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Application of Genetic Algorithms in Voltage Profile Improvement and Loss Reduction in Interconnected Power Systems

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Abstract: **Voltage profile at different nodes in the power system is greatly affected by the variations in load and generation profiles during normal and abnormal operating conditions. Under-voltages adversely impact the system voltage stability margin and bulk power carrying capacity of transmission lines, which may lead to steady state or dynamic voltage collapse phenomena. On the other hand, over-voltages ultimately lead to equipment insulation failure. In order to avoid these situations, the power utility operator in the control center will have to re-dispatch the reactive power control devices. The reactive power control devices are generators, tap positions of on-load tap changer of transformers, and shunt capacitors and reactors that are used to correct voltage limits violations while simultaneously reducing the system real power losses. In this work, a genetic algorithm (GA) based approach to the optimization of reactive power, voltage profile improvement and real power loss is presented. GAs are well-known global search techniques anchored on the mechanisms of natural selection and genetics. The feasibility and effectiveness of the used algorithm is tested and verified on the IEEE 30 bus system for six different case studies.**

Keywords: **Genetic algorithm; hybrid intelligent system; voltage profile; loss reduction; topology evaluation; sensitivity factors.**

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1. INTRODUCTION

ONE of the important operating tasks of power utility operator is to maintain the voltage profile within specified limits for high quality of services at each consumer load point. The variations in load and generation profiles during normal and abnormal operating conditions of a power system may worsen the voltage profile at different nodes. This is so because sustained or intermittent over voltages ultimately lead to equipment insulation failure. On the other hand, under-voltages impact adversely on the system voltage stability margin and bulk power carrying capacity of transmission lines which, if left unchecked, can lead to steady state or dynamic voltage collapse phenomena. Consequently, the power utility operator in the control centre re-dispatch the reactive power control devices such as generators, tap positions of on-load tap changer of transformers, static shunt capacitors and shunt reactors result not only the voltage profiles are kept within the desired limits but also the power losses are reduced. Earlier, several techniques have been employed using sensitivity relationships and gradient search approaches to overcome this complex problem [1, 2]. These techniques give the approximate changes in bus voltages for a given control action. In these approaches, the bus voltage violations are alleviated one by one. So these methods can be used in small number of violations. In case of many violations, the method may run into an infinite number of iteration.To avoid these difficulties linear programming (LP) approach [3-6] has been proposed to yield the control actions. In most of these studies, the LP problem has been formulated using real valued control variables in order to reduce the computational effort. However these methods are complex and require significant computational effort to determine the required adjustments to control variables. Artificial intelligence (AI) methods have also been applied to control the reactive power and voltage to be within acceptable limits. The expert system (ES) techniques [7] are applied to identify the system operating conditions, detect the bus or buses at which certain constraints have been violated, and select the appropriate control actions to alleviate the voltage violations. Therefore, ES decides and gives proper signals to perform the control actions of the power system. References [8-10] presented fuzzy logic theory to optimal control of reactive power. Using fuzzy sets operators, the coefficient of the objective functions are calculated for each bus and membership functions are defined for bus voltages. The advantage of these techniques is to overcome the limit of bus voltage variations by adjusting one of the control devices. The line outage contingency create the under and over voltage condition in the system. The most critical bus was identified by the voltage difference from the base case and contingency case. The most effected bus has been selected as the point where MVAR has to be injected. ANN technique [11] was implemented for predicting the injected MVAR at critical bus. Reference [12] presented a review of computational intelligence techniques as applied in load shedding and discussed the relative merits and demerits of each against the others. Reference [13] presented the differential search algorithm for solving the reactive power planning. The technique designed to solve the problem of the non-feasibility solution of the fuel cost minimization problem where the IPM is applied, for a given operating point. The reactive power control devices such as generators, tap positions of on-load tap changer of transformers, shunt reactors were considered in this work. Genetic algorithms are stochastic search techniques based on the mechanism of natural selection and survival of the fittest. Also, they combine solution evaluation with randomized, structured exchange of information among solutions to obtain optimality. As a robust and powerful adaptive tool for solving search and optimization problems they have been proposed for various applications in the power systems [14]. Reference [17] presents a methodology to evaluate the impacts of distributed generator (DG) unit installations to reduce transmission loss and improve voltage profiles of power systems using quantum GA combined with Newton Raphson method. Reference [18] Reactive power/voltage control for unbalanced distribution system using genetic algorithms, optimal reactive power/voltage control for unbalanced distribution system using GA taking into account identical, as well as, different daily phase load patterns. Reference [19] presents implementation of GA to search the optimal location and sizing of static var compensator (SVC) to minimize real power loss, load bus voltage deviation and to reduce size of SVC. As a first step, contingency ranking has been performed to determine the most severe line outages by evaluating voltage performance index (VPI). Thereafter, GA has been applied to solve the mixed continuous-discrete optimization problem of SVC placement. Effectiveness of the proposed GA based method has been tested on IEEE 30-bus system.

In this work, a genetic algorithm (GA) based approach to the optimization of reactive power, voltage profile improvement and real power loss is presented. GAs are well-known global search techniques anchored on the mechanisms of natural selection and genetics. The reactive power control devices such as generators, tap positions of on-load tap changer of transformers, shunt reactors and capacitors are used to correct voltage limits violations while simultaneously reducing the system real power losses. The feasibility and effectiveness of the developed algorithm is tested and verified on the IEEE 30 bus system. Six different case studies are then considered and it is demonstrated that the GAs is an effective tool in removing the voltage problems and loss reduction

2. REACTIVE POWER OPTIMIZATION PROBLEM DEFINITION

The definition of reactive power optimization can be divided into four categories: network, controls, objectives, and constraints.

- ***Network:*** the model common in all functions that require a network definition. The optimal power flow must respect the physical constraints implied by the network definition. The primary network constraints are the bus real and reactive power mismatch equation, the same ones that the basic power flow solves.

- ***Objectives:*** the desirable solution attributes that are not specified as constraints. Many common objective functions, such as minimizing fuel cost, or finding a feasible solution with minimum control movements, can be expressed as cost function of the control. One common objective function, minimizing active power losses, cannot be directly expressed as cost function of the control. The job of the reactive power optimization is to optimize the objective function while meeting all constraints, if possible.

- ***Controls:*** the set of the power system controls (such as adjusting transformer tabs, changing generator voltages and switching reactive power compensators) that the reactive power optimization is allowed to move to meet constraints and optimize objectives.

- ***Constraints:*** the limits defined by operating procedure that keep the power system within a safe, sustainable operating region. These are the equipment operating and system security limits, such as bus voltage magnitude or line flow limits and so on. Useful by-products of solving the reactive power optimization are the sensitivities of enforcing each constraints, relative to the objective (cost) function. This gives the user information on how much it is costing to hold each of the constraints at its present value.

It is important that the user understands how to translate real world operation problems into reactive power optimization problem definitions, and how to interpret the reactive power optimization results. Defining the problem may require several iteration between definition and solution. As the user sees the results from one definition, it may be necessary to change that definition. For example if the reactive power optimization suggests unreasonable control recommendations due to inappropriate problem definition, it will be necessary to correct the problem definition and tray again [16]

3. TRADITIONAL OPTIMIZATION TECHNIQUES

Because reactive power optimization can be set up in so many different ways, this section will focus upon a few typical scenarios. To become familiar with how reactive power optimization functions, it is useful to look at typical power system problem definitions [10]. When the user specifies an empty set of controls, the optimization program effectively reduces to a power flow solution. This is a relatively inefficient way to run a power flow, but optimal power flow solves the bus mismatch equations and provides output similar to a power flow solution. Optimization program provides the same state solution, including bus voltage and branch flows, as the standard power flow.

- Also optimization program may be set up to run a constrained economic dispatch of the generation. For example, given the generation cost data, the network model and the load profile, the optimal power flow can be run to give a power flow solution with an economic generation profile. The optimization program can determine the lowest cost solution that does not cause network security problems.

- Optimization program can be used to minimize real power loss through reactive power dispatch. In this case, only reactive controls (e.g. transformer tap positions, shunt capacitors and reactors, and MVAR output of generating units) are used to minimize losses on the entire network, or on a subset of the network.

- Using a “minimum of control movements” from the starting point, the optimal power flow can be used to find a feasible solution (or determine if one exists). In this case the objective is to minimize the cost function based on control deviation from the base case. The user may define parabolic cost curves, with their minimum point centered on the base case control setting. Only those controls that must move to alleviate constraints violations will move, due to the resultant increase in cost.

Traditional optimization techniques have some disadvantages such as:

- data communications requirements,
- algorithmic complicity, and
- Execution time, which restrict their use in real-time voltage optimization or losses minimization strategies.

4. A NEW GENETIC ALGORITHM SYSTEM CONFIGURATION DETAILS

In this section, a description of the proposed Genetic algorithm system components and its operation is introduced. The block diagram of the proposed system is shown in Figure 1. The system consists of four stages which are: Sensitivity Factor Module (SFM), Actual Topology Evaluation Module (ATEM), Load Flow Module (LFM), and Genetic Algorithm module. These stages can be described as following:

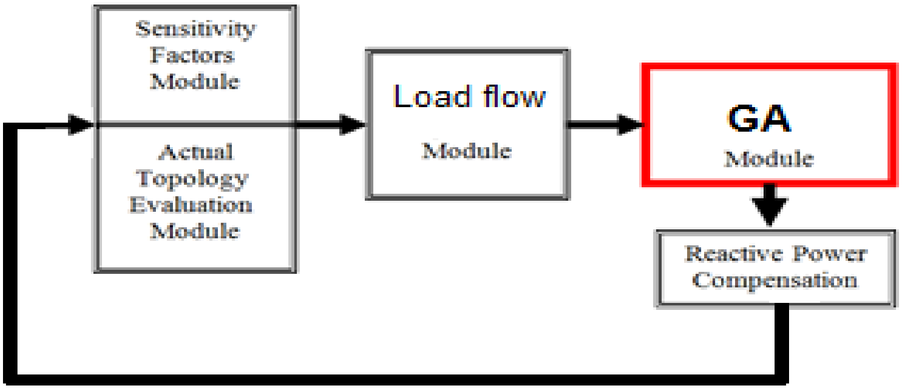

Fig.1. The structure of the new genetic algorithm system used for voltage profile improvement and loss reduction

1. Stage 1: In this stage, the actual topology evaluation module will be run to calculate the actual topology of the power system. Then, the sensitivity factor module is used to calculate the sensitivity factors.

2. Stage 2: to update the data used in the next step, the load flow module is employed in this stage.

3. Stage 3: The genetic algorithm module is used to calculate the required reactive compensation, to alleviate the voltage problems

4. Stage 4: make the switching action to solve the voltage problem. After that, repeat these steps until the voltage problem is alleviated.

ACTUAL TOPOLOGY EVALUATION MODULE (ATEM):

The term "Actual Topology" is meant to cover the nodes and impedance bearing branches necessary for a physical description of the system with reference to the switching state at a certain point in time. And the term "Potential Topology" is meant to cover all existing switchable and fixed connecting elements of a network between and within substations, fields, etc. The topology evaluation routine is able to read the data-base, to calculate the actual topology and to generate special lists of network elements as:

- nodes
- branches (lines and transformers)
- loads

The actual topology consists of all nodes and branches with impedances, which are connected with a synchronized power unit. The data available from the listing after the actual topology evaluation are:

- R [Ohm], X [Ohm], G [Siemens] and B [Siemens]
- maximum power [MVA]
- connectivity

SENSITIVITY FACTORS MODULE (SFM):

The sensitivity factor module assists the system during the solution of the problem. In order to calculate the changes in the load bus voltages and generator reactive power outputs for a given increment in control variables sensitivity factors can be employed.

GENETIC ALGORITHM MODULE (GAM):

The genetic algorithm is carried out to obtain the reactive power required to solve the problem. It can be summarized as following steps as in Fig. 2:-

Step 1: randomly generate an initial population i.e. N string of length L.

Step 2: evaluate the fitness for each N strings in population

Step 3: select the mating pairs of Chromosomes.

Step 4: create new Chromosomes (Off springs) through crossover &mutation operations.

Step 5: Form a population of the next generation.

Step 6: If process is converged, return the best Chromosome as the solution otherwise go to step2.

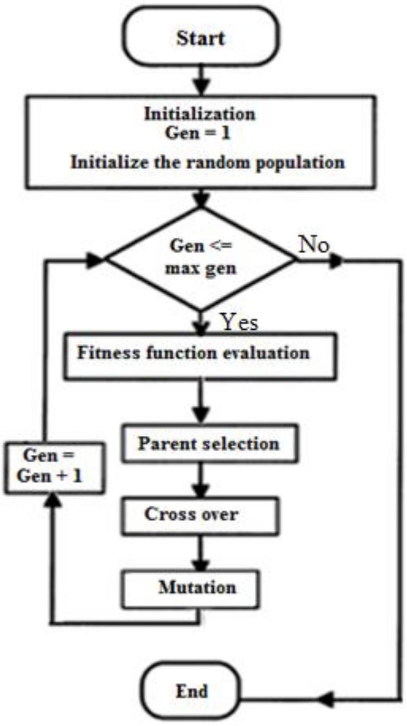

Fig. 2. Flow chart For Genetic Algorithm

OBJECTIVE FUNCTION:

To use the Genetic Algorithm approach to compute the required control actions, an objective function to be minimized and a set of constraints must be first defined. In the literature, several objectives function such as minimizing the total amount of adjustments or minimizing transmission losses have been employed. Before the objective function for this work was chosen, a discussion with operators at Egyptian unified power network (EUP) has been made. After these discussions the impression that the operators favor a control action that requires least number of switchings of capacitors/inductors and/or an adjustment to transformer taps had been got. The main reason why they favor such a control action is that capacitor/inductor switching and tap adjustment tend to reduce the life expectancy of these devices and increase the maintenance cost. Based on these practical considerations, we propose to use the objective function of minimizing the total number of required switching/adjustments to control the voltage in this paper. In other words, the objective is to

Minimize $Z = \sum_i x_i$ (1)

where X_i is the number of capacitors/inductors that have to be switched on/off or the number of steps that the transformer tap should adjusted to at bus i. Note the other objective functions can also be employed if desired.

CONSTRAINTS:

The constraints include the following:

- Constraints on control variables.

$\Delta Q_i^{min} \leq \Delta Q_i \leq \Delta Q_i^{max}$ (2)

$\Delta t_{pq}^{min} \leq \Delta t_{pq} \leq {}_{tpq}^{max}$ (3)

- Constraints in bus voltage

$V_i^{\min} \leq V_i \leq V_i^{\max}$ (4)

Where:

ΔQ_i is the increment of the reactive power of switchable Capacitors/Inductors at bus i,

Δt_{pq} is the increment of the transformer tap between buses p and q

5. CASE STUDIES

In real world operating conditions of the system are changed due to the change in the load demand. This will lead to changes in the load bus voltage violation. The developed system has been applied on the IEEE 30 Bus network in order to demonstrate its effectiveness. The single line diagram of the IEEE 30 bus network is shown in the appendix A1. A final voltage profile characterized by minimum and maximum voltage levels of 1.0 pu, and 1.05 pu, respectively was considered six this study

CASE ONE:

The results of the application of the new Genetic algorithm system on the IEEE 30 bus network shown in Fig 3. Over-voltages observed at buses (11-13), and under-voltages observed at buses (25-26-29-30). After applying the proposed system one can see from the results in Fig 3. that, all the bus voltage violations are alleviated. On the other hand the value of transmission losses was 0.055 pu. and improved to 0.053 pu. Thus more than 7% reduction in power loss is achieved, the mount of reactive power required to reach the solution is equal to 0.93 pu.

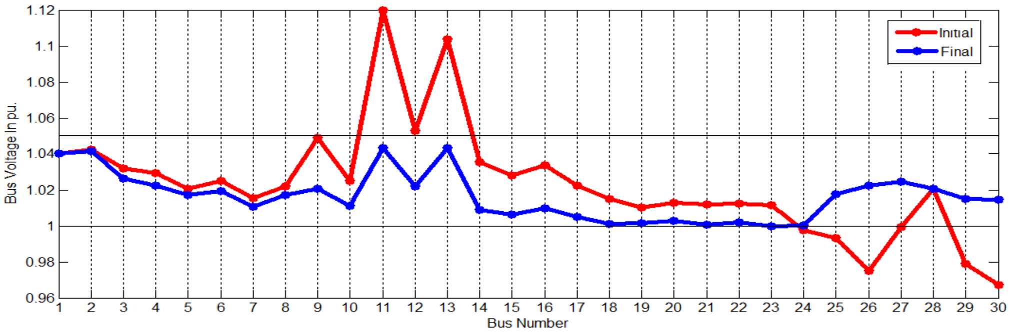

Fig. 3. Initial and final voltage profile for the IEEE 30 bus system

CASE TWO:

In this case after voltage correction (refer to the results of item (V.1) the load at bus (24) in the IEEE 30 bus system is doubled, resulting in distortion in the system voltage profile as in Fig 4. Over-voltage are observed at two buses (11-13) and under-voltages observed at buses (18 -19 - 20 - 21 - 22 - 23- 24 - 25 -26 - 27 - 29 - 30). After applying the proposed system one can see from the results in Fig 4. that, all the bus voltage violations are alleviated. On the other hand the value of value of transmission losses was 0.064 pu. and improved to 0.059 pu. Thus, more than 7% reduction in power loss is achieved, the a mount of reactive power required to reach the solution is equal to 0.9 pu.

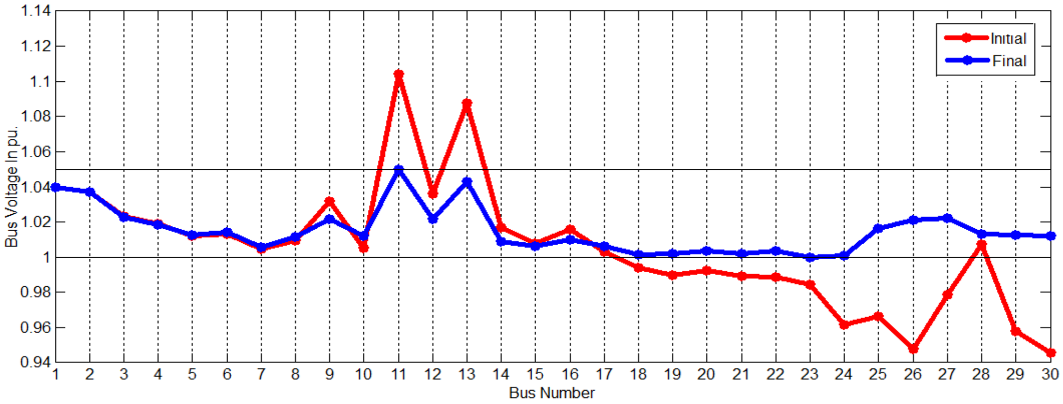

Fig. 4. Initial and final voltage profile if the load at bus 24 in the IEEE 30 bus network is doubled.

CASE THREE:

In this case after voltage correction (refer to the results of item (V.1) the load at bus (7) in the IEEE 30 bus system is doubled, resulting in distortion in the system voltage profile as in Fig 5. Under-voltage are observed at all buses except buses (1- 2 -11) and over-voltages observed at bus (11). After applying the proposed system one can see from the results in Fig 5. that, all the bus voltage violations are alleviated. On the other hand the value of transmission losses was 0.14 pu. and improved to 0.12 pu. Thus, more than 14% reduction in power loss is achieved, the a mount of reactive power required to reach the solution is equal to 1.41 pu.

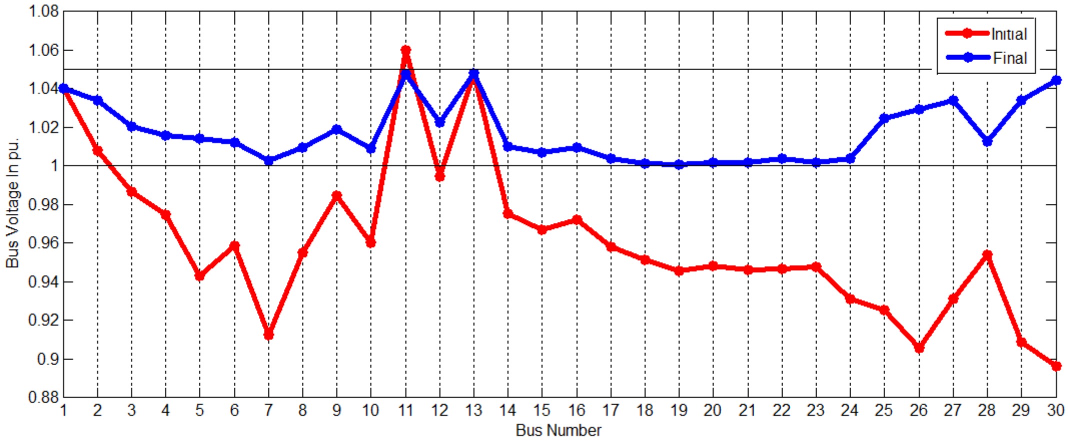

Fig. 5. Initial and final voltage profile if the load at bus 7 in the IEEE 30 bus network is doubled.

CASE FOUR:

In this case after voltage correction (refer to the results of item (V.1) the load at bus (5) in the IEEE 30 bus system is removed, resulting in distortion in the system voltage profile as in Fig 6. Over-voltage only are observed at buses (2- 3 - 4-5 - 6-7- 8 - 9 -10 - 11-12 -13 -14 -15 -16). After applying the pro value of posed system one can see from the results in Fig 6. that, all the bus voltage violations are alleviated. On the other hand the transmission losses was 0.034 pu. and improved to 0.029 pu. Thus, more than 14% reduction in power loss is achieved, the a mount of reactive power required to reach the solution is equal to 1.14 pu.

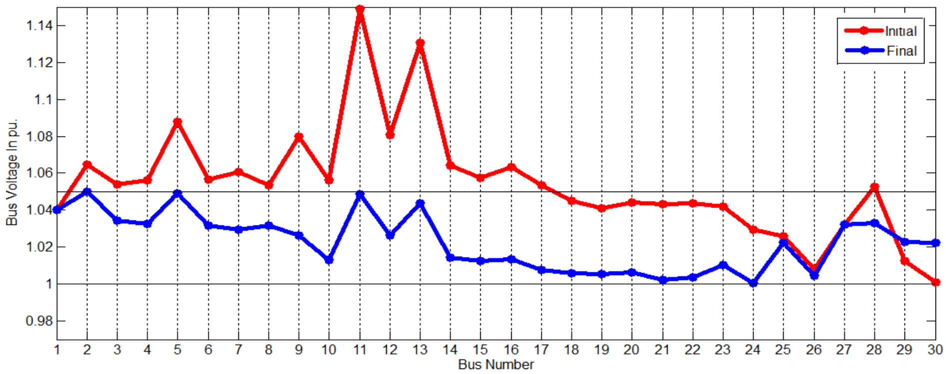

Fig. 6. Initial and final voltage profile if the load at bus 5 in the IEEE 30 bus network is removed.

CASE FIVE:

In this case after voltage correction (refer to the results of item (V.1) the lines between buses (14 - 15) and (22 – 24) in the IEEE 30 bus system is Switched off, resulting in distortion in the system voltage profile as in Fig 8. Over-voltage are observed at buses (11-13) and under-voltages observed at buses (24 - 25- 26 – 27 - 29 - 30). After applying the proposed system one can see from the results in Fig 8. that, all the bus voltage violations are alleviated. On the other hand the value of transmission losses were 0.055 pu. and improved to 0.051 pu. Thus, more than 7% reduction in power loss is achieved, the a mount of reactive power required to reach the solution is equal to 0.75 pu.

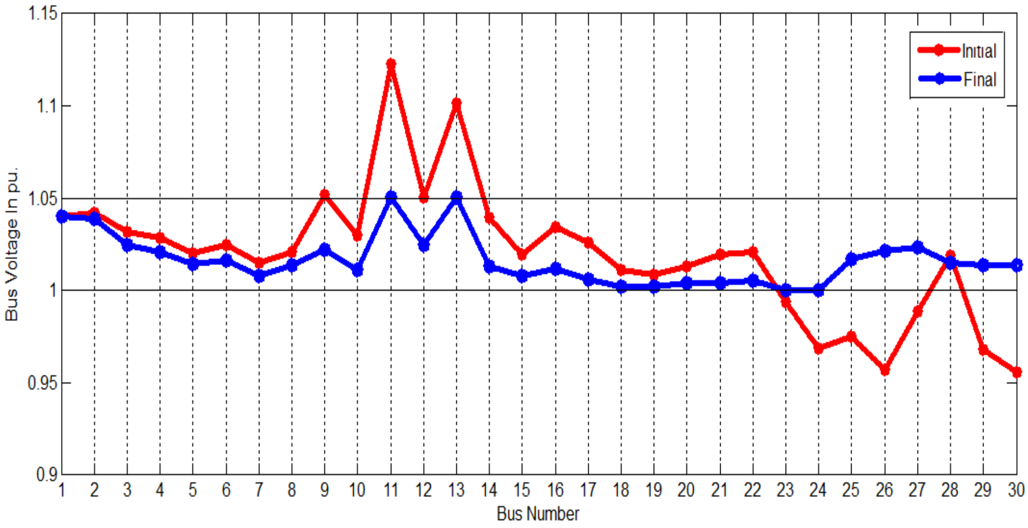

Fig. 8. Initial and final voltage profile if the lines between buses (14 - 15) and (22 – 24) in the IEEE 30 bus system is Switched off

CASE SIX:

In this case after voltage correction (refer to the results of item (V.1) the line between buses (21 - 22) in the IEEE 30 bus system is Switched off, resulting in distortion in the system voltage profile as in Fig 9. Over-voltage are observed at buses (11-13) and under-voltages observed at buses (26 - 29 - 30). After applying the proposed system one can see from the results in Fig 9. that, all the bus voltage violations are alleviated. On the other hand the value of transmission losses was 0.053 pu. and improved to 0.051 pu. Thus, more than 3% reduction in power loss is achieved, the a mount of reactive power required to reach the solution is equal to 0.78 pu.

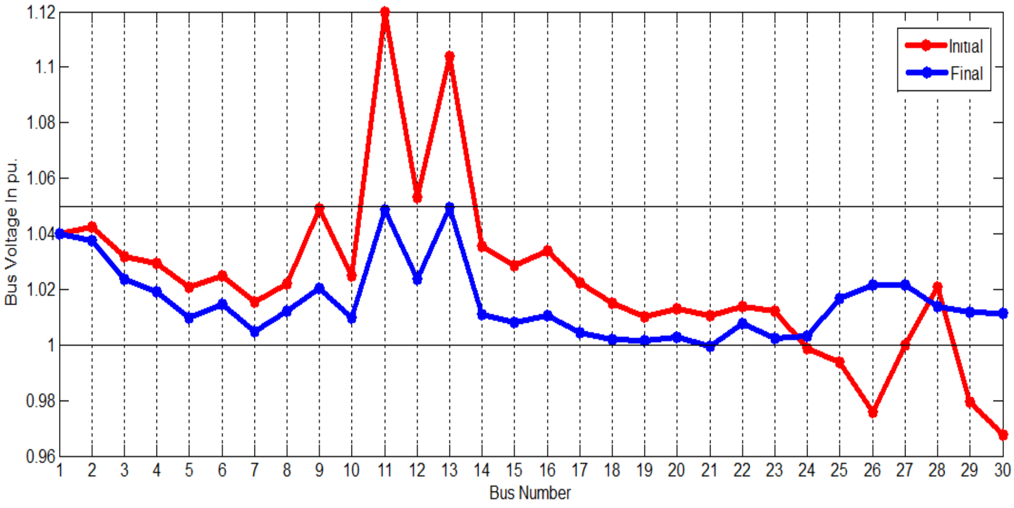

Fig. 9. Initial and final voltage profile if the line between buses (21 – 22) in the IEEE 30 bus system is Switched off

6. CONCLUSION

A new Genetic Algorithm System used for improvement voltage profiles and reduction the transmission losses is developed in this paper. The proposed approach was able to correct the resulting abnormal bus voltages to within prescribed limits and real power loss reduction. The (GA) system was tested on the IEEE 30 bus power system with six case studies and proved to be efficient. The (GA) system results proved the high accuracy and the suitability for the on line applications. The (GA) system is an excellent model that can be integrated in an open SCADA/EMS environment. Using the system in an actual control center will enable the control of the system voltage profile in a tracking mode.

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APPENDIX - A

Appendix A1: The single line diagram of the IEEE 30 Bus Power System