Enhancement of Voltage Profile in Power Systems by Using Genetic Algorithm

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***Abstract*— One of the main requirements of modern power system is the enhancement and control of voltage varying from its desired value. This paper presents and investigates suggested methods for improving voltage profile of in delta Egypt network to ensure voltage stability using optimum reactive power compensators (capacitor bank). The capacitor bank allocation is performed using Genetic Algorithm (GA) technique. The results are performed by comparing the system voltage profile considering four different scenarios. The first one (basic scenario) is that without using any reactive power support or voltage improving devices. The second scenario is by using transformer Automatic Tap Changer (ATC), while the third scenario is by using ATC in addition to installing a reactive power compensator device (capacitor bank) using trial method based on the experience of operators. Finally, the fourth scenario is performing the optimum location and size of reactive power compensator devices by using GA. The best results are achieved using the last scenario based on GA optimization procedures. The comparison is developed according to the improvement of voltage profile, power losses and active power reserve, which enable operating the system with high reliability, stability, and efficiency. The simulation and calculation of electrical network are carried out by (DIgSILENT power factory software) and (MATLAB – software) to investigate the voltage profile.**

Keywords*— Automatic Tap Changer, Genetic Algorithm, Reactive Power compensator, Voltage Improvement.

I. INTRODUCTION

The increase of inductive loads and power demand in electrical network absorbs more reactive power and increases power losses. Thus, generators and transmission lines are heavily loaded and approach their maximum limits. Voltage stability of a power system is directly affected by reactive power of the network. Power system must consider a voltage stability to ensure continuous operation, where voltage collapse was the common reason for power outage. So, enhancement of voltage profile leads power systems to be more efficient, economic, reliable and decreases power losses. Regarding voltage stability, the system will be stable if it can sustain all buses voltage with-in allowable limits after a disturbance [1]. On the other hand, voltage instability occurs when all voltages in a system drop out of permissible variation magnitudes where the system becomes unstable and the power to the load is disturbed, beside the possibility of voltage collapse occurrence [2].

The network performance must sustain stable voltage with magnitude variation levels with-in ± 10% of rated voltage at all buses [3].

The major causes of poor power system quality are: malfunctioning, under voltage, sag, unbalance and sudden power failure. The possibility of these problems increases with big strategic and industrial loads where there is insufficient reactive power support [4,5]. There are many suggested solutions available to eliminate this problem, enhance voltage profile and power system quality. The most common solutions are: ATC, reactive power supporting devices such as capacitor bank, Static VAR System (SVS).

I.Nassar investigated the voltage profile in Indian city called Hyderabad. Its network has a voltage level 220 kV, 132 kV, 33 kV and 11 kV, by using ATC and installing SVS by trial method to improve voltage profile [6,7].

Ramandeep Kamboj and Gagandeep Kaur studied the optimal value of the DG capacity to improve voltage profile on a standard IEEE-14 bus using voltage profile improvement index and C++ programming language [8].

Khaled M. Metweely, Gamal A. Morsy and Ragab A. Amer used Particle swarm optimization technique PSO. It is one of the artificial intelligent search approaches which used to solve such a problem. They used m-code in MATLAB software, to obtain optimum allocation and parameters of FACTS in IEEE 30-bussystem [9].

Siti Amely Jumaat, Ismail Musirin, Muhammad Murtadha Othman and Hazlie Mokhlis investigated the optimal sizing of static var compensator (SVC) based on PSO for minimization the losses of transmission considering the function of cost. The simulations results compared with those obtained from the Bee Algorithm (BA) technique in the attempt to highlight its merit. Validation through the implementation on the IEEE 26-bus system shows that the PSO is found feasible to achieve the task [10].

This paper investigates four scenarios to get the best voltage profile with minimum power losses in delta Egypt network which constructed and simulated by using DIgSILENT power factory and m-code in MATLAB software, using GA technique [11-15].

II. MODELING OF ELECTRICAL NETWORK

The sector of the Egyptian network in this study includes five power stations with the following data shown in table I, according to Egyptian Electricity Holding Company (EEHC) annual report [16].

TABLE I: POWER STATION DATA.

Power station tag name	Type	units	Rated (MW)	Actual (MW)
Talkha combined	Combined cycle	8×19.5+2×40	236	236
Talkha Extension 210	Gas turbine	2×210	420	420
Talkha combined 750	Combined cycle	2×250+1×250	750	750
Al-Mahmodia combined	Combined cycle	8×21+2×50	268	268
Damietta West	Gas turbine	4×125	500	500
New Damietta	Gas turbine	4×125	500	500
Damietta combined	Combined cycle	6×132+3×136	1200	1164

All these power stations are connected to the external grids that supply the delta Egypt network loads. The voltage levels in this study are as following: Generating units at specified voltage (11.5, 15 and 16.5 kV). Each one is connected to a step-up transformer to increase voltage to 220 kV level and then to step-down transformers 220/66 kV for network of transmission lines. The distribution network has voltage levels of 11, 6.6 and 0.4 kV, where all of them are established as shown in Fig. 1.

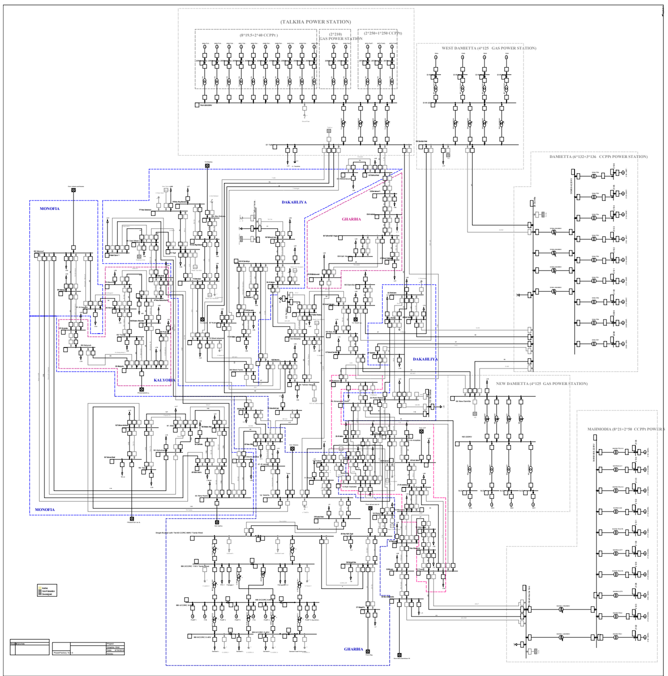

Fig. 1. A single line diagram of delta Egypt constructed.

III. CASE STUDY

A validation investigation is performed to compare the voltage profile and power losses in the system for the suggested four scenarios: scenario 1; normal operation (basic scenario) of power system, scenario 2; by using transformers ATC, scenario 3; applying a reactive power compensator device by using trial method with ATC, scenario 4; installing the optimum reactive power compensator device by using GA technique with ATC. The suggest scenarios perform to compare system power losses and voltage profile, where 22 buses selected and assumed to be satisfied to indicate the whole system voltage profile.

A. Scenario 1: normal power system operation

The network constructed in Fig. 1 and calculations of power flow to determine the bus voltage magnitudes are shown in table II and Fig. 2.

TABLE II: VOLTAGE MAGNITUDES IN PU FOR NORMAL OPERATION

Bus Name	Voltage, amplitude in (PU) at (normal operation)
Bus 2	0.9671741
Bus 3	0.9614755
Bus 4	0.952836
Bus 5	0.9358421
Bus 6	0.9143717
Bus 13	0.8669178
Bus 15	0.8832814
Bus 18	0.9520593
Bus 24	0.8487731
Bus 27	0.8814027
Bus 32	0.8627561
Bus 33	0.8511503
Bus 52	0.8619087
Bus 62	0.9171459
Bus 63	0.8694103
Bus 64	0.8702825
Bus 65	0.8856294
Bus 77	0.9458781
Bus 88	0.9299407
Bus 91	0.9556391
Bus 94	0.9638245
Bus 99	0.9585681

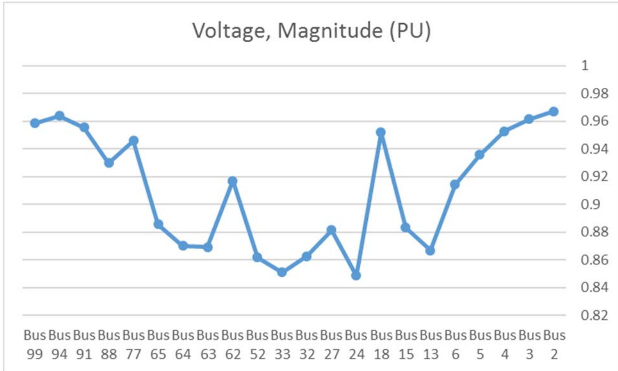

Fig. 2. Voltage amplitude in pu at (basic scenairo)

Regarding results of scenario 1 and the results in table II and Fig.2. Under-voltage condition is clearly notice, where the voltage amplitude at bus 24 is 0.8487731 pu. This value represents about 15% voltage drop at Bus 33, i.e. this value is out of allowable voltage limits, so the voltage profile should be enhanced.

B. Scenario 2: by using ATC

Tapping is a specific winding connection which can change an effective number of turns in tapped coil. The transformer turns ratio can be easily changed by varying tapping and, hence, regulate the voltages amplitude [17].

$$\frac{Vp}{Vs} = \frac{Np}{Ns} \quad (1)$$

Where Vp is the primary voltage, Vs is the secondary voltage, Np is the primary number of turns, Ns is the secondary number of turns [18].

Equation (1) shows that, the voltage magnitude can be controlled through changing the tapping factor at high voltage coil. Tap-changer device has many benefits, which can control the voltage magnitude of transformer easily. In addition, it is commonly existing and used in the distribution and power transformers, beside, at on-load tap changer type, a continuous power supply to load is providing without interruption, because the transformer is energizing during changing over between taps, until the required voltage magnitude achieved [17]. Installed distribution transformers data and parameters in the system are shown in table III.

TABLE III: TRANSFORMERS DATA

Quantity	Transformer voltage ratio	RatedMega VoltAmpere (MVA)	Vector group	Impedance voltage %
2	66/11 kV	12.5	Dyn 11	5
2	11/6.6 kV	4	Dyn 11	4.5
2	11/6.6 kV	2.5	Dd 0	5.3
2	6.6/0.4 kV	2	Dyn 11	5.8
2	6.6/0.4 kV	2	Dyn 11	6.6

Automatic tap changer (ATC) is provided with all transformers at high voltage coil with data shown in table IV.

TABLE IV: DATA OF TRANSFORMER TAP-CHANGER

Set point of voltage	1.0 pu
Bound of upper voltage	1.1 pu
Bound of lower voltage	0.9 pu
Tap position min. and max.	-10 and 10
Voltage additional per tap	1.0%
Time constant of controller	0.5 s

By using ATC of transformers, the calculations of power flow determine the voltages magnitude at all buses that are compared with scenario 1, as indicated in table V and Fig. 3.

TABLE V: VOLTAGE AMPLITUDE IN PU FOR NORMAL OPERATION AND WITH ATC

Bus Name	voltage amplitude in pu (normal operation) (scenario 1)	Voltageamplitudei npu(WithATC) (scenario2)
Bus 2	0.9671741	0.9717654
Bus 3	0.9614755	0.9660944
Bus 4	0.952836	0.9578038
Bus 5	0.9358421	0.9413379
Bus 6	0.9143717	0.9205597
Bus 13	0.8669178	0.875613
Bus 15	0.8832814	0.8917351
Bus 18	0.9520593	0.9595581
Bus 24	0.8487731	0.8605022
Bus 27	0.8814027	0.8973856
Bus 32	0.8627561	0.8710686
Bus 33	0.8511503	0.8596778
Bus 52	0.8619087	0.8702293
Bus 62	0.9171459	0.9211949
Bus 63	0.8694103	0.8744136
Bus 64	0.8702825	0.875373
Bus 65	0.8856294	0.8909697
Bus 77	0.9458781	0.9521657
Bus 88	0.9299407	0.9301118
Bus 91	0.9556391	0.9573873
Bus 94	0.9638245	0.966938
Bus 99	0.9585681	0.9589168

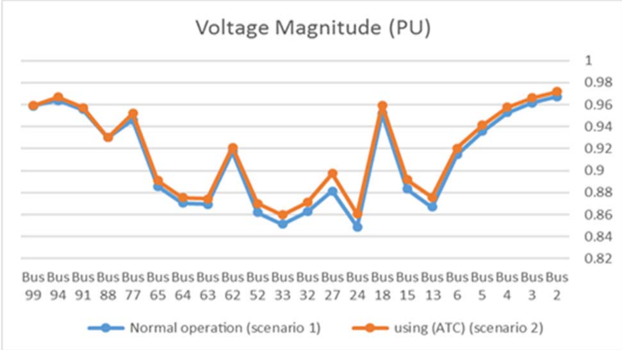

Fig. 3. Voltage amplitude in pu at normal operation and with ATC

Regarding results of scenario 2, the voltage profile with ATC has a little enhancement at all buses, but under-voltage condition still exists with the minimum recorded voltage amplitude of 0.8596778 pu. This represents about 14% voltage drop at Bus 33, i.e. this value is out of allowable voltage limits.

C. Scenario 3: applying a reactive power compensator

The most common reactive power compensator device is shunt capacitor banks that, have a direct impact on transmission and distribution networks regarding reactive power and voltage issues. To achieve these goals, the installation location and size of a capacitors are of a crucial importance. Reduction of power losses is one of the major benefits of capacitor banks, besides improving the power factor, system voltage profile and power quality. In addition, they increase available capacity of feeders, transmission lines and generating power reserve [19]. In this scenario a trial method is performed according to experience of operators. The location and sizing of installing shunt capacitor banks in the electrical network are performed according to procedures described in the following steps:

- First step: perform the power flow calculations.
- Second step: check all magnitudes of each bus voltage on the system. Then, select a minimum voltage magnitude buses in the system to inject a reactive power by installing a suitable shunt capacitor bank to improve a voltage profile.
- Third step: apply a suitable shunt capacitor bank to improve a voltage profile.
- Fourth step: perform the power flow calculation again and check all magnitudes of each bus voltage on the system to be at acceptable magnitude range. The third step is repeated again by resizing or replacing a suitable shunt capacitor bank, and so on until all bus voltage amplitudes are confirmed in acceptable limits.
- Finally: location and sizing for installing optimum reactive power compensation device (capacitors bank) by achieving the best voltage profile in the system, so the controlled reactive power impact directly on voltage profile. Fig.4 indicates the procedure flow chart of scenario 3.

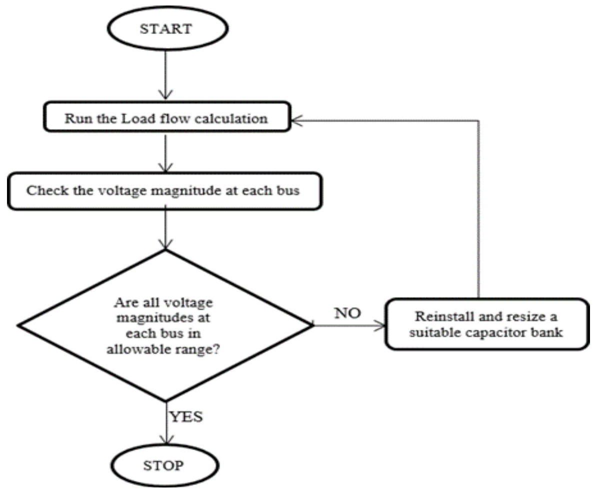

Fig.4. Scenario 3 procedure flow chart

The calculations of power flow identify voltage profiles of the system after installing a reactive power supporting devices (capacitors bank) with ATC and the comparison between all previous scenarios is clearly shown at table VI and Fig. 5.

TABLE VI: VOLTAGE MAGNITUDES IN PU FOR THREE SCENARIOS

Name	Voltage amplitude in pu (normal operation) (scenario 1)	Voltage amplitude in pu (with ATC) (scenario 2)	Voltage amplitude in pu trial method ATC + C (scenario 3)
Bus 2	0.9671741	0.9717654	0.993825
Bus 3	0.9614755	0.9660944	0.9882825
Bus 4	0.952836	0.9578038	0.9814877
Bus 5	0.9358421	0.9413379	0.9673157
Bus 6	0.9143717	0.9205597	0.9497329
Bus 13	0.8669178	0.875613	0.9196918
Bus 15	0.8832814	0.8917351	0.9274036
Bus 18	0.9520593	0.9595581	0.9785022
Bus 24	0.8487731	0.8605022	0.9176988
Bus 27	0.8814027	0.8973856	0.9276983
Bus 32	0.8627561	0.8710686	0.9126431
Bus 33	0.8511503	0.8596778	0.9025088
Bus 52	0.8619087	0.8702293	0.9118422
Bus 62	0.9171459	0.9211949	0.9498866
Bus 63	0.8694103	0.8744136	0.9262254
Bus 64	0.8702825	0.875373	0.9300131
Bus 65	0.8856294	0.8909697	0.9404744
Bus 77	0.9458781	0.9521657	0.9837536
Bus 88	0.9299407	0.9301118	0.9309587
Bus 91	0.9556391	0.9573873	0.9663332
Bus 94	0.9638245	0.966938	0.9828282
Bus 99	0.9585681	0.9589168	0.9607076

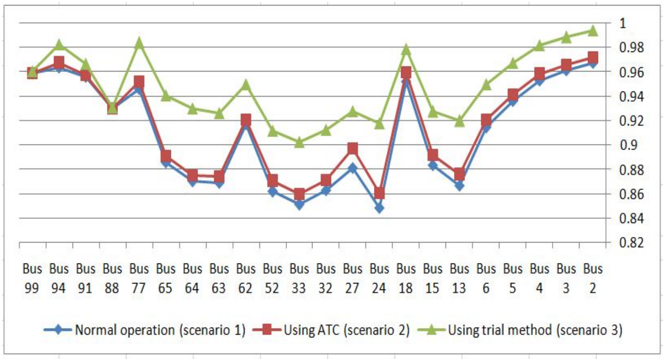

Fig. 5. Voltage amplitude in pu for (scenario1), after using ATC and capacitor bank (by using trial method)

According to the results of scenario 3, Fig. 5 and table VI show that all system voltage buses magnitudes are within the acceptable range and the voltage profile is completely enhanced. The voltage profiles are enhanced with scenario 3 than previous scenarios, where all bus voltage amplitudes are within acceptable limits. In this scenario, applying shunt reactive power supporting devices is performing by trial method, but it cannot ensure the optimal economics and it has low accuracy to predict the optimum size and location of the capacitor to achieve the objective of minimum power loss and enhancing voltage profile in the system. So, an optimization algorithm like GA will suggest in the next scenario, which can easily overcome all of these problems faced in trial method.

D. Scenario 4: by using GA technique

GA is a probabilistic intelligent search technique used to find approximate solutions to optimization problems. In this scenario this technique is implemented to define the optimum location and size of reactive power compensation device (capacitor bank) [20], the procedures flow chart is performed as shown in Fig.6 and the required parameters of the GA - based optimization process is defined as shown in table VII.

TABLE VII: THE GA-BASED OPTIMIZATION PROCESS PARAMETERS

Parameter	Value
Variables number	23
Individuals number per subpopulation	20
Gap of generation	0.8
Population size (total)	200
Generations number between migration	20
Subpopulations number	10
Crossover probability	0.9
Rate of migration between subpopulations	0.2
Mutation Probability	0.04
Rate of insertion	0.9
Maximum number of generations	100

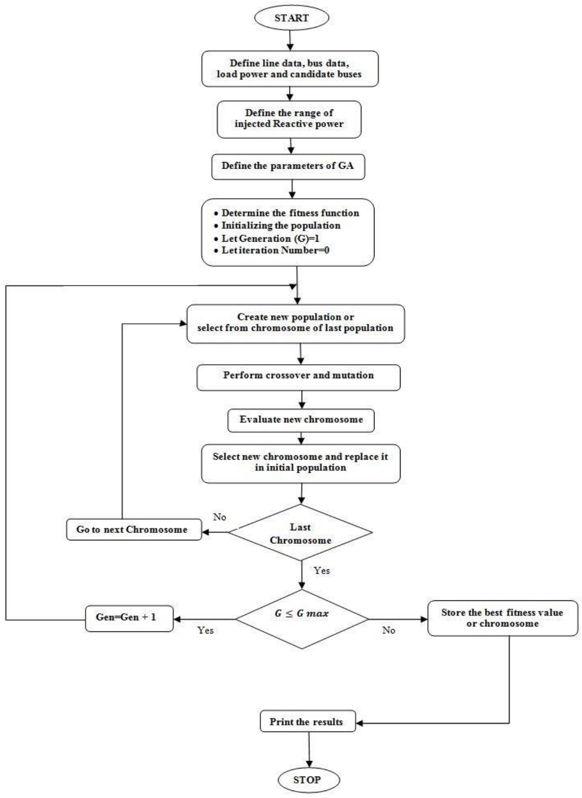

Fig. 6. The GA procedure flow chart

To start, candidate buses, available capacitor, number of all system buses, load data, bus data, and line data will be defined. GA is performed to get the best profile of the system voltage of delta Egypt network, where power loss and voltage deviation should be minimum. The main objective function is derived as shown by equations (2 - 4).

$$P_{Losses} = P_G - P_{Load} \quad (2)$$

$$\Delta V = |1 - V_i| \quad (3)$$

$$Objective\ function = \min\ (P_{Losses} + \Delta V) \quad (4)$$

where P_{Losses} is the active power losses, P_G is the active power generation, P_{Load} is the active power load, ΔV is the voltage deviation and V_i is the voltage magnitude in (pu) at each bus (i).

The initial candidate buses to be supported with optimum reactive power compensator devices are 12, 13, 14, 15, 24, 25, 26, 27, 30, 31, 32, 33, 52, 63, 64, 65, 68, 69, 70, 71, 95, 96 and 97 with a total number of 23 buses. After performing scenario 4 in delta Egypt network by using a GA optimization, the results are as shown in table VIII.

TABLE VIII: INJECTED REACTIVE POWER AFTER USING (GA)

Item	The initial candidate buses No	Q injected After using (GA)
1	Bus 12	0
2	Bus 13	2.2371
3	Bus 14	2.8880
4	Bus 15	1.5503
5	Bus 24	0
6	Bus 25	5.3710
7	Bus 26	1.7839
8	Bus 27	3.3346
9	Bus 30	0
10	Bus 31	0
11	Bus 32	2.9718
12	Bus 33	1.2686
13	Bus 52	5.1956
14	Bus 63	0
15	Bus 64	2.0369
16	Bus 65	1.4933
17	Bus 68	3.8993
18	Bus 69	1.9274
19	Bus 70	3.7477
20	Bus 71	3.9238
21	Bus 95	2.3350
22	Bus 96	2.0430
23	Bus 97	2.8572

The total injected reactive power in the network is 50.8645 Mvar, the best profile of system voltage was confirmed after performing scenario 4, where all bus voltage amplitudes are within acceptable limits as shown in Fig. 7 and table IX.

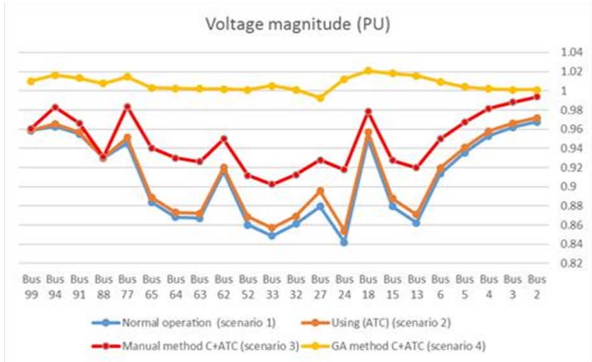

Fig. 7. Voltage amplitudes in pu for four scenarios.

TABLE IX: VOLTAGE AMPLITUDE IN PU FOR FOUR SCENARIOS

Name	Normal operation scenario1	With (ATC) (scenario 2)	trial method C+ATC (scenario 3)	GA method C+ATC (scenario 4)
Bus 2	0.9675508	0.9718316	0.993825	1.0011
Bus 3	0.9618544	0.9661609	0.9882825	1.0011
Bus 4	0.9530067	0.9576601	0.9814877	1.0022
Bus 5	0.9356651	0.9408454	0.9673157	1.0042
Bus 6	0.9134111	0.9193029	0.9497329	1.0094
Bus 13	0.8622445	0.8708629	0.9196918	1.0158
Bus 15	0.8792577	0.8876508	0.9274036	1.018
Bus 18	0.9494161	0.9568804	0.9785022	1.0208
Bus 24	0.8420353	0.8537476	0.9176988	1.0123
Bus 27	0.8793768	0.8953347	0.9276983	0.9927
Bus 32	0.8611954	0.8693134	0.9126431	1.001
Bus 33	0.8486351	0.8570016	0.9025088	1.0053
Bus 52	0.8603464	0.8684724	0.9118422	1.001
Bus 62	0.9159053	0.9198627	0.9498866	1.0017
Bus 63	0.8671959	0.87202	0.9262254	1.0023
Bus 64	0.8681325	0.8730296	0.9300131	1.0024
Bus 65	0.8838017	0.8888941	0.9404744	1.003
Bus 77	0.9452613	0.9512322	0.9837536	1.0147
Bus 88	0.929911	0.9300746	0.9309587	1.0078
Bus 91	0.9549566	0.9566371	0.9663332	1.0132
Bus 94	0.9625683	0.9655646	0.9828282	1.0163
Bus 99	0.9584362	0.9587711	0.9607076	1.0103

According to the results of scenario 4 at Fig.7 and table IX, the whole system voltage profile is completely enhanced with the minimum voltage drop (2.1%) by using GA technique, where the optimum size and location of reactive power supporting device is installed.

A comparison between active power loss, voltage deviations, active power generation reserve and reactive power injected in all scenarios are shown in table X.

TABLE X: COMPARISON BETWEEN ALL SCENARIOS

Scenario No.	P_{Losses} (MW)	ΔV (pu)	$P_{Reserve}$ (MW)	$Q_{Inj.}$ (Mvar)
Scenario (1)	802.55	0.15	672.57	0
Scenario (2)	790	0.14	685.1	0
Scenario (3)	740	0.097	734	87
Scenario (4)	122.3	0.021	1352.85	50.8645

where $P_{Reserve}$ is a reserve generation power that can be calculated as follows:

$$P_{Reserve} = P_{Capacity} - (P_{Load} + P_{Losses}) \quad (5)$$

where $P_{Capacity}$ is the total installed generation power capacity, P_{Load} is load active power, and P_{Losses} is active power loss. From all previous scenarios, it can be noticed that the reactive power compensation devices have a direct impact to improve the voltage profile, power factor, voltage quality, generation power reserve and reduce system power losses. On the other hand, if there is insufficient reactive power in the system (generated or externally injected), the system will face stability problems, specially due to voltage collapse.

IV. CONCLUSION

Four different scenarios performed to achieve the best voltage profile in delta Egypt network. First scenario performed power flow calculation without using any reactive power supporting devices, but under voltage case was notified at voltage level 66 kV, it was around (15%) beside the system had a high active power losses 802.55 MW (18%). and low reserve active power generation 672.57 MW from installed capacity 5082.75 MW which it is around (13%). So, the second scenario suggested by using ATC of transformer, in this scenario the voltage profile enhanced a little, but under voltage condition still exist, where it was around (14%), on the other hand the system had a relatively high active power losses 790 MW (17.9%), and the reserve active power generation is 685.1 MW (13.4%). The third scenario suggested to eliminate this problem, by applying a reactive power compensator device (capacitor bank) using trial method (as discussed before) with ATC, this solution enhanced the voltage profile in the network, where voltage deviation was around (9.7%), but this trail method consumed large reactive power injection 87 Mvar, beside low accuracy in bus selection to install a capacitor and its size. On the other hand, the system had a little high active power loss 740 MW (17%) and reserve active power generation 685.1 MW (13.5%), so the last suggested scenario performed by using a GA technique to define the optimum location and size of a reactive power compensator device. Initially candidate 23 buses are selected to be supported with (capacitor bank), by using GA technique the voltage profile is extremely enhanced with the least voltage drop (2.1%), power losses 122.3 MW with high active power reserve (26.6%), the results proved that this solution is the best one at all, by this way, the system operates with more stability, reliability and efficiency.

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