Voltage Stability Improvement using Unified Power Flow Controller (UPFC)

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Abstract - **Voltage stability problem with voltage collapse as its final consequence is an emerging phenomenon in electrical power systems. In recent year, there are a lot of devices used to control the stability of voltage. One of the well known devices is the FACTS devices. There are many devices categorized under FACTS devices. One of the FACTS controllers is the Unified Power Flow Controller (UPFC). This paper presents the effectiveness of UPFC in controlling voltage stability of power system. UPFC is utilized in this study due to its versatile capabilities of line power flow regulation and oscillations damping; can provide simultaneous, real-time control of all basic power system parameters (transmission voltage, impedance and phase angle) and dynamic compensation of power system. A voltage stability index, namely *Line Stability Index L_{mn}* is used to indicate the stability of each line in the system. Several UPFCs are installed at selected lines in order to improve the voltage stability in the power system. The optimal sizings of UPFCs are identified using Evolutionary Programming (EP). The proposed optimization technique was validated on the IEEE Reliability Test System and indicating that the technique is feasible to be implemented in larger system.**

Keywords - Voltage stability, FACTS devices, UPFC, Line Stability Index L_{mn}, Evolutionary programming.

I. INTRODUCTION

The problem of voltage stability with voltage collapse as its final consequence is an emerging phenomenon in generation, transmission and distribution/load aspects of electric power systems [1]. Since the demand for electric power in many countries was increased, it requires increasing the transmission capabilities [2, 3]. Many factors, such as financial and environmental concerns, constrain the construction of new transmission lines. Electric utilities are forced to operate the system in ways which make maximum use of existing transmission facilities [3]. As a consequence, some transmission lines are more loaded than what was planned. With the increased loading of long transmission lines, the problem of transient stability after a major fault can become a transmission power limiting factor [4].

There are many devices known as FACTS controllers which can be used to control the stability of voltage. One of the FACTS controllers is the Unified Power Flow Controller (UPFC). UPFC is the most versatile and powerful device among the FACTS device family [5]. UPFC can provide simultaneous control of all basic power system parameters; transmission voltage, impedance and phase angle [7].

In this paper, the shunt branches of UPFC model are used for voltage stability improvement. The application of Evolutionary Programming (EP) in optimization is used to select the optimal value of UPFC. A line-based voltage stability index termed as Line Stability Index (L_{mn}) [9] was introduced as the fitness function in the objective function. The technique was validated on the IEEE 30 bus Reliability Test System and the results indicated that UPFC is feasible for EP optimization technique for the task of improving the voltage stability and loss minimization in power system.

II. UNIFIED POWER FLOW CONTROLLER

UPFC model are consists of a combination of a series device and a shunt device, which are connected to a common dc link capacitor. As shown in Fig. 1, UPFC is usually installed between the sending end, V_S and the receiving end, V_R. The series device acts as a controllable voltage source, V_C, whereas the shunt device acts as a controllable current source, I_C. The main purpose of the shunt device is to regulate the dc link voltage by adjusting the amount of active power drawn from the transmission line.

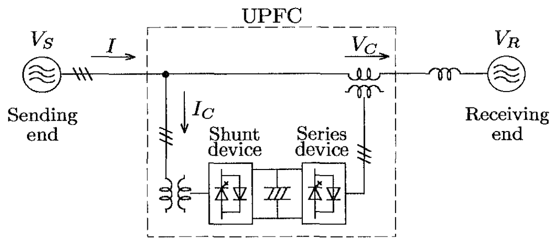

Fig. 1. Basic configuration of UPFC

In addition, the shunt device has the capability of controlling the reactive power. In this study, UPFC model of a shunt device was examined because it can greatly affect the voltage stability.

A. UPFC model

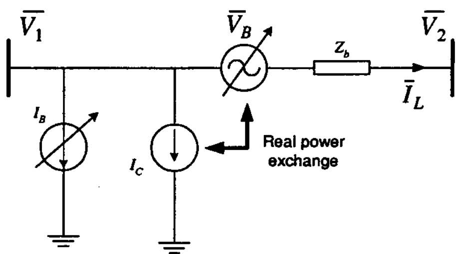

Fig. 2. UPFC model

The shunt branch is represented by two current sources: I_B and I_C. The adjustable reactive current I_B is used to denote the independent reactive compensation of the shunt branch. Since the shunt branch also functions as the real source for the series converter, another controllable real current I_C is added to represent the real power exchange between the two converters. The series branch is represented by impedance z_b connected in series with a variable voltage source $\overline{V}_B$. The voltage $\overline{V}_B$ can be decomposed into in phase and quadrate components with respect to either the voltage, i.e.,$\overline{V}_B = (a + jb)\,\overline{V}_1$, or the line current, i.e.,$\overline{V}_B = (a + jb)\,\overline{I}_L$. Since the UPFC as a whole does not absorb or generate real power, the DC capacitor voltage E_{dc} must be maintained constant. At steady state, this relationship can be expressed as:

$$V_1 I_C - \mathrm{Re}\left\{ \overline{V}_B I_L^* \right\} = 0 \qquad (1)$$

Where V_1 is the magnitude of the complex voltage $\overline{V}_1$, Re represents the real part of a complex variable, the superscript '*' denotes complex conjugate. However (1) does not hold in transient period because there is real power exchange between the two converters and the capacitor voltage E_{dc} is no longer constant. The charging dynamics of the capacitor is given by:

$$E_{dc}(t) = \frac{1}{C_{dc}E_{dc}}\left(V_1(t)I_C(t) - \mathrm{Re}\left\{ \overline{V}_B(t) I_L^*(t) \right\} \right) \qquad (2)$$

In the above model, four variables are controllable. They are I_B, I_c, a and b. Except for the variable I_c whose only purpose is to maintain a constant DC capacitor voltage, the other three variables can be designed to meet different objectives. The regulating dynamics are expressed as follows:

$$I_B(t) = \frac{1}{T_B}\left(-I_B(t) + I_{B0} + u_B(t) \right) \qquad (3)$$

$$I_C(t) = \frac{1}{T_C}\left(-I_C(t) + I_{C0} + u_C(t) \right) \qquad (4)$$

$$a(t) = \frac{1}{T_a}\left(-a(t) + a_0 + u_a(t) \right) \qquad (5)$$

$$b(t) = \frac{1}{T_b}\left(-b(t) + b_0 + u_b(t) \right) \qquad (6)$$

where T_B, T_C, T_a and T_b are the regulator time constants; I_{B0}, I_{C0}, a_0 and b_0 are the initial values of states $I_B(t)$, $I_C(t)$, $a(t)$ and $b(t)$respectively; $u_B(t)$, $u_C(t)$, $u_a(t)$ and $u_b(t)$ are the regulator inputs.

B. Shunt branch control

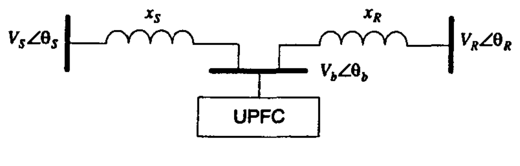

Fig. 3. Three bus UPFC system

The parallel branch can act as an independent reactive source. The reactive current I_B aims at maintaining the bus voltage V_b at a reference dueV_{bref}. We introduce a new state $e_B(t)$ as defined by:

$$e_B(t) = KI_B(t)\left(V_b(t) - V_{bref} \right) \qquad (7)$$

From Fig. 2, we get the following relationship:

$$\frac{V_S\cos(\theta_S - \theta_b)}{x_S} - \frac{V_b}{x_S} + I_B = \frac{V_b}{x_R - b} - \frac{V_R\cos(\theta_b - \theta_R)}{x_R - b}$$

It follows that:

$$e_B(t) = KI_B\,\left(\alpha(t)I_B(t) - d(t)\right) \qquad (8)$$

Where,

$$d(t) = \frac{(x_R - b)V_S\cos(\theta_S - \theta_b) + x_S V_R\cos(\theta_b - \theta_R)}{x_S + x_R - b}$$

and,

$$\alpha(t) = \frac{(x_R - b)x_S}{x_S + x_R - b}$$

Where $d(t)$ is treated as an external disturbance. Rewrite (3) and (8) in state-space form, we have

$$\begin{bmatrix} I_B(t) \\ e_B(t) \end{bmatrix} = \begin{bmatrix} -\dfrac{1}{T_a} & 0 \\ KI_B\alpha(t) & 0 \end{bmatrix} \begin{bmatrix} I_B(t) \\ e_B(t) \end{bmatrix} + \begin{bmatrix} \dfrac{1}{T_B} \\ 0 \end{bmatrix} u_B(t) + \begin{bmatrix} \dfrac{I_{B0}}{T_a} \\ -KI_B d(t) \end{bmatrix} \qquad (9)$$

Again we use robust approach to deal with the uncertain parameters $\alpha(t)$ andT_B. Denote the nominal value of T_B and $\alpha(t)$ **as** T_{B0} andα_0, and the uncertainties **as** ΔT_B and$\Delta\alpha$, respectively, the system model **(9)** can be expressed **as** follows

$$\dot{x}(t) = (A_0 + \Delta A)x(t) + (B_0 + \Delta B)u_B(t) + \Gamma(t) \qquad (10)$$

Where $x(t) = [I_B(t) \quad e_B(t)]^T$

$$A_0 = \begin{bmatrix} -\dfrac{1}{T_{B0}} & 0 \\ KI_B\alpha_0 & 0 \end{bmatrix}$$

$$\Delta A = \begin{bmatrix} \Delta\alpha_{11} & 0 \\ \Delta\alpha_{21} & 0 \end{bmatrix} = \begin{bmatrix} \dfrac{1}{T_{B0}} - \dfrac{1}{T_{B0} + \Delta T_B} & 0 \\ KI_B\Delta\alpha & 0 \end{bmatrix}$$

$$B_0 = \begin{bmatrix} \dfrac{1}{T_{B0}} \\ 0 \end{bmatrix}$$

$$\Delta B = \begin{bmatrix} \Delta\beta \\ 0 \end{bmatrix} = \begin{bmatrix} \dfrac{1}{T_{B0} + \Delta T_B} - \dfrac{1}{T_{B0}} \\ 0 \end{bmatrix}$$

$$\Gamma(t) = \begin{bmatrix} \dfrac{T_{B0}}{T_B} \\ -KI_B d(t) \end{bmatrix}$$

Decompose the parametric uncertainties ΔA and ΔB **as** follows:

$[\Delta A \quad \Delta B] = DF[E_1 \quad E_2]$, where

$$D=\begin{bmatrix} c_{11} & 0 \\ 0 & c_{12} \end{bmatrix} \quad F=\begin{bmatrix} \dfrac{\Delta\alpha_{11}}{\max|\Delta\alpha_{11}|} & 0 \\ 0 & \dfrac{\Delta\alpha_{21}}{\max|\Delta\alpha_{21}|} \end{bmatrix}$$

$$E_1=\begin{bmatrix} \dfrac{\max|\Delta\alpha_{11}|}{c_{11}} & 0 \\ \dfrac{\max|\Delta\alpha_{21}|}{c_{21}} & 0 \end{bmatrix} \quad E_2=\begin{bmatrix} \dfrac{\max|\Delta\alpha_{11}|}{c_{11}} \\ 0 \end{bmatrix},$$

c_{11} and c_{12} are constants that can be chosen freely. If there are exists a stabilizing solution $P \geq 0$ for the Riccati equation, then we get the following linear feedback law:

$$u_b(t) = -K_{b1}b(t) - K_{b2}\omega(t) \tag{11}$$

III. VOLTAGE STABILITY

In power system planning and its operation, the major concern is the problems that related to voltage stability in power systems. The increased demand of electric power will affect the stability of voltage in power system become instability. Voltage stability is the ability of a power system to maintain an acceptable voltages at all nodes in the system either in normal condition or in high stressed condition of demand. A power system is said to have a situation of voltage instability when a disturbance causes a progressive and un-controllable decrease in voltage level.

A. Line Stability Index Formulation

Line Stability Index L_{mn} is one of the methods used to analyze the voltage stability condition in power system. L_{mn} was derived based on the power transmission concept in a single line, in which the discriminant of the voltage quadratic equation is set to be greater or equal than zero to achieve stability. If the discriminant is small than zero, the roots will be imaginary, which means that cause instability in the system. Fig. 4 illustrates a single line of an interconnected network where the L_{mn} is derived from.

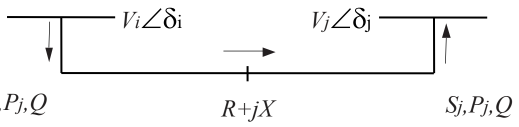

Fig. 4. Typical one line diagram of transmission line

From Fig. 1,

$$S_j = \frac{|V_i||V_j|}{Z}\angle(\theta - \delta_i + \delta_j) - \frac{|V_j|^2}{Z}\angle\theta \tag{12}$$

$$S_i = \frac{|V_i|^2}{Z}\angle\theta - \frac{|V_i||V_j|}{Z}\angle(\theta + \delta_i - \delta_j) \tag{13}$$

From (12),

$$P_j = \frac{|V_i||V_j|}{Z}\cos(\theta - \delta_i + \delta_j) - \frac{|V_j|^2}{Z}\cos\theta \tag{14}$$

$$Q_j = \frac{|V_i||V_j|}{Z}\sin(\theta - \delta_i + \delta_j) - \frac{|V_j|^2}{Z}\sin\theta \tag{15}$$

Assume $\delta = (\delta_i - \delta_j)$

From (15),

$$V_j = \frac{V_i\sin(\theta-\delta) \pm \left\{ \left[V_i \sin(\theta-\delta) \right]^2 - 4ZQ_j\sin\theta \right\}^{0.5}}{2\sin\theta} \tag{16}$$

Assume $x = Z\sin\theta$

$$V_j = \frac{V_i\sin(\theta-\delta) \pm \left\{ \left[V_i \sin(\theta-\delta) \right]^2 - 4xQ_j \right\}^{0.5}}{2\sin\theta} \tag{17}$$

real value of $V_j = \dfrac{4XQ_j}{[V_i\sin(\theta-\delta)]^2}$

$$\therefore \text{The line stability index, } L_{mn} = \frac{4XQ_j}{[V_i\sin(\theta-\delta)]^2} \tag{18}$$

Where θ is the line impedance angle and δ is the angle difference between the supply voltage and the receiving end voltage. Lines that demonstrates values of L_{mn} close to 1, indicates that those lines are closer to theirs instability points. To maintain a secure condition, the L_{mn} index should be less than 1.

IV. EVOLUTIONARY PROGRAMMING

Evolutionary Programming (EP) is one of the most intelligent techniques in optimization approaches. This technique involves process of generating the random number at the initialization. The result of generated random numbers can be represented as the parameters of the fitness value. In addition, EP also involves statistics, fitness calculation and mutation process. The new generation of EP will be taken as a result of the selection.

A. Evolutionary Programming Algorithm

As mentioned before, EP is the process which involved initialization, fitness calculation, statistics, mutation and selection. Detailed explanation of each of the process will be explained in next sections. The overall EP process is represented in the form of flow chart as illustrated in Fig. 5.

A1. Random Number Generation

Initialization process in EP is conducted by generating a series of random number using a uniform distribution number. For the UPFC optimization process, the random number represents the additional capacitance to be added to the system. The number of variables was chosen to show the effectiveness of using UPFC in controlling the voltage stability. For IEEE 30 bus system, five variables namely X_1, X_2, X_3, X_4 and X_5 will be generated to represent the additional shunt capacitance that need to add to line 8, 11, 12, 13 and 15.

These variables will be assigned as the additional capacitance value (C_a). Some constraints must be set at the beginning so that the EP will only generate random numbers that satisfy some predetermined conditions. The constraints imposed during the initialization are the L_{mn} value must be less than L_{mn_set}. The L_{mn} value calculated using the generated random numbers must be smaller than L_{mn_set} so that the fitness will be improved. Otherwise, the solution may converge but does not optimize the voltage stability condition [8].

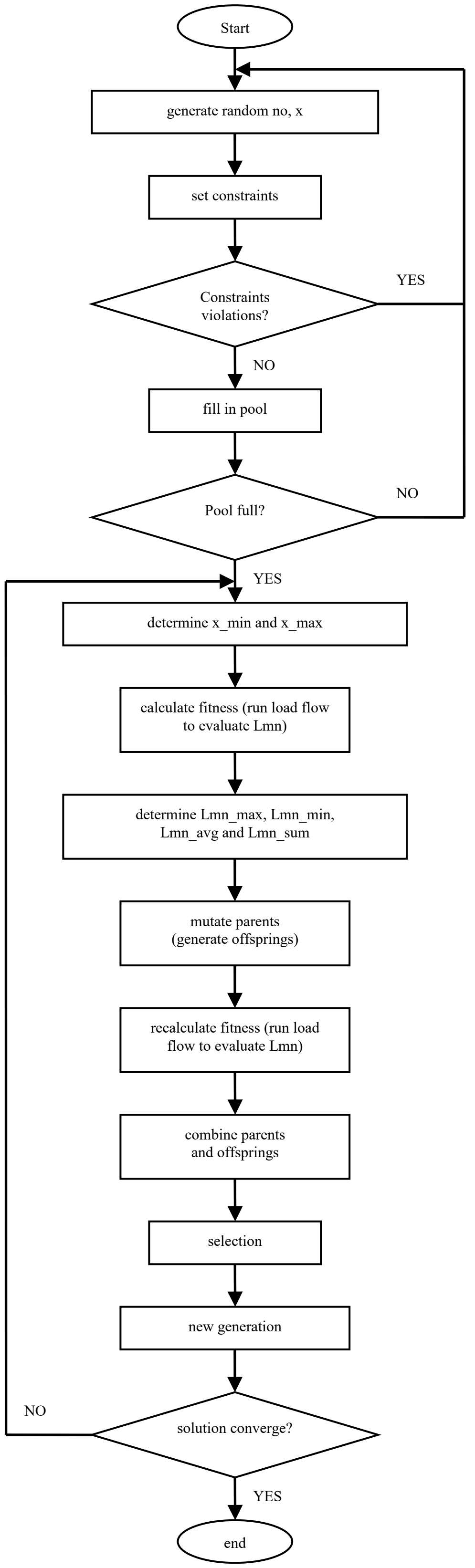

Fig. 5. Flow chart for EP

A2. Fitness Calculation and Statistics

L_{mn} is taken to be the objective function, which needs to be minimized. In this study, the fitness is calculated by an ac load flow program. It is done by calling the load flow programmed into the EP main program in order to compute the L_{mn} values. Thus in this problem, the objective function is not going to be a single mathematical equation but rather a subroutine which will be executed accordingly in the EP main programmed. Subsequently, evaluation of maximum, minimum, sum and average of fitness will be carried out which will be utilized in the mutation process [8].

A3. Mutation

Mutation is performed on the random number, x_i to produce offspring. The mutation process is implemented based on the following equation:

$$x_{j+m,j} = x_{i,j} + N\left(0, \beta\left(x_{j\max} - x_{j\min}\right)\left(\frac{f_i}{f_{\max}}\right)\right) \quad (19)$$

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

$x_{i,j}$ = parents

N = Gaussian random variable with mean, μ and variance, γ2

β = mutation scale, 0<β<1

$x_{j\max}$ = 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_{mzx} = maximum fitness

The mutation scale, β can be manually adjusted in original EP to achieve better convergence. The larger value of β can cause fast convergence of the EP and vice versa.

A4. Selection

The offspring produced from the mutation process are combined with the parents to undergo a selection in order to identify the candidates that have chance to be transcribed into the next generation. Since the objective of this study is to improve the voltage stability using L_{mn} value as the fitness, therefore the population will be ranked in ascending order based on the minimum L_{mn} value.

A5. Convergence Test

The convergence criterion is specified by the difference in maximum fitness and minimum fitness ≤ 0.0001. If it is not reached, the process will repeat.

$$\max_{fitness} - \min_{fitness} \leq 0.0001 \quad (20)$$

V. TEST SYSTEMS

The proposed UPFC installation scheme was validated on the IEEE 30 bus Reliability Test System in order to optimize the L_{mn} value. This system has 24 load buses and 6 generator buses with 41 interconnected lines [8]. Once L_{mn} has been optimized, the capacitance value in the system that should be added in line can be determined.

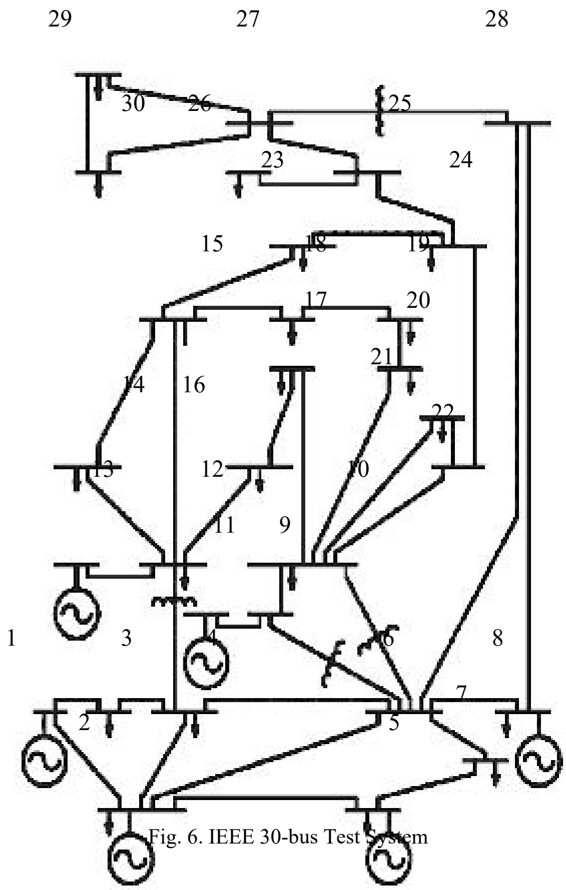

Fig. 6. IEEE 30-bus Test System

VI. RESULTS AND DISCUSSION

As described in the previous sections, the objective function is to improve voltage stability index and voltage in an electric power system by taking L_{mn} as the fitness value. Tests were performed to the system with load subjected to buses 9, 17 and 24 at various loading conditions. The effect of population size to the optimization performance was also conducted; where it is adjusted from 5 to 20.

A. Voltage Profile Improvement with UPFC Installation

TABLE I, II and III tabulated the results of the voltage profile improvement at buses 9, 17 and 24.

The results of voltage profile improvement when loading condition variation subjected to bus 9 was tabulated as in TABLE I. Since the reactive power loading was increased, the voltage profile is decreased. It is also shown that the voltage profile will be improved after the implementation of UPFC. The size of UPFC is determined by using EP.

TABLE I: RESULTS FOR VOLTAGE PROFILE IMPROVEMENT AT BUS 9

Loading Condition	Voltage (p.u)	
(MVAr)	Without UPFC	With UPFC
10	1.0430	1.0458
20	1.0291	1.0334
30	1.0167	1.0227
40	1.0041	1.0118
50	0.9913	1.0007
60	0.9750	0.9862
70	0.9640	0.9784
80	0.9574	0.9711

Fig. 7 shows the illustration of voltage profile improvement when loading condition variation is subjected to bus 9. The voltage at bus 9 increased significantly with the installation of UPFC.

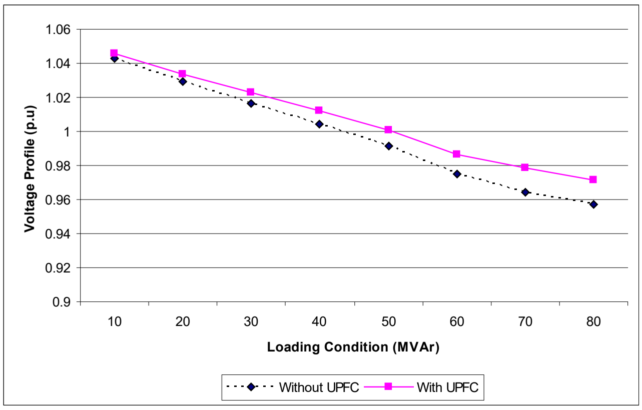

Fig 7: Results for voltage profile improvement with and without UPFC installation when load is subjected to bus 9

On the other hand, the results of voltage profile improvement for bus 17 are tabulated as in TABLE II.

TABLE II: RESULTS FOR VOLTAGE PROFILE IMPROVEMENT AT BUS 17

Loading Condition	Voltage (p.u)	
(MVAr)	Without UPFC	With UPFC
10	1.0328	1.0353
20	1.0156	1.0189
30	0.9996	1.0018
40	0.9806	0.9865
50	0.9603	0.9707
60	0.9272	0.943
70	0.9046	0.9166
80	0.8728	0.8901

From TABLE II, it is observed that voltage at bus 17 will decrease as the reactive power loading is increased. It is also noticed that the voltage profile will be improved after the implementation of UPFC. The results of voltage profile improvement when loading condition variation is subjected to bus 17 are illustrated in Fig. 8.

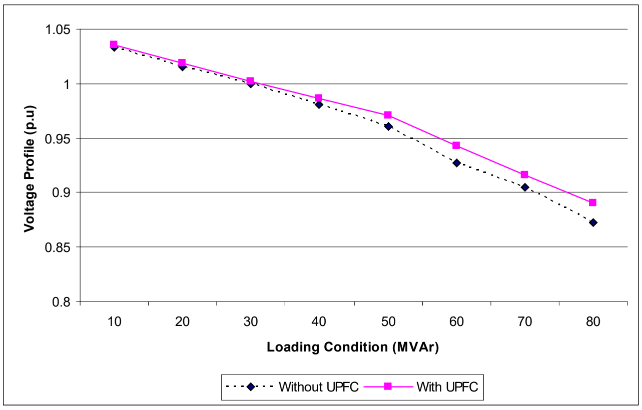

Fig 8: Results for voltage profile improvement with and without UPFC installation when load is subjected to bus 17

TABLE III tabulated the result of voltage profile improvement when loading variation is subjected to bus 24. Voltage at bus 24 is accordingly decreased when the reactive power loading is increased.

TABLE III: RESULTS FOR VOLTAGE PROFILE IMPROVEMENT AT BUS 24

Loading Condition (MVAr)	Voltage (p.u)	
	Without UPFC	With UPFC
10	1.0149	1.0163
20	0.9921	0.9981
30	0.9703	0.9781
40	0.9451	0.9539
50	0.9174	0.9253
60	0.8748	0.8847
70	0.8367	0.8451
80	0.7877	0.8022

The results for voltage profile improvement with the effect of UPFC installation are shown in Fig 9.

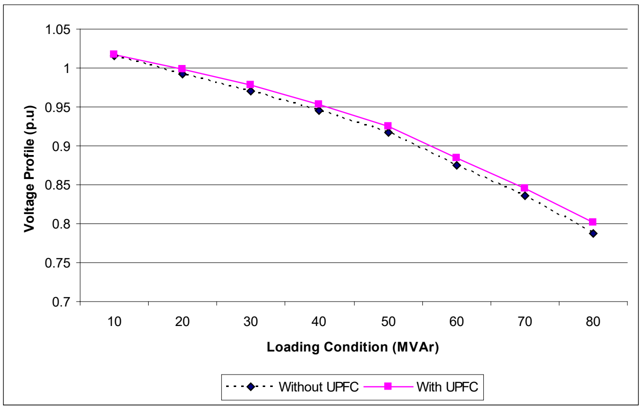

Fig 9: Results for voltage profile improvement with and without UPFC installation when load is subjected to bus 24

From Fig. 9, we can see that the voltage profile will be improved with UPFC installation.

B. Voltage Stability Index Improvement with UPFC Installation

Results for the voltage stability index improvement at buses 9, 17 and 24 are tabulated in TABLE IV, V and VI.

TABLE IV: RESULTS FOR VOLTAGE STABILITY INDEX IMPROVEMENT AT BUS 9

Loading Condition (MVAr)	L_{mn}	
	Without UPFC	With UPFC
10	0.1989	0.0771
20	0.2028	0.0709
30	0.2036	0.0885
40	0.208	0.0893
50	0.215	0.0947
60	0.2475	0.0973
70	0.3022	0.1262
80	0.3504	0.2845

Table IV shows the results of voltage stability index improvement when loading condition variation was subjected to bus 9. As the reactive power loading is increased, voltage stability index at the corresponding line also increased. It is also shown that the voltage stability index can be improved after the implementation of UPFC indicated by the reduction in L_{mn}.

The voltage stability improvement with the effect of UPFC installation is shown in Fig 10. Apparently, the voltage stability is lower with the UPFC installation.

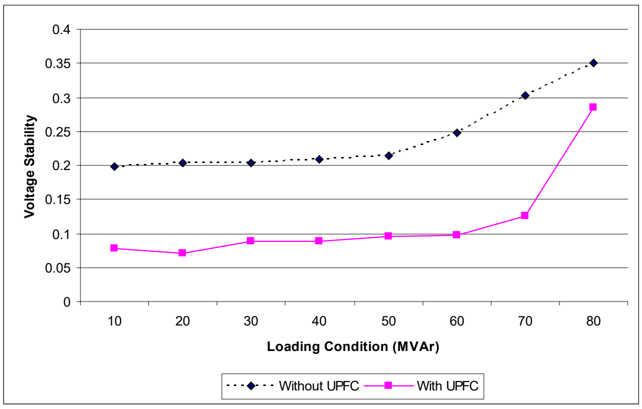

Fig 10: Results for voltage stability index improvement with and without UPFC installation for load variation at bus 9

TABLE V tabulates the results for voltage stability index improvement when load is subjected to bus 17.

TABLE V: RESULTS FOR VOLTAGE STABILITY INDEX IMPROVEMENT AT BUS 17

Loading Condition (MVAr)	L_{mn}	
	Without UPFC	With UPFC
10	0.2010	0.0515
20	0.1993	0.0564
30	0.1874	0.0583
40	0.2017	0.0830
50	0.2319	0.0676
60	0.2579	0.0795
70	0.3172	0.1057
80	0.3719	0.2412

From TABLE V, it is observed that voltage stability index L_{mn} at the corresponding line when load was subjected to bus 17 is increased as the reactive power loading is increased. From TABLE V, it is also noticed that the voltage stability index will be improved after the implementation of UPFC. Voltage stability index improvement when loading condition variation is subjected to bus 17 is illustrated in Fig. 11.

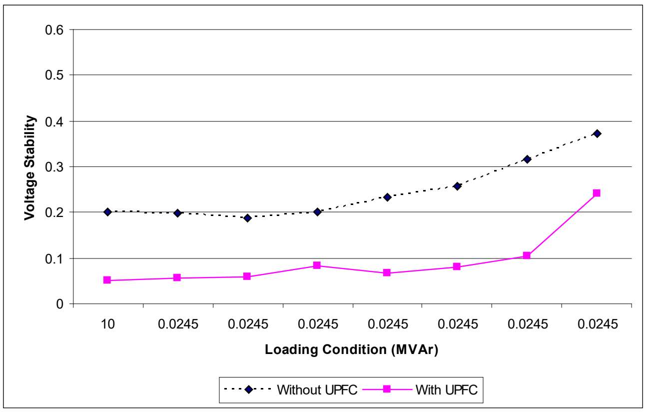

Fig 11: Results for voltage stability index improvement with and without UPFC installation for load variation at bus 17

Result of voltage stability index improvement when loading variation is subjected to bus 24 is tabulated as in TABLE VI. As we can see in TABLE VI, voltage stability index at the corresponding line will be accordingly increased when the reactive power loading is increased.

TABLE VI: RESULTS FOR VOLTAGE STABILITY INDEX IMPROVEMENT AT BUS 24

Loading Condition (MVAr)	L_{mn}	
	Without UPFC	With UPFC
10	0.2022	0.0879
20	0.2013	0.0869
30	0.1900	0.0913
40	0.2069	0.0925
50	0.2754	0.1029
60	0.3526	0.1105
70	0.4404	0.1818
80	0.5442	0.3459

The voltage stability index profiles are shown in Fig. 12.

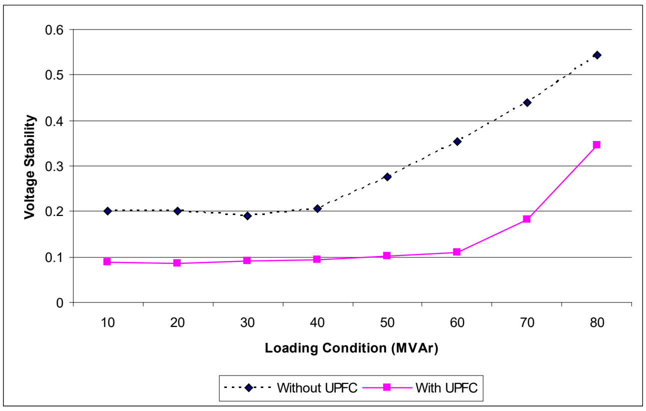

Figure 12: Results for voltage stability index improvement with and without UPFC installation for load variation at bus 24

From the figure, it can be seen that the voltage stability index is improved with the UPFC installation in the system.

C. Effect of Population Size to Optimization Performance

Results for the effect of population size to voltage profile improvement at buses 9, 17 and 24 are tabulated in TABLE VII, VIII and IX. TABLE VII tabulates the effect of population size to voltage profile when reactive load variation was subjected to bus 9.

TABLE VII: RESULTS FOR THE EFFECT OF POPULATION SIZE PERFORMED AT BUS 9

Pop. Size	Voltage Value at Bus 9 for Several Loading Condition			
	$Q_9 = 10$ MVAr	$Q_9 = 14$ MVAr	$Q_9 = 26$ MVAr	$Q_9 = 30$ MVAr
5	1.0581	1.0429	1.0320	1.0283
10	1.0601	1.0455	1.0331	1.0309
15	1.0709	1.0475	1.0379	1.0349
20	1.0714	1.0535	1.0401	1.0361

From the table, Ii can be seen that the voltage is decreased as the reactive power loading is increased accordingly. It is observed that larger population size causes higher voltage. From results, it can be indicated that the higher population size gives better performance.

Results for the effect of population size to voltage profile improvement at buses 17 are tabulated in TABLE VII. From results in TABLE VIII, it also indicates that the higher population size gives better performance in voltage values.

TABLE VIII: RESULTS FOR THE EFFECT OF POPULATION SIZE PERFORMED AT BUS 17

Pop. Size	Voltage Value at Bus 17 for Several Loading Condition			
	$Q_{17} = 10$ MVAr	$Q_{17} = 14$ MVAr	$Q_{17} = 26$ MVAr	$Q_{17} = 30$ MVAr
5	1.0514	1.0320	1.0203	1.0148
10	1.0523	1.0339	1.0249	1.0152
15	1.0574	1.0342	1.0258	1.0175
20	1.0611	1.0446	1.0267	1.0234

The effect of population size pertaining to voltage profile improvement subjected to bus 24 is tabulated in TABLE IX. From the table, the best voltage can be observed at population size of 20, particularly at higher loading condition.

TABLE IX: RESULTS FOR THE EFFECT OF POPULATION SIZE PERFORMED AT BUS 24

Pop. Size	Voltage Value at Bus 24 for Several Loading Condition			
	$Q_{24} = 10$ MVAr	$Q_{24} = 14$ MVAr	$Q_{24} = 26$ MVAr	$Q_{24} = 30$ MVAr
5	1.0086	1.0009	0.9985	0.9888
10	1.0091	1.0039	0.9995	0.9902
15	1.0113	1.0071	1.0015	0.9931
20	1.0228	1.0078	1.0040	1.0054

From TABLE VII, VIII and IX; 20 is the most suitable population size to achieve the best performance in voltage profile improvement because the reading of voltage at population of 20 are more constant compared to other population size.

7. CONCLUSION

An approach for voltage profile and voltage stability index improvement by using UPFC via EP as an optimization technique is presented. Programming codes for EP optimization technique was developed to determine the optimal value of UPFC in order to maximize the voltage profile and to minimize the voltage stability index of the transmission lines.

Tests we performed on the IEEE 30-bus Reliability Test System (RTS). The results obtained from the tests indicate that the implementation of EP has improved voltage profile and voltage stability index of the system.

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