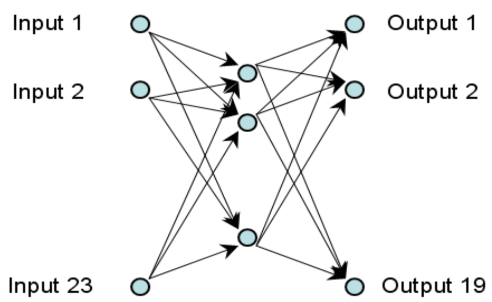

Fig. 2 Structure of ANN

In a real power system the operational conditions are changed with the loads. Therefore, in the training of the designed ANN, the load has been varied gradually from 0% to 120% with the step of the 20%. Also the coherent variation of the loads on the buses has been applied to the loads from 75% to 115% with the step of 10%. Then, the input and the outputs have been determined. Finally the best model has been selected for the ANN training.

Training inputs is normalized using the following relation [14]:

$$P_n = \frac{2(P - P_{\min})}{P_{\max} - P_{\min}} - 1 \tag{5}$$

The outputs are also normalized using this relation [14]:

$$T_n = \frac{T}{T_{\max}} \tag{6}$$

The results of LP and ANN methods are shown in the tables brought at last pages. Table 1 shows the results of the initial power flow.

IV. Results

The results of LP and ANN methods are shown in the tables brought in the appendix. Table I shows the results of the initial power flow

Table II has initial information of proposed system and includes kindness of shines, load value and voltage of each shine. In tables III, IV and V the results from LP and ANN are compared when the load of all PQ shines were reduced to 75%. Also, the results from LP and ANN are compared at l15 load and shown in tables VI, VII and VIII. These tables include, the load value of shine in percent, initial voltage before and after optimization, final voltage after optimization with two proposed methods, tap transformers values between shines (4,8), (4,9), (6,5), reactive power source value in shines 4, 15 , 28, system losses value, produced active power value of shine 1, produced reactive power value of shine 1 to 13 in three situations before optimization, after optimization by LP method and after implementation of ANN.

V.Conclusion

In grid with 33 shines, the reduction of loads to 75% results in increase of voltages of shines 7, 11, 12, 13 illegally. In all cases, LP method causes to return of voltages in allowable limit. So proposed method is applicable for shines where have faulty limits.

The ANN method is almost defected in shine 7 but grid response are satisfied the constraints well in other situations. For load of 115%, when the shines have not faulty limits the implementation of proposed optimization methods, result in reduction of losses and improvement of voltage profile so that the voltages of buses 4 and 6 are reduced.

Therefore, the proposed methods have good performance for profile improvement and loss reduction in non- faulty limits.

TABLE I
INITIAL INFORMATION OF SYSTEM

Shine	Kindness of shine	Production MW	Production Mvar	Load MW	Load Mvar	Voltage (P.U)	Angle degree
1	Slack	518.84	10.4	0	0	1.030	0
2	PV	326.81	4.848	80	12.7	1.031	-4.9924
3	PV	402.54	2.739	60	1.9	1.00	-12.758
4	PV	592.05	2.29	90	7.5	1.06	-14.241
5	PV	445.26	5.228	92	8.2	1.07	-13.229
6	PV	119.85	1.018	50	2.2	1.01	-8.561
7	PV	310.04	3.21	110	3.8	1.04	-11.542
8	PV	60.248	1.005	90	1.5	1.01	-13.132
9	PV	56.023	0.95	70	1.3	1.04	-7.054
10	PV	21.636	0.025	15	0.7	1.06	-13.256
11	PQ	----	----	60	4.7	1.0185	-10.227
12	PQ	----	----	110	15	1.0504	-13.229
13	PQ	----	----	70	5.7	1.0186	-8.7519
14	PQ	----	----	80	10.6	1.0401	-14.811
15	PQ	----	----	85	3.8	1.0325	-15.025
16	PQ	----	----	56	4.8	1.0502	-14.84
17	PQ	----	----	60	4.6	1.0517	-15.269
18	PQ	----	----	55	5.8	1.0429	-15.301
19	PQ	----	----	85	9	1.0270	-16.03
20	PQ	----	----	50	14	1.0201	-12.361
21	PQ	----	----	140	12	1.0541	-15.036
22	PQ	----	----	50	15	1.0586	-11.256
23	PQ	----	----	100	29	1.0242	-9.659
24	PQ	----	----	80	11	1.0541	-15.236
25	PQ	----	----	70	24	1.0579	-16.235
26	PQ	----	----	105	10	1.0600	-12.326
27	PQ	----	----	80	21	1.0305	-16.230
28	PQ	----	----	70	15	0.9850	-12.123
29	PQ	----	----	86	4.2	1.0159	-11.325
30	PQ	----	----	120	9.2	0.9895	-17.0
31	PQ	----	----	170	38	1.0500	-14.231
32	PQ	----	----	65	10.2	1.0179	-16.025
33	PQ	----	----	152	36	1.0362	-18.369

TABLE II
INITIAL TAPS OF TRANSFORMERS

Transformer Tap	Transformer Tap	Transformer Tap	Reactive resource	Reactive losses
T56	T49	T48	T29	T17
0.978	0.969	0.932	0.965	0.986

TABLE III
SHINES VOLTAGES AT 75% LOAD

Shine	Kindness of shine	Load	Initial voltage	Final voltage (LP)	Final voltage (ANN)
1	Slack	----	1.05	1.0705	1.0684
2	PV	75	1.045	1.0429	1.0422
3	PV	75	1.01	1.0248	1.0295
4	PV	75	1.07	1.0578	1.0523
5	PV	75	1.09	1.0527	1.065
6	PV	75	1.03	1.0253	1.0282
7	PV	75	1.05	1.0456	1.0360
8	PV	75	1.01	1.0095	1.0112
9	PV	75	1.06	1.0706	1.0685
10	PV	75	1.07	1.0826	1.0896
11	PQ	75	1.0196	1.0282	1.0295
12	PQ	75	1.0566	1.0486	1.0502
13	PQ	75	1.0228	1.0341	1.0336
14	PQ	75	1.0438	1.0598	1.0489
15	PQ	75	1.0428	1.0456	1.0439
16	PQ	75	1.0536	1.0491	1.0455
17	PQ	75	1.0577	1.0468	1.0416
18	PQ	75	1.0529	1.0433	1.0384
19	PQ	75	1.0336	1.0328	1.0302
20	PQ	75	1.0263	1.0256	1.0226
21	PQ	75	1.0563	1.0653	1.0772
22	PQ	75	1.0627	1.0548	1.0394
23	PQ	75	1.0256	1.0403	1.0358
24	PQ	75	1.0620	1.0589	1.0750
25	PQ	75	1.0581	1.0429	1.0430
26	PQ	75	1.0621	1.0750	1.0556
27	PQ	75	1.0332	1.0115	1.0098
28	PQ	75	1.0012	1.0150	1.0356
29	PQ	75	1.0249	1.0506	1.0558
30	PQ	75	1.0094	1.0102	1.0230
31	PQ	75	1.0562	1.0551	1.486
32	PQ	75	1.0251	1.0220	1.0112
33	PQ	75	1.0419	1.0623	1.0426

TABLE IV
ACTIVE AND REACTIVE POWERS OF GENERATORS AT 75% LOAD

	T17	T29	T48	T49	T56
Value	0.986	0.965	0.932	0.969	0.978
LP	0.968	0.949	0.9821	0.9752	0.9861
ANN	0.941	0.956	0.9784	0.981	0.9932

TABLE V
SHINES VOLTAGES AT 15% LOAD

Shine	Kindness of shine	Load	Initial voltage	Final voltage (LP)	Final voltage (ANN)
1	Slack	----	1.030	1.0705	1.0826
2	PV	115	1.025	1.0429	1.0644
3	PV	115	0.95	1.0248	1.0337
4	PV	115	1.01	1.0578	1.057
5	PV	115	1.03	1.0527	1.069
6	PV	115	0.94	1.0025	1.0102
7	PV	115	1.00	1.0029	1.0031
8	PV	115	1.01	1.0059	1.0090
9	PV	115	1.01	1.0520	1.0430
10	PV	115	1.02	1.0471	1.0382
11	PQ	115	0.9900	1.0282	1.0314
12	PQ	115	1.0201	1.0486	1.0393
13	PQ	115	0.9856	1.0341	1.0354
14	PQ	115	1.0209	1.0498	1.0321
15	PQ	115	1.0025	1.0456	1.0278
16	PQ	115	1.0108	1.0491	1.0382
17	PQ	115	1.0230	1.0468	1.0389
18	PQ	115	1.0056	1.0433	1.0326
19	PQ	115	0.9859	1.0328	1.0101
20	PQ	115	1.0200	1.0011	1.0045
21	PQ	115	1.0216	1.0102	1.0456
22	PQ	115	1.0365	1.0625	1.0426
23	PQ	115	0.9895	1.0110	1.0210
24	PQ	115	1.0369	1.0528	1.0569
25	PQ	115	1.0319	1.0652	1.0702
26	PQ	115	1.0405	1.0320	1.0452
27	PQ	115	1.0305	1.0602	1.0721
28	PQ	115	0.9590	1.0210	1.0362
29	PQ	115	0.9856	0.9820	0.9952
30	PQ	115	0.9791	1.020	1.0300
31	PQ	115	1.0361	1.0426	1.0523
32	PQ	115	1.0015	1.0112	1.0210
33	PQ	115	1.0056	1.0230	1.0321

TABLE VI
TAPS OF TRANSFORMERS AT 115% LOAD

	T56	T49	T48	T29	T17
Value	0.978	0.969	0.932	0.965	0.986
LP	0.9861	0.9752	0.9821	0.9981	0.9885
ANN	1.0105	0.9974	0.9659	0.9865	0.9901

TABLE VII
THE COMPARISON OF EXECUTION TIMES

33 BUS	LP	ANN
	17.8sec	6.51sec

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