Applying Genetic Algorithm to Minimize Power Loss and Establish Voltage Control

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Abstract - In this paper, algorithm that was developed will be discussed for controlling the bus voltage action selection and reactive power of a generator in electrical power system. Genetic Algorithm (GA) with linear power flow equations was used to minimize the number of control actions and real power loss. Participating controls are selected and combined together. GA is used primarily to reduce the calculation time and it is apt for real time applications.
Keywords: Genetic algorithm (GA), reactive power, reactive power control, voltage control.

I. INTRODUCTION

Basically, in electrical systems, bus voltage and reactive power parameters must be maintained within certain specified limits and any deviations or aberrations from these limits can be corrected by using Secondary Voltage Control (SVC). Instead of performing SVC by manual control by the use of an operator, which increases the risk of reaching an emergency state, we go in for automatic control SVC. In case of a manually controlled SVC, the experience and performance of the operator is key to the life of the electrical power system. In this paper, we have discussed that the Reactive power of generator and bus voltage constraint violations are eliminated with control action selection without automatic SVC. An allowance of $\pm$5% of constraint violations is given and reaches unstable state if the violation exceeds the prescribed allowance of $\pm$5%. In that situation, proper control action is to be taken. Line load was removed automatically by under voltage protection. The above problems can be solved by using Genetic Algorithm (GA) because it deals with both discrete and continuous variables, and can also deal with a multitude of optimization objectives.

II. LITERATURE REVIEW AND SYSTEM MODELING

When the limits are violated, control action is required to correct this emergency state [1]. Many methods were developed in the past for control action selection. The main problem that occurs in those methods is that the calculations treat all variables are continuous. In such case the solution is to round off the variables to a near discrete value which results in inadequate solutions [2]. The solutions also require large number of actions. By the following energy balance equation in every node m of a electricity supply system, the theoretical background of bus voltage control and generator reactive power control problem will be presented.

$$A_{Pm} = P_{Gm} - P_{Lm} \qquad (1)$$

$$\sum_{j=1}^{n} E_m = E_j\left(G_{mj}\cos(\theta_j-\theta_m)-B_{mj}\sin(\theta_j-\theta_m)\right)$$

$$A_{Qm} = Q_{Gm} - Q_{Lm} \tag{2}$$

$$\sum_{j=1}^{n} E_m = E_j\left(G_{mj}\cos(\theta_j-\theta_m)-B_{mj}\sin(\theta_j-\theta_m)\right)$$

Where,

A_{Pm}, A_{Qm}- active and reactive power energy balance of bus m;

P_{Gm}, Q_{Gm},- generated active and reactive power at bus m;

P_{Lm}, Q_{Lm}- active and reactive power of load at bus m;

E_m, E_j- voltage amplitudes at buses m and j;

Gmj, Bmj- active and reactive parts of line admittance between buses m and j;

θ_m, θ_j - voltage phase angles at bus m and j;

n- Number of buses.

To o0btain the solution of power flow problem, the variables and constants mentioned above are classified as:

$\vec{l}$ *State variables* (reactive power of generator and voltage phase angle, load voltage amplitude and phase angle);

$\vec{x}$ *Control variables* (active power of generator and Voltage amplitude);

$\vec{y}$ *Disturbance variables* (active and reactive power of load);

$\vec{c}$ *Constants* (admittance of line and transformer ratio).

Vector f represents the energy balance equation for all the buses normally. A load flow solution is obtained when $\vec{f}(\vec{l},\vec{x},\vec{y},\vec{c}) = \vec{0}$, where $\vec{y}$ and $\vec{c}$ are constants. By adjusting voltages of generator, transformer ratio, and switching shunt devices, we can eliminate voltage constraint violations. The controlled quantities is shown to be the transformer ratio and switching shunt devices. Our aim is to find a proper combination of $(\vec{x},\vec{y},\vec{c})$ such that

$$\vec{f}(\vec{l},\vec{x},\vec{y},\vec{c}) = \vec{0}. \tag{3}$$

The variables like generator loads, bus voltage, controlled quantities, and line currents are together represented by $\vec{g}$ while enforcing the constraints $\vec{g}$.

$$\vec{g}(\vec{l},\vec{x},\vec{y},\vec{c}) \le \vec{g} \tag{4}$$

Optimize $\vec{h}(\vec{l},\vec{x},\vec{y},\vec{c})$ subject to

$$\vec{f}(\vec{l},\vec{x},\vec{y},\vec{c}) = \vec{0}$$
$$\vec{g}(\vec{l},\vec{x},\vec{y},\vec{c}) \le \vec{g} \tag{5}$$

III. SOLUTION METHODS

The first analytical method was 'Linear Programming' that was published. It is based on classic optimization methods. In this method, the power flow problem is presented as a linear approximation of system equations. It has an initial solution:

$$\Delta\vec{l} = S(\Delta\vec{x},\Delta\vec{y},\Delta\vec{c}) \tag{6}$$

Where, S represents the sensitivity matrix. It indicates the sensitivity of state variables to changes of controls. For n bus system, with t tap changing transformers, i generators and q VAr devices, the model can be written as,

$$\begin{bmatrix} \Delta Q_{G1} \\ \vdots \\ \Delta Q_{Gi} \\ \Delta E_{i+1} \\ \vdots \\ \Delta E_{n} \end{bmatrix} = \begin{bmatrix} S_1 & S_2 & S_3 \\ S_4 & S_5 & S_6 \end{bmatrix} \begin{bmatrix} \Delta E_1 \\ \vdots \\ \Delta E_i \\ --- \\ \Delta Tap_1 \\ \vdots \\ \Delta Tap_t \\ \Delta Q_{Z1} \\ \vdots \\ \Delta Q_{Zq} \end{bmatrix} \tag{7}$$

Optimal Power Flow (OPF) problem has played a role in some publications [10], [11]. But in OPF solution, control actions results in loss or cost optimization. Eliminating the constraint violations is the main aim of this paper. Through the use of pre-selection of control devices, minimization of the number of control actions are included in this paper [11], [12]. In this paper, we have improved the algorithm and results that are presented in the paper published [13].

IV. PROPOSED METHOD

The basic or the primary step is the proper selection of the control devices for improving the calculation time for GA,in case of corrective control problem. An algorithm is developed and is presented below which gives advantages and nuances of both the GA and liner system model.

(i) The sensitivity coefficients are calculated for each control devices.

(ii) First set of number of controls are selected that are involved in the upcoming calculation stage in order to reduce the constraint violations based on the ability of the control devices.

(iii) GA is used predominantly to identify the proper set of control action, .The remaining constraint violations and the number of controls used finds the fitness of a solution.

Where,

$\Delta E_1 \ldots \Delta E_i$ generator voltage amplitude changes; $\Delta Q_{G1},\ldots,\Delta Q_{Gi}$ generator reactive power changes; $\Delta E_{i+1},\ldots\Delta E_n$ load bus voltage amplitude changes; $\Delta Q_{L1},\ldots,\Delta Q_{Lq}$ reactive load changes;

$\Delta Tap_1,\ldots,\Delta Tap_t$ transformer taps changes;

$S_1 \ldots S_6$ sub matrices of sensitivity matrix S.

The restrictions that are there in Linear programming to solve the equation are (5):

1. Rounding off is essential because the obtained variables are continuous.
2. The calculation time and number of control actions are more. To optimize the output, there are many methods previously used in publications such as cost minimization of control action [4], the use of the number of controls, and time required for control actions to complete [4]. One or more control actions in a set are required to save cost and do way with constraint violations. Manual control actions require less number of control actions. Both discrete and continuous variables are included in mixed integer programming and applied to the problem, however, the calculation time is long in this method [5].

   Expert systems have been developed in recent years based on the supervisor's experience [6], [7], which does not optimize any objective function. GA does not require linearity and differentiability of the objective function. Hence GA is more effective in dealing with objectives and with discrete control devices. Many GA applications exist for the bus voltage and generator reactive power problem that can be used for planning and allocation of reactive power sources and also for voltage security.

   The above flowchart and algorithm proves that GA can deal with non-continuous objective function and discrete variables. The flowchart of GA in figure 1 shows the calculation scheme. It is a three step process:

- Sensitivity coefficients are found for the intital values of generator voltages and transformer ratio, which influences all the control devices on reactive power and load bus voltage.
- A quick or fast estimation of the improvement of bus voltage and reactive power of generator can be estimated by using the sensitivity coefficients. For each out of limit variable g_m, the amount by which the constraint violation $\hat{g}_m - g_m$ can be minimized was found. This makes to rank the controls based on the value of their effectiveness which decreases and make a selection of set of candidates $\vec{p}$ to eliminate constraint violation m. The most effective control for constraint violation is chosen from the ranking and is selected. This rule is applied to determine the set of controller candidates for each out of limit variable. There are cases where there are huge control violations. During these cases, the control that is effective in reducing constraint violation in b, will increase constraint violation in a ($b \neq a$). A new control violation might occur during few control actions. In these cases, the set of candidate controls for all violated constraint $\hat{g}_m > g_m$ is enlarged so that it removes twice the value of constraint violation $\hat{g}_m - g_m$.
- Genetic algorithm finds the control devices which are included in $\vec{p}$ are to be activated. In each generation this algorithm is created with man y sets of possible control actions $\Delta \vec{p}$ and their fitness is checked. Control actions are represented in terms of binary values and continuous variables are represented in terms of discrete values. The function of changes in power flow is the fitness of a set of controls. For each string which represent the set of control actions $\Delta \vec{p}$, the approximated resulting system state

$$\vec{l} = \overrightarrow{la} + s\Delta p \qquad (8)$$

And new constraint violations are

$$g(\overrightarrow{la} + S\overrightarrow{\Delta p}, \vec{pd} + \overrightarrow{\Delta p}) > \bar{g} \qquad (9)$$

In this equation, $\overrightarrow{la}$ and $\overrightarrow{po}$ are the previous values of state variables and control. The solution's fitness is given by,

$$f = M - r_1 \sum_{m=1}^{n} |gm - \bar{g}m|^2 - r_2 \sum_{j=1}^{m} P_j \qquad (10)$$

Where the number of violated constraints are represented by m = 1,…..,n and the set of controls included in $\vec{p}$ is represented by j= 1,…..,m. Also $P_j = 0$ for $\Delta p_j = 0$ and $P_j = 1$ for Δp_j 0.

M is chosen to be a large value so that we will get a positive value for the fitness function. In equation (10), the second and third terms indicate the penalty for violation and the penalty added to reduce number of controls respectively. Terms r_1 and r_2, are the weight factors which are constants. The value of r_1 is considered in such a way that it is large when compared to r_2, so that we can determine the control action set.

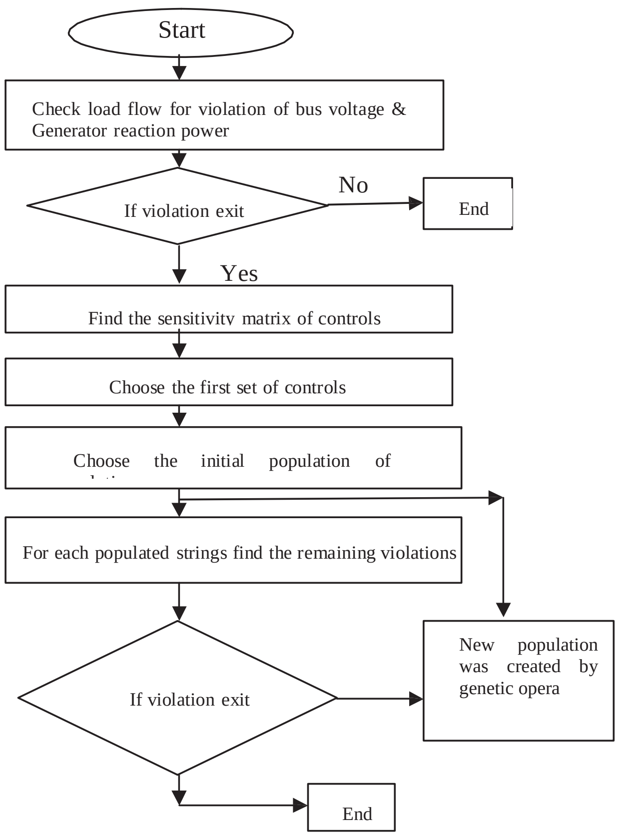

Figure 1. Flowchart of Genetic Algorithm

The constraint violations which were created by GA will be reduced to zero in the first generations if the control problem solution is noted. The algorithm can be stopped as the primary aim of the process is reached at this stage. The population solutions will be developed based on the last term of the fitness that represents the number of control used, and this process may be continued. Unacceptable changes of control variables are avoided by the constraints in GA. Random selection of initial population of solutions process takes place. As the proper selection of initial population increases, the efficiency increases along with it. To present the solution of one control action, a part of initial population is chosen and always solution with less number or minimized number of control actions are preferred.

V. CASE STUDIES FOR IEEE 30 BUS SYSTEM

Real time voltage control using Genetic Algorithm has been carried out for IEEE 30 bus system. Figure 5.2.1 shows the one-line diagram of IEEE 30 bus system. Bus data and Line data for IEEE 30 bus system is given in section 5.2.2 and 5.2.3. Algorithms are coded using MATLAB programming. Load flow studies are carried out for the system and real power loss before correction and after correction is found out. It is also seen that the number of control actions is also minimized. The bus voltage before correction and after correction is also carried out.

5.1 ONE LINE DIAGRAM OF IEEE 30 BUS SYSTEM

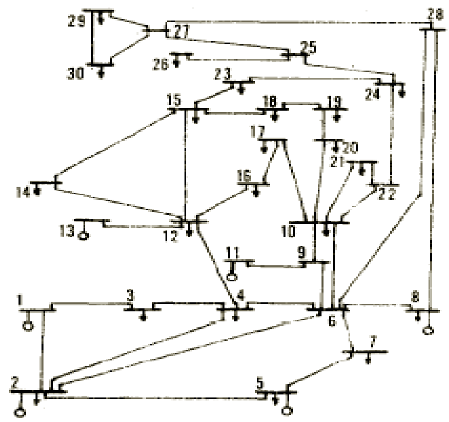

Figure 5.1: One-Line Diagram of IEEE 30 Bus System

5.2 BUS DATA

Figure 5.2.1 below displays the bus data for IEEE 30 bus system. Column 1 of Figure 5.2.1 outlines the bus number and column 2 contains the bus code. Columns 3 and 4 show the voltage magnitudes in p. u. and phase angle in degrees. Columns 5 and 6 outline the size of the active and reactive loads connected to the corresponding buses in MW and MVAr. Columns 7 through to 10 are MW, MVAr, minimum MVAr and maximum MVA of generation, in that order. The last column is the injected MVAr of capacitance into the system. The bus code entered in column 2 is used for identifying load, voltage-controlled, and slack buses as outlined below;

1 – This code is used for the slack bus.

0 – This code is used for load buses.

2 – This code is used for the voltage controlled buses.

				Load		Generator				Injected
Bus No.	Bus Code	Voltage Magnitude	Angle Degree	MW	MVAr	MW	MVAr	Q_{min}	Q_{max}	MVAr
1	1	1.050	0.0	0.0	0.0	0	0	0	0	0
2	2	1.034	-2.73	21.7	12.7	40	27.17	50	-40	0
3	0	1.031	-4.68	2.4	1.2	0	0	0	0	0
4	0	1.026	-5.61	7.6	1.6	0	0	0	0	0
5	2	1.005	-8.99	94.2	19.0	24.6	29.5	40	-40	0
6	0	1.021	-6.45	0.0	0.0	0	0	0	0	0
7	0	1.007	-08.02	22.8	10.9	0	0	0	0	0
8	2	1.023	-06.47	30.0	30.0	35.0	40	40	-10	0
9	0	1.033	-08.03	0.0	0.0	0	0	0	0	0
10	0	1.018	-09.92	5.8	2.0	0	0	0	0	0
11	2	1.082	-06.13	0.0	0.0	17.9	9.09	24	-6	0
12	0	1.040	-09.40	11.2	7.5	0	0	0	0	0
13	2	1.088	-08.21	0.0	0.0	16.9	7.3	24	-6	0
14	0	1.024	-10.31	6.2	1.6	0	0	0	0	0
15	0	1.018	-10.36	8.2	2.5	0	0	0	0	0
16	0	1.024	-09.90	3.5	1.8	0	0	0	0	0
17	0	1.014	-10.14	9.0	5.8	0	0	0	0	0
18	0	1.006	-10.92	3.2	0.9	0	0	0	0	0
19	0	1.012	-11.06	9.5	3.4	0	0	0	0	0
20	0	1.005	-10.83	2.2	0.7	0	0	0	0	0
21	0	1.006	-10.41	17.5	11.2	0	0	0	0	0
22	0	1.007	-10.39	0.0	0.0	0	0	0	0	0
23	0	1.005	-10.73	3.2	1.6	0	0	0	0	0
24	0	0.997	-10.85	8.7	6.7	0	0	0	0	0
25	0	1.008	-10.91	0.0	0.0	0	0	0	0	0
26	0	0.991	-11.33	3.5	2.3	0	0	0	0	0
27	0	1.025	-10.66	0.0	0.0	0	0	0	0	0
28	0	1.016	-06.87	0.0	0.0	0	0	0	0	0
29	0	1.005	-11.89	2.4	0.9	0	0	0	0	0
30	0	0.993	-12.77	10.6	1.9	0	0	0	0	0

Figure 5.2.1. IEEE 30 Bus Data

5.3 LINE DATA

Table 5.2.3 below displays the line data for IEEE 30 bus system. Columns 1 and 2 of Table 5.2.3 outline the corresponding line bus numbers. Columns 3 through to 5 contain the line resistance, reactance, and one-half of the total line charging susceptance in per unit on the MVA base of 100MVA. The last column details the transformer tap setting.

The bus and line data was structured in such a way so that the MATLAB load flow program could be used for the simulation.

Bus n_l	Bus n_r	R p.u	X p.u	½ B p.u	Line code or Tap setting
1	2	0.0192	0.0575	0.0528	1
1	3	0.0452	0.1652	0.0408	1
2	4	0.0570	0.1737	0.0368	1
3	4	0.0132	0.0379	0.0084	1
2	5	0.0472	0.1983	0.0418	1
2	6	0.0581	0.1763	0.0374	1
4	6	0.0119	0.0414	0.0090	1
5	7	0.0460	0.1160	0.0204	1
6	7	0.0267	0.0820	0.0170	1
6	8	0.0120	0.0420	0.0090	1
6	9	0.0	0.2080	0.0	0.978
6	10	0.0	0.1100	0.0	0.969
9	11	0.0	0.2560	0.0	1
9	10	0.0	0.1400	0.0	1
4	12	0.0	0.2559	0.0	0.932
12	13	0.0	0.1304	0.0	1
12	14	0.1231	0.1987	0.0	1
12	15	0.0662	0.1997	0.0	1
12	16	0.0945	0.1923	0.0	1
14	15	0.2210	0.2185	0.0	1
16	17	0.0524	0.1292	0.0	1
15	18	0.1073	0.0680	0.0	1
18	19	0.0639	0.2090	0.0	1

19	20	0.0340	0.0845	0.0	1
10	20	0.0936	0.0749	0.0	1
10	17	0.0324	0.1499	0.0	1
10	21	0.0348	0.0236	0.0	1
10	22	0.0727	0.2020	0.0	1
21	22	0.0116	0.1790	0.0	1
15	23	0.1000	0.2700	0.0	1
22	24	0.1150	0.3292	0.0	1
23	24	0.1320	0.3800	0.0	1
24	25	0.1885	0.2087	0.0	1
25	26	0.2544	0.3960	0.0	1
25	27	0.1093	0.4153	0.0	1
28	27	0.0	0.6027	0.0	0.968
27	29	0.2198	0.4533	0.0	1
27	30	0.3202	0.2200	0.0	1
29	30	0.2399	0.0599	0.0	1
8	28	0.0636	0.0428	0.0	1
6	28	0.0169	0.0130	0.0	1

Figure 5.3.1. Line Data for IEEE 30 Bus System

VI. RESULTS AND DISCUSSION

The stochastic nature of the GA is the reason behind the obtained results may slightly deviate or differ from the calculation runs. The following are the particular results of a single calculation run.
As it can be observed in the Fig. 5.6, the average fitness of the collection of the solutions has increased on a faster rate during the first generations, stipulating a reduction of the constraint violations. Fitness values shown here were adjusted and normalized, and a value of 13 presents or implies the theoretical case that constraint violations are imposed and the number of control actions is reduced to zero. The fitness of the best solution in the collection or population has increased considerably in a faster rate. There were 24 controls used in the solution, as shown in the Fig. 5.7. The further and the following generations has produced solutions with less control actions, and adequate solutions were found based on eighteen controls. The population size that was applied was 50. The strings that were initially present, 50 in number, we selected either to be a step up or step down controller of the devices. Mutation rate was 0.05 and Crossover rate was 0.800. It can be observed that all the final values of voltages were within the limits, approximately, 5% margin around nominal value (indicated by dashed line).

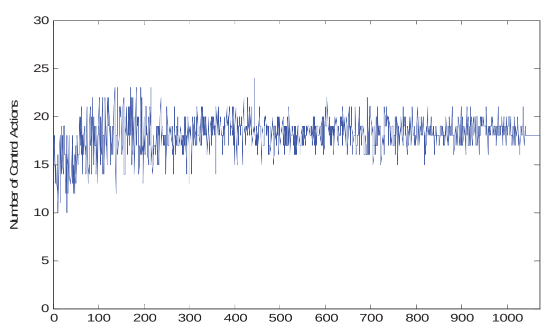

Figure 6.1. Number of Controls Used in Best Solution

The control actions were cross checked by using Newton-Raphson Load Flow algorithm. We observed not much of constraint violation and the results were consistent (0.95 and 1.05 p. u.). A minimal violation remained after application of the control actions. The reactive powers were also brought within boundaries (not depicted in graphs). Since no control devices exist at the extreme ends of the network (close to the initial low voltages), the effect of the control actions on buses with correct voltage in the center of the system is unavoidable but causes no new constraint violations.

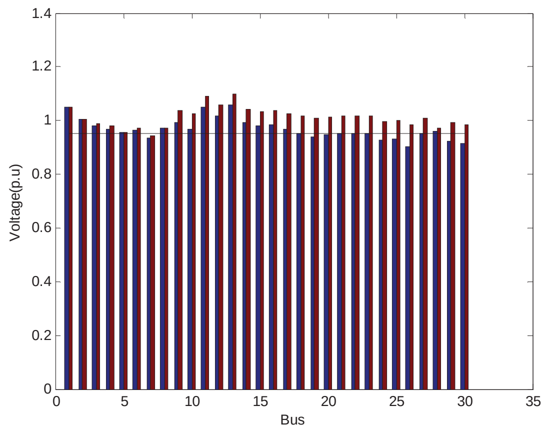

Figure 6.2. Bus Voltage Before and After Execution of Voltage Control Action

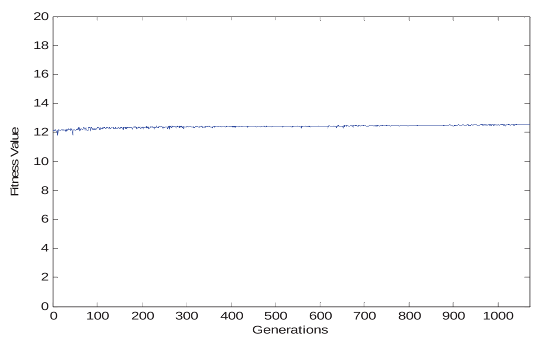

Figure 6.3. Average Fitness of Population of Solution

Bus	**Requirement of VAR Sources p. u**
1	0
2	0
3	0
4	0
5	0.400
6	0
7	0.0400
8	0
9	0.0600
10	0.0200
11	0
12	0
13	0
14	0.0100
15	0
16	0.0100
17	0.0400
18	0.0100
19	0.0300
20	0.0300
21	0.0800
22	0.0300
23	0.0300
24	0.0500
25	0
26	0.0300
27	0.0200

28	0
29	0.0100
30	0.0300

Figure 6.4. Requirement of VAR Sources in Each Bus

Real Power Loss Before Correction p.u	**Real Power Loss After Correction p.u**
0.494462	0.477842

Figure 6.5. Real Power Loss Before and After Correction

Bus	**Bus Voltage Before Correction p.u**	**Bus Voltage After Correction p.u**
1	1.0500	1.0500
2	1.0040	1.0040
3	0.9800	0.9891
4	0.9672	0.9785
5	0.9550	0.9550
6	0.9631	0.9735
7	0.9365	0.9550
8	0.9730	0.9730
9	0.9925	1.0374
10	0.9669	1.0259
11	1.0520	1.0920
12	1.0158	1.0596
13	1.0580	1.0980
14	0.9929	1.0438
15	0.9789	1.0337
16	0.9842	1.0374
17	0.9671	1.0268
18	0.9531	1.0171
19	0.9413	1.0094
20	0.9469	1.0142
21	0.9507	1.0171
22	0.9504	1.0171
23	0.9521	1.0180
24	0.9257	0.9978
25	0.9316	0.9993
26	0.9022	0.9839
27	0.9498	1.0073
28	0.9596	0.9730
29	0.9246	0.9920
30	0.9136	0.9861

Figure 6.6. Bus Voltages Before and After Correction

The results were documented for a single calculation run as aforementioned. To obtain the lowest possible number of control actions (eighteen controls used), which was computed within 25 s. According to the requirement of VAR source in each bus, the compensation will be carried by the capacitor as shown in the following table 6.1. Table 6.2 shows the real power loss before and after corrective control and table 6.3 shows the bus voltage before and after corrective action.

VII. CONCLUSION

The bus voltage was obtained within the constraints and limits. Consequently the proposed or presented genetic algorithm is highly capable of governing the near global solution. From the tables 6.2 and 6.3, it can be observed that genetic algorithm ultimately results in efficient voltage profile and appreciable reductions in power loss. From the figure 6.2, the enumerated number of control actions are reduced. Dependent on the requirement or the needs of VAR sources in each bus shown in the table 6.1, the system losses are minimized and ultimately results in sizable economic savings. As a result, the presented Genetic Algorithm for the capacitor placement evades local optima and meets the near global solution.

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