Voltage Profile Improvement Using Unified Power Flow Controller via Artificial Immune System

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Abstract: - Voltage profile is one of the concerned issues in power system studies. This is due to the fact that voltage profile decay can be experienced by the system when system is subjected to load increment or disturbances. Unscheduled increment of load variation in a power transmission system has driven the system to be stressful, leading to potential cascading trip on the entire system. Thus, close monitoring of load variation in a power network can help to avoid the system operating close to its maximum capacity. In addressing this phenomenon, special scheme can be implemented such as reactive power compensation; installation of flexible AC transmission system (FACTs) devices and capacitor placement. Identification of the optimal value of compensating capacitors required proper optimization technique; able to search the optimal solution with less computation time. This paper presents the voltage profile improvement using unified power flow controller (UPFC) approach based on artificial immune system (AIS). In this study, AIS optimization engine is developed for voltage profile improvement which utilized UPFCs as the control variables embedded into the system's data. Implementation on the IEEE Reliability Test System (RTS); considering several variations in the AIS properties indicated AIS potential in solving voltage control problems. Verification through comparison of results using evolutionary programming utilizing the similar system data indicated that AIS is feasible to solve voltage depreciation problems.

Key-Words: - Artificial immune system, fitness, objective function, optimization, UPFC, voltage profile.

1 Introduction

Voltage instability phenomenon has been considered as a crucial issue resulted from improper plan of load increment; causing the system to be in stressed condition, while reducing voltage profile accordingly at a particular load bus. These inter-related issues can be addressed separately or together in a package depending upon the system requirement. One can address voltage profile improvement without having to consider the effect of voltage stability effect, loss or cost increment. This is due to the fact that, the increase of loading condition particularly the reactive in nature has caused voltage profile decay leading to current increase and reduction of voltage stability. Increase in current has led to the increase of I^2R in a line leading to total increase of system's transmission loss. Past researches had addressed these phenomena in terms of alleviating transmission loss, voltage profile and voltage stability improvement. Among the effective techniques are reactive power support scheme through the implementation of generator reactive power support and shunt capacitor placement. On the other hand, readjustment of transformer tap ratio and installation of flexible ac transmission systems is able to alter the transmission line parameters which eventually improve the power system performance in terms of minimizing the loss, voltage stability and voltage profile improvement. UPFC has been profoundly recognized as one of the most technically promising devices in the flexible ac transmission systems (FACTs) family [1-3, 5-8]. The objective of FACTs devices is to bring a system under control and to transmit power as ordered by the control centers, it also allows increasing of the usable transmission capacity to its thermal limits [2]. UPFCs have the capability to control voltage magnitude and phase angle. Besides, UPFC can independently provide either positive or negative reactive power injections.

Many advantages in power system operation and planning can immediately be realized by achieving the function of globally regulating the power flows and simultaneously supporting the bus voltages. Such advantages include the minimization of system losses without generation rescheduling, elimination of line overloads and low voltage profiles as reported by T. T. Ma *et.al* in [3]. The applications of UPFCs are very broad including the effort of representing UPFC in mathematical model [9-11]. The application of UPFC as the main instrument to improve voltage profile has also been addressed in various researches [13, 15-17]. Voltage control involves optimization requirement as addressed by Musirin *et al.* in [12] and Tae-Hyun Kim *et al.* in [18]. Other works can also be referred to other published work reported in [19]. In this study, a modified control strategy for UPFC has been rigorously described. This indicates that broad study of UPFC is progressing accordingly to further explore its application, modeling and control strategy. Determination of UPFC parameters can also alter the solution in power flow. This is termed as optimal power flow, required optimization technique considering a particular objective function. One of the dominant techniques involving optimization process is solving power flow can be referred to the work developed by Jason *et al.* [20] and Norziana *et al.* [22]. The introduction of evolutionary programming (EP) in solving optimal power flow can speed up the process in obtaining optimal solution due to the ability of EP to search the solutions from hill to valley within the search space.

Voltage control study is often regarded to voltage stability, transmission loss control and/or cost improvement. This is very synonym to voltage collapse occurrence, where it normally depends on the loading margin of the system [21]. Previous works described in this literature indicated that optimization has been profoundly accepted as an important technique in solving various problems provided that the control variables and objective function can be identified. The applications of either single objective [23] or multi-objective functions [24] have solved many power system problems. The implementation of optimization techniques in power system environment has produced promising results, accurate, reliable and less burdensome.

This paper presents artificial immune system based optimization technique for voltage profile improvement using UPFC as the method of voltage control variables. AIS can be defined as a metaphorical computational system developed using ideas, theories and components extracted from the immune system [4]. The installation of UPFC into the system's data has altered the transmission line parameters which directly affect the power flow solution in a system. However, UPFC model can be represented as a series which gives influence to the effective reactance of the transmission line. Tests were performed on the IEEE 30-bus RTS to realize the effectiveness of the proposed technique, while verification was conducted through comparative studies with evolutionary programming.

2 Unified Power Flow Controller

Flexible AC transmission system (FACTS) devices have several types namely, static VAR compensator (SVC), thyristor controlled static compensator (TCSC) and unified power flow controller (UPFC). UPFC is identified as one of the most technically promising devices in the FACTS devices family which has the capability to control the voltage magnitude and phase angle in a system. This is achieved by independently providing (positive or negative) reactive power injections. Therefore, the UPFC can provide voltage support, control of real power flow, and other functions; subsequently modifying the power flow solution in a system.

2.1 Operating Principles of UPFC

UPFC model is illustrated in Fig. 1. It consists of two voltage-source converters, which is connected back to back through a DC capacitor.

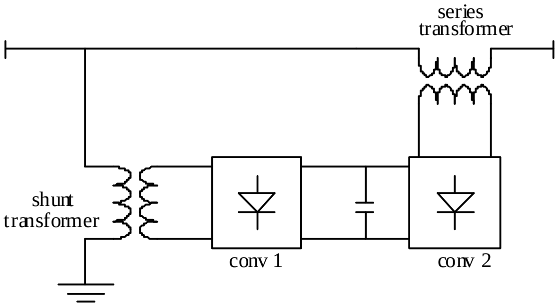

Fig. 1: UPFC Model

An AC series voltage is injected into the transmission lines and regulates the power flow by controlling the amplitude and phase voltage. The series voltage converter is connected to the transmission line by means of a series transformer while the shunt converter can exchange active and reactive powers with the system that enables the system to do shunt compensation independently [5].

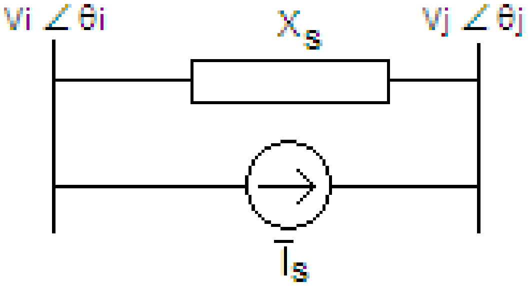

Fig. 2: Equivalent Norton circuit for series branch

2.2 Series Model of UPFC

In UPFC, both the amplitude and phase of the series voltage source are controllable. Assume that the voltage source is connected in series to the line between bus '*i*' and bus '*j*'. This series branch can be modeled as an ideal voltage source $\bar{V}_s$ in series with a reactance X_s [6]. Fig. 2 illustrates $\bar{V}_s$ that represents an ideal voltage source; and $\bar{V}_i$ which represents the voltage behind the series reactance.

In order to obtain the model for the series branch, the voltage source $\bar{V}_s$ is replaced by the current source $I_s = -jb_s\bar{V}_s$ in parallel with X_s [6].

The current source injects S_{is} and S_{js} powers into bus '*i*' and bus '*j*', where:

$$\bar{S}_{is} = \bar{V}_i\,(-\bar{I}_s)^* \quad (1)$$

$$\bar{S}_{js} = \bar{V}_j\,(-\bar{I}_s) \quad (2)$$

$$S_{is} = \bar{V}_i\,[\,jb_s r\bar{V}_i e^{j\gamma}]^* \quad (3)$$

$$= -b_s rV_i^2 \sin\gamma - jb_s rV_i^2 \cos\gamma$$

Assuming $\theta_{ij} = \theta_i - \theta_j$; therefore,

$$\bar{S}_{js} = \bar{V}_j\,[-jb_s r\bar{V}_i e^{j\gamma}]^*$$

$$= -b_s r\bar{V}_i V_j \sin(\theta_i + \gamma_j) + jb_s r\bar{V}_i V_j \cos(\theta_{ij} + \gamma) \quad (4)$$

From the above equations, $\bar{V}_s$ is defined as; $\bar{V}_s = r\bar{V}_i$; where $0 \le r \le 1$;

Based on equations (1) and (2), the series voltage source is considered as two-voltage dependent loads. Therefore, the equivalent reactance, X_s will alter the effective parameter of the transmission line. This gives influence to the amount of power flow through the line, which subsequently giving impact to the voltage at the receiving bus. Several UPFCs can be installed in the system, depending upon the financial capability due to its high cost. Therefore, determination of exact location for voltage control study must be conducted prior to optimizing the UPFCs values.

3 Artificial Immune System

Artificial Immune System (AIS) is a biological immune system which is highly parallel, distributed and adaptive system. In other words, AIS is an adaptive system inspired by theoretical immunology and observed immune functions, principles and models, which are applied to complex problem domains. Some of the scopes of AIS are; fault and anomaly detection, data mining, agent based systems, scheduling, autonomous control, optimization, robotics and security of information systems. In this study, it focuses on cloned selection concept and the affinity maturation (or mutation) process. These two concepts are taken from sub-attribute from negative selection or clone selection concept. The basic immune models and algorithm in AIS are; Bone Marrow models, negative selection algorithm, cloned selection algorithm and immune network models.

3.1 General AIS Algorithm

AIS involves several operators such as initialization, fitness computation, cloning, mutation, cloned selection and new generation definition. The AIS algorithm is given in the following procedural steps:-

i. Initial population process.
ii. Cloning process. The AIS will produce the same number of clones for each individual.
iii. The affinity maturation procedure which will result a population of matured clones.
iv. Determine the affinity of the matured clones in conjunction with the objective function whether to maximize or minimize.
v. Compare the affinity of the memory population, if converge the optimization is achieved, if diverge the algorithm go back to ii.

The implementation of voltage profile improvement in this study considers three control variables namely; x_1, x_2 and x_3. These control variables are assigned as UPFCs, installed in the transmission lines. The UPFCs are installed in series connection. As a result, this study generates three random numbers during the initialization process with the objective function to improve the voltage profile at the chosen transmission line in the system. The three random numbers which are assigned as the UPFCs are inserted in the line-data 25, 28 and 30 in the IEEE 30-bus Reliability Test System (RTS). Resulted voltage which is greater than the *Voltage_set* is set as the inequality constraint. The *Voltage_set* is computed by executing the load flow program. All tests were performed at several loading conditions.

3.2 Algorithm for AIS Implementation in Voltage Profile Improvement

The implementation of voltage profile improvement considers three control variables which act as UPFCs. Multi UPFCs are inserted in series with the transmission lines. Thus, in this study three random numbers are generated during the initialization process with the objective to optimize the voltage profile at the subjected bus. Results for the voltage should be greater than the *voltage_set*; therefore this is set as the inequality constraint. The *voltage_set* is computed by running the load flow program. Tests were performed at several loading conditions. The proposed AIS algorithm for voltage profile improvement is given in procedural steps as follows:-

Step 1. Set the voltage constraints, i.e. *Voltage* ≤ *V_set*. This is to ensure that all the generated initial populations satisfied all the equality and inequality constraints.

Step 2. Generate three random numbers, variables x_1, x_2 and x_3. They are termed as the *parents*. The generated random numbers are subjected to the following constraints:-

$$[X] = \begin{bmatrix} x_{11} & x_{12} & x_{13} \\ x_{21} & x_{22} & x_{23} \\ x_{31} & x_{32} & x_{33} \\ \cdots & \cdots & \cdots \\ x_{j1} & x_{j2} & x_{j3} \end{bmatrix} \tag{1}$$

$$where:\ j = No.of\ \ population$$

Matrix size: [j x 3]

Step 3. Find for constraints violations. If violated, go to Step 2; otherwise go to the next step 4.

Step 4. Fill in the population pool according to the required value.

Step 5. If the pool is not full, go back to step 2; otherwise go step 4.

Step 6. Determine the *x_min* and *x_max*.

Step 7. Assign the x_1, x_2 and x_3 in the system line-data.

Step 8. Calculate fitness 1 by running the load flow program in order to evaluate the voltage values.

Step 9. Determine the *voltage_min* and *voltage_max*. These properties are required in the mutation process.

Step 10. Clone the *parents*. This process copies all the populations by multiple of 10. The size of matrix becomes 10 times of the original row size, with the original number of columns.

$$[X_{c\ln}] = \left[\begin{array}{l} \left.\begin{matrix} x_{11} & x_{12} & x_{13} \\ x_{11} & x_{12} & x_{13} \\ x_{11} & x_{12} & x_{13} \\ \cdots & \cdots & \cdots \end{matrix}\right\} 10 \\ \left.\begin{matrix} x_{21} & x_{22} & x_{23} \\ x_{21} & x_{22} & x_{23} \\ x_{21} & x_{22} & x_{23} \\ \cdots & \cdots & \cdots \end{matrix}\right\} 10 \\ \left.\begin{matrix} x_{31} & x_{32} & x_{33} \\ x_{31} & x_{32} & x_{33} \\ x_{31} & x_{32} & x_{33} \\ \cdots & \cdots & \cdots \end{matrix}\right\} 10 \\ \left.\begin{matrix} x_{j1} & x_{j2} & x_{j3} \\ x_{j1} & x_{j2} & x_{j3} \\ x_{j1} & x_{j2} & x_{j3} \\ \cdots & \cdots & \cdots \end{matrix}\right\} 10 \end{array}\right]$$

Step 11. Mutate the *parents*. This will breed *offsprings*. Where the offsprings are written in the mathematical equation.

$$[\Gamma] = \left.\begin{bmatrix} \lambda_{11} & \lambda_{12} & \lambda_{13} \\ \lambda_{21} & \lambda_{22} & \lambda_{23} \\ \lambda_{31} & \lambda_{32} & \lambda_{33} \\ & & \\ \lambda_{10j1} & \lambda_{10j2} & \lambda_{10j3} \\ \cdots & \cdots & \cdots \end{bmatrix}\right\} 200$$

Matrix size = [(jx10) 3]

Step 12. Recalculate fitness using the *offsprings*.

Step 13. Selection of *offsprings*. In this process, selection can be performed by pair-wise comparison, elitism, Roulette Wheel or priority strategy. It depends on the objective functions of the study. This transcribes the 20 fittest populations to be brought up to step 6.

Step 14. Define next generation to be the parents for next evolution.

Step 15. If solution converges, stop the process otherwise; repeat step 10 to 14. In this process, the difference between the maximum and minimum fitness is defined as the stopping criterion. However, this will depend on particular problems since very low convergence criterion will end up with long computation time, which may be not significant.

Step 16. Stop the AIS process.

In order to generate the AIS computational codes, the initialization process should be done first. Theoretically, the impedance before insertion of UPFC is shown in equation (5), while with the installation of UPFC, impedance equation changes to (6).

$$Z_{old} = R + jX \tag{5}$$

$$Z_{new} = R + j(X - X_{UPFC}) \tag{6}$$

Where:

Z = Impedance of the transmission line
R = Resistance of the transmission line
X = Reactance of the transmission line
X_{UPFC} = Capacitive reactance of UPFC in the transmission line

4 Evolutionary Programming

Evolutionary Programming (EP) is an optimization technique falls under the Evolutionary Computation (EC) category in the artificial intelligence (AI) hierarchy. This technique has been reported to be as a fast search technique which commonly opted to ease the calculation process as well as to fine tuning the results. It has been increasingly applied for solving power system optimization problem in recent years.

It is a stochastic optimization strategy, which is based on the mechanics of natural selections-mutation, competition and evolution [20-22]. This technique stressed on the behavioral linkage between parents and their offspring. The most important advantage of using EP is that, it uses only the objective function information and hence independent of the nature of the search space such as smoothness, convexity, etc. In general, the flowchart is shown in Fig. 3. It is based on the survivors of the fittest; which involved initialization, mutation, fitness computation and tournament selection prior to the prescription to the next iteration.

Step 1: Random Number Generation

Initialisation process in EP is conducted by generating a series of random number using a uniform distribution number generator. For the purpose of maximizing the voltage profile in the system, the random number represents the UPFC values at the pre-selected line-data. Positioning of UPFCs in transmission lines in the system can be determined using sensitivity analysis. However, in this study the locations are selected arbitrarily due to the fact that, its implementation is looking towards the effectiveness of voltage profile improvement. In this case, the locations of the UPFC are the same as those implemented in the AIS.

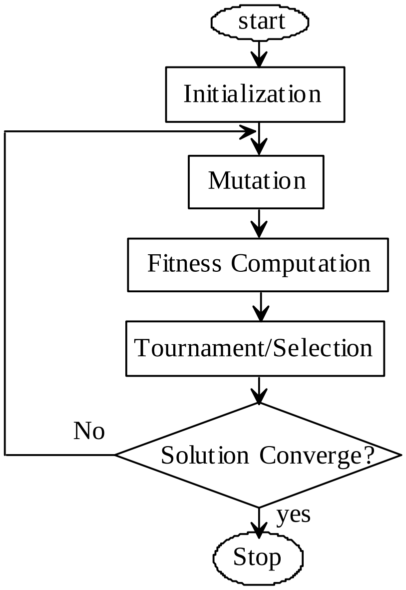

Fig. 3: General flowchart for Evolutionary Programming

Step 2: Fitness Calculation and Statistical Evaluation

In this study voltage at the loaded bus was taken as the fitness function, which needs to be maximised and solved using the ac load flow. It was done by calling the load flow programme into the EP main programme. Thus in this problem, the objective function would not be a single mathematical equation but rather a subroutine which was executed accordingly in the EP main programme. Subsequently, evaluation of maximum, minimum, sum and average of fitness are carried out which will be utilised in the mutation process.

Step 3: Mutation

Mutation was performed on the generated random numbers, x_i to produce the offsprings. The mutation process was implemented based on the following equation:

$$x_{i+m,j} = x_{i,j} + N(0, \gamma^2) \tag{7}$$

$$\gamma^2 = \beta(x_{j\max} - x_{j\min})(\frac{f_i}{f_{\max}}) \tag{8}$$

where:

$x_{i+m,j}$ = mutated parents (offspring)

x_{ij} = parents
N = Gaussian random variable with mean μ and variance γ^2
β = mutation scale, $0<\beta<1$
x_{jmax} = maximum random number for every variable
$x_{j\ min}$ = minimum random number for every variable
f_i = fitness for the i^{th} random number
f_{max} = maximum fitness

The mutation scale, β could be manually adjusted in order to achieve better convergence. Large value of β implies large search step, which causes slow convergence of the EP leading to large computation time and vice versa. Other mutation techniques such as Cauchy technique can also be utilized for comparison purposes. Since β is a mutation scale ranging from 0 to 1, therefore it can also be considered as another parameter which can also be optimized. In this case, the algorithm can be called adaptive Gaussian mutation technique.

Step 4: Selection

The offsprings produced from the mutation process are combined with the parents to undergo a selection process in order to identify the candidates to be transcribed into the next generation. Two selection strategies were tested namely the priority selection and pair wise comparison. In priority selection strategy, the populations were sorted in descending order according to their fitness values since the objective function is to obtain the maximum voltage level at the subjected bus in the system. The first half of the populations is transcribed as the next generation.

On the other hand, in the pair wise comparison strategy; ten opponents were randomly generated for every combined population. Opponents underwent tournament process with the combined populations via pair wise comparison and number of wins was calculated for every element in the combined population. These populations were sorted in descending order according to the number of wins. The first half population is then transcribed for the next generation. Comparing the two selection strategies; the priority selection provides a better results and therefore it is employed in the selection process of the developed EP.

Step 5: Convergence Test

Convergence test is important to determine the stopping criteria of the evolution. The pre-determined accuracy is normally dependent on the problem orientation. The convergence criterion is duly specified by the difference between the maximum and minimum fitness $\leq$ 0.0001. The mathematical equation is given as follows:-

$$maximum_{\ fitness} - minimum_{\ fitness} \leq 0.0001 \qquad (9)$$

As explained in the mutation for AIS, the similar rule is applied here; meaning that the convergence criterion can actually vary depending on the desired accuracy.

5 Results and Discussion

UPFC installations in the transmission system to improve the voltage profile in the system have been conducted. Tests were performed at buses 9, 17 and 24 at several loading conditions. The impact of population size to the optimization performance was also monitored so that the best population size can be identified from the experiments.

5.1 Voltage Profile Improvement with UPFC Installation

Results for voltage profile improvement at buses 9, 17 and 24 are tabulated in Tables 1, 2 and 3. The results for voltage profile improvement when loading condition variation is subjected to bus 9 are tabulated in Table 1. From the table, it is observed that voltage at bus 9 increases accordingly as the reactive power loading is increased. It is also shown that, with the implementation of UPFC, the voltage profiles of the bus for all loading conditions have been improved significantly.

Table 1: Voltage profile improvement at bus 9

Loading Condition (MVar)	Voltage (p.u)		UPFC values (p.u)		
	Without UPFC	With UPFC	x_1	x_2	x_3
10	1.0430	1.0442	0.4826	0.3529	0.2195
20	1.0291	1.0305	0.4357	0.3716	0.3869
30	1.0167	1.0223	0.4357	0.3716	0.3869
40	1.0000	1.0058	0.4357	0.3716	0.3869
50	0.9913	0.9932	0.4357	0.3716	0.3869
*60	0.9750	0.9771	0.4357	0.3716	0.3869
70	0.9640	0.9661	0.4914	0.2941	0.3600
80	0.9547	0.9557	0.3133	0.2669	0.3373

For instance, at Q_{d9} = 60 MVar as highlighted in the table, the voltage value has been increased from 0.9750 p.u. to 0.9771 p.u.. This is due to the fact that the installation of UPFC has modified the effective reactance of the transmission line which subsequently improved the voltage profile in the system. The size of UPFCs determined by the AIS to achieve this increment is 0.4357, 0.3716 and 0.3869 p.u. respectively as indicated in the table. Suppose a power system operator attempts to do UPFCs installation at this loading condition, these values should be taken as the optimal values for the UPFCs sizing.

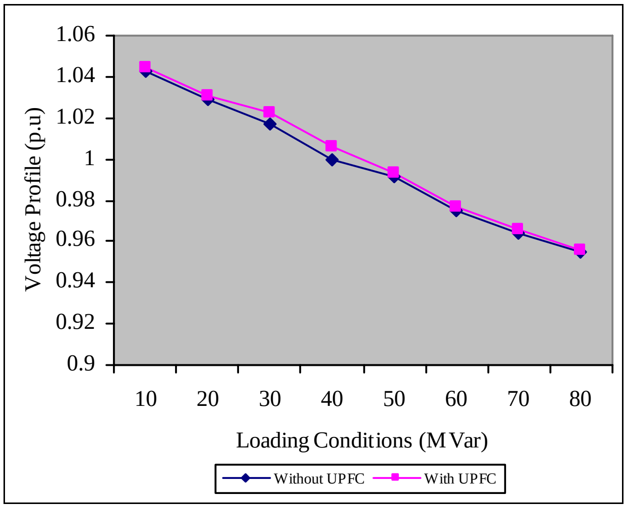

Fig.4: Results for voltage profile at bus 9 improvement with and without UPFC

Table 2: Voltage profile improvement at bus 17

Loading Condition (MVar)	Voltage (p.u)		UPFC values (p.u)		
	Without UPFC	With UPFC	x_1	x_2	x_3
10	1.0328	1.0348	0.4357	0.3716	0.3869
20	1.0156	1.0178	0.4357	0.3716	0.3869
30	0.9996	1.0021	0.4357	0.3716	0.3869
40	0.9806	0.9834	0.4357	0.3716	0.3869
50	0.9577	0.9632	0.4357	0.3716	0.3869
60	0.9272	0.9304	0.4357	0.3716	0.3869
70	0.9046	0.9083	0.3767	0.3077	0.3662
***80**	**0.8728**	**0.8769**	**0.3133**	**0.2669**	**0.3873**

The results for voltage profile improvement when loading condition variation is subjected to bus 9 are illustrated in Fig. 4. With UPFCs installed in the system, voltage at bus 9 had been increased accordingly. However, the increment is not obviously indicative because voltage profile does not vary linearly with respect to the loading increment.

On the other hand, the results for voltage profile improvement for bus 17 are tabulated in Table 2. From the table, similar trend can be noticed here. Voltage at bus 17 increases as the reactive power loading at this bus is increased. Once UPFCs are installed in the system, voltage profiles of the bus for all loading conditions have been improved significantly. These phenomena can be observed from the table.

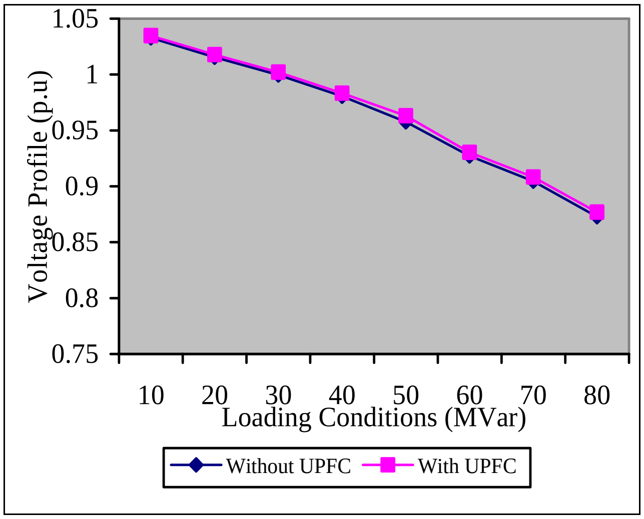

Fig. 5: Results for voltage profile at bus 17 without UPFC and with UPFC.

For instance, at Q_{d17} = 80 MVar, voltage is increased from 0.8728 p.u. to 0.8769 p.u. as highlighted in the table. The size of UPFCs determined by the AIS to achieve this increment is 0.3133, 0.2669 and 0.3873 p.u. respectively as indicated in the table. The results for voltage profile improvement when loading condition variation is subjected to bus 17 are illustrated in Fig. 5.

The results for voltage profile improvement when loading condition variation is subjected to bus 24 are tabulated in Table 3. From the table, it is observed that the voltage at bus 24 also increases when the reactive power loading is increased, as those observed in previous cases. For instance, at Q_{d24} = 80 MVar, the voltage is increased from 0.7877 p.u. to 0.8551 p.u.. The size of UPFCs determined by the AIS to achieve this increment is 0.4112, 0.1529 and 0.3966 p.u.

The results for voltage profile improvement when loading condition variation is subjected to bus 24 are illustrated in Fig. 6. It is observed that, the installation of UPFCs has significantly increased the voltage profile at bus 24, particularly at higher loading condition region. However, at lower loading the difference is not that obvious. This indicates that any attempt to improve the voltage profile at this bus, recommendation should be given for higher loading condition.

Table 3: Voltage profile improvement at bus 24

Loading Condition (MVar)	Voltage (p.u)		UPFC values (p.u)		
	Without UPFC	With UPFC	x_1	x_2	x_3
10	1.0149	1.0348	0.3069	0.1213	0.3059
20	0.9921	0.9964	0.3069	0.1213	0.3059
30	0.9703	0.9797	0.3069	0.1213	0.3059
40	0.9451	0.9622	0.4929	0.1630	0.3941
50	0.9111	0.9383	0.3069	0.1213	0.3059
60	0.8748	0.9049	0.3069	0.1213	0.3059
70	0.8367	0.8738	0.3069	0.1213	0.3059
***80**	**0.7877**	**0.8551**	**0.4112**	**0.1592**	**0.3966**

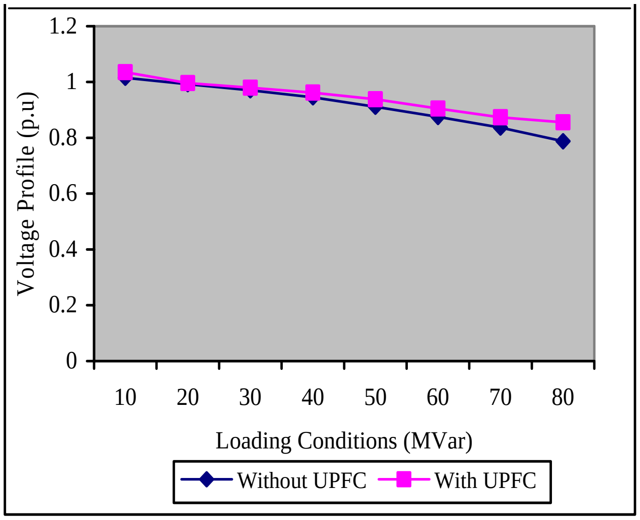

Fig 6: Results for voltage profile without UPFC and with UPFC at bus 24

5.2 Effect of Population Size to Optimization Performance

The results for the effect of population size pertaining to voltage profile improvement are tabulated in Tables 4, 5 and 6. Table 4 tabulates the effect of population size to voltage profiles when reactive load variation was subjected to bus 9.

Numerous experiments were conducted to the system, so as to realize the effect of population size adequate to converge to a solution with high accuracy and/or less computation time.

Table 4: Results for the Effect of Population Size Performed at Bus 9

Pop. Size	Voltage Value at Bus 9 for Several Loading Conditions			
	Q_{d9} = 10 Mvar	Q_{d9} = 14 Mvar	Q_{d9} = 26 Mvar	Q_{d9} = 30 Mvar
5	1.0442	1.0393	1.0256	1.0223
10	1.0445	1.0395	1.0259	1.0227
15	1.0427	1.0396	1.0258	1.0226
20	1.0452	1.0403	1.0267	1.0234

From the table, it is observed that the voltage reduces accordingly as the reactive power loading is increased. Larger population size gives the highest voltage profile in the system, and vice versa. This can imply that population size of 20 allows the process to search within broad search space from valley to the hill. For instance, at population size of 5, the voltage profile at Q_{d9} = 10 Mvar is 1.0442 p.u., while the voltage is 1.0452 p.u. when population size is increased to 20. This indicates that higher population size gives better performance. Same scenarios can also be observed in different loading conditions. As a matter of fact, large population size has a significant impact in performing optimization process using the proposed AIS technique.

Table 5: Results for the Effect of Population Size Performed at bus 17

Pop. Size	Voltage Value at Bus 17 for Several Loading Conditions			
	Q_{d17} = 10 Mvar	Q_{d17} = 14 Mvar	Q_{d17} = 26 Mvar	Q_{d17} = 30 Mvar
5	1.0348	1.0292	1.0084	1.0021
10	1.0351	1.0292	1.0090	1.0027
15	1.0351	1.0291	1.0088	1.0024
20	1.0362	1.0303	1.0101	1.0038

The effect of population size pertaining to voltage profile improvement subjected to bus 17 is tabulated in Table 5. Similar scenario can be observed in this case. For instance, at Q_{d17} = 10 Mvar, the voltage value at bus

17 is 1.0348 p.u. at population size of 5, while the value increases to 1.0362 p.u. when the population size is increased to 20. Results for other loading conditions are also indicated in the same table.

The effect of population size pertaining to voltage profile improvement subjected to bus 24 is tabulated in Table 6. From the table, the best voltage can be observed at population size of 10. Therefore, 10 populations can be the most population size for this bus.

Table 6: Results for the Effect of Population Size Performed at Bus 24

Pop. Size	Voltage Value at Bus 24 for Several Loading Conditions			
	Q_{24} = 10 Mvar	Q_{24} = 14 Mvar	Q_{24} = 26 Mvar	Q_{24} = 30 Mvar
5	1.0143	1.0080	0.9864	0.9797
10	1.0166	1.0104	0.9891	0.9825
15	1.0109	1.0038	0.9797	0.9720
20	1.0115	1.0044	0.9804	0.9728

From Tables 3, 4 and 5; 20 is the most suitable population size to achieve the best performance in voltage profile improvement optimized using AIS. Therefore, it is suggested to have populations size of 20 for all buses in order to achieve better voltage profile improvement in the system. This is due to the fact that, adequately large population size allows the process to search within broad search solution space prior converging to an optimal solution.

5.3 Comparative Studies with other Technique

Comparative studies were conducted with respect to the results obtained using the EP. The results are tabulated in Tables 7 and 8 for load subjected to buses 17 and 24. From both tables, it is observed that AIS outperformed EP in terms of voltage profile improvement in all loading conditions. This is suspected due to the fact that in EP, combination between parents and offsprings is conducted; while in AIS only cloning process is conducted with the exclusion of combination process. Combination process between both; the parents and offsprings will cause inaccuracy due to the difference in population variables. On the other hand, in AIS; cloning process is introduced which can lead the system to converge to an accurate solution due to the fact that in AIS each individual is cloned into 10 identical populations. This has helped the optimization process to converge to an accurate solution.

Table 7: Voltage profile improvement at bus 17 performed using AIS and EP

	Voltage (p.u)		
Loading Condition (MVar)	Without UPFC	AIS	EP
30	0.9996	1.0021	1.0007
40	0.9806	0.9834	0.9819
50	0.9577	0.9632	0.9616
60	0.9272	0.9304	0.9287
70	0.9046	0.9083	0.9064
80	**0.8728**	**0.8769**	**0.8749**

In Table 7, at loading condition of 80 MVAr; AIS managed to improve the voltage profile from 0.8728 p.u. to 0.8769 p.u., while EP only managed to improve the voltage profile to 0.8749 p.u.. This implies that the cloning process introduced in AIS has able the solution to search the better results over EP. Looking at other loading conditions, results performed using AIS are higher than that in EP indicating the capability of AIS is maintained throughout the process.

Table 8: Voltage profile improvement at bus 24 performed using AIS and EP

	Voltage (p.u)		
Loading Condition (MVar)	Without UPFC	AIS	EP
10	1.0149	1.0348	1.0184
30	0.9703	0.9797	0.9799
50	0.9111	0.9383	0.9268
60	0.8748	0.9049	0.8974
70	0.8367	0.8738	0.8696
***80**	**0.7877**	**0.8551**	**0.8550**

Similar scenario can be observed for the results of bus 24. In Table 8, at loading condition of 80 MVAr; AIS managed to improve the voltage profile from 0.7877 p.u., to 0.8551 p.u., while EP only managed to improve the voltage profile to 0.8550 p.u.. This implies that the cloning process introduced in AIS has able the solution to search the better results over EP. Looking at other loading conditions, most of the results performed using AIS are higher than that in EP indicating the capability of AIS is maintained throughout the process.

6 Conclusion and Future Work

An approach for voltage profile improvement by using UPFC via AIS as the optimization technique is presented. Programming codes for AIS optimization technique was developed to determine the optimal value of UPFCs in order to maximize the voltage profile in the transmission lines. Tests were performed on the IEEE 30-bus Reliability Test System (RTS). Results obtained from the study indicated that the implementation of AIS have improved the voltage profile of the system indicating it as a feasible technique to perform the voltage optimization process. Comparative studies with the results obtained from EP indicated that AIS is better than EP in terms of ability to produce the more accurate results. However, this is not a generalization to claim that AIS is always better than EP in all cases, rather depending upon the problem formulation. In some other cases, there would be cases where EP could be better than AIS in terms of achieving better computation time, accuracy and ability in dealing with complex optimization problems. Minor alteration in the developed engine can be further explored in order to solve other optimization problems. Implementation in a larger system can realize the robustness of the developed technique in solving more complex problems.

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