Voltage Control Study Using UPFC Based on Biological Computing Optimization Technique

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Abstract: - Unscheduled increment of load variation in a power transmission system has driven the system to experience stressed condition leading to potential cascading trip on the entire system. Thus, close monitoring of load variation in a power network can help in avoiding system operating close to its maximum capacity. This phenomenon has also led to voltage profile depreciation below the acceptable secure limit. 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 in order to alleviate the voltage profile decay problem. Identification of the optimal value of compensating capacitors required proper optimization technique; able to search the optimal solution with less computation burden avoided. This paper presents the voltage control study using unified power flow controller (UPFC) approach based on biological computing optimization technique. In this study, optimization engine was developed for voltage profile enhancement in a power transmission system which utilized the UPFC as the control variables embedded into the system's data. The biological computing optimization technique which can also be termed as artificial immune system (AIS) has proven its feasibility to search the optimal solution of the problems. Implementation on the IEEE Reliability Test System (RTS); considering several variations in the AIS properties indicated its potential in solving voltage control 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 be immediately 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 in [3]. The applications of UPFC 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 [14] and Tae-Hyun Kim *et al.* in [18]. Other works can also be referred to other published work reported in [19].

This paper presents artificial immune system based optimization technique for voltage profile improvement using UPFC. AIS can be defined as a metaphorical computational system developed using ideas, theories and components extracted from the immune system [4]. This study involved the implementation of AIS by taking the voltage profile improvement as the objective function. Tests were performed on the IEEE 30-bus RTS to realize the effectiveness of the proposed technique.

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.

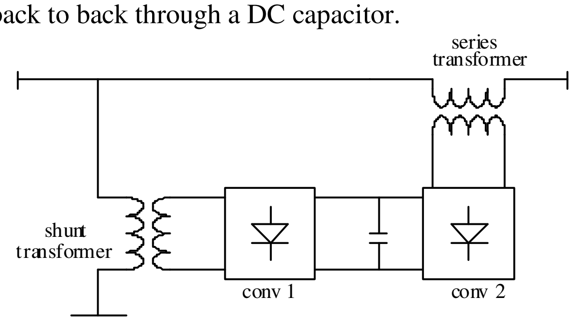

Fig. 1: UPFC Model

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].

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 the 'i' and 'j' buses. This series branch can be modeled as an ideal voltage source $\overline{V}_s$ in series with a reactance X_s [6]. On the other hand, Fig. 2 illustrates $\overline{V}_s$ that represents an ideal voltage source; and $\overline{V}_i$ represents the voltage behind the series reactance.

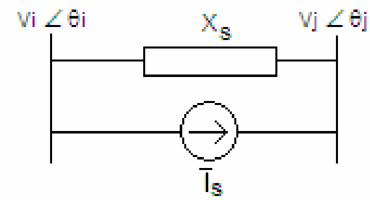

Fig. 2: Equivalent Norton circuit for series branch

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

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

$$\overline{S}_{is} = \overline{V}_i(-\overline{I}_s)^* \tag{1}$$

$$\overline{S}_{js} = \overline{V}_j(-\overline{I}_s) \tag{2}$$

$$S_{is} = \overline{V}_i[jb_s r\overline{V}_i e^{j\gamma}]^* \tag{3}$$

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

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

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

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

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

Based on equation (1) and (2), the series voltage source is considered as two-voltage dependent loads.

3 Artificial Immune System

Artificial Immune System is a biological immune system which is highly parallel, distributed and adaptive system. Another definition for AIS is that; it 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 clonal 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, clonal selection algorithm and immune network models.

3.1 General AIS Algorithm

AIS involves several operators such as initialization, fitness computation, clonal, mutation, clonal 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.

4 Methodology

The implementation of voltage profile improvement considers three control variables which act as UPFCs. Multi UPFCs are inserted in the transmission lines in series connection. Thus in this study three random numbers are generated during the initialization process with objective function to optimize the voltage profile at the subjected bus in the transmission system. Resulted voltage greater than the *voltage_set* 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:-

- i. Set the voltage constraints, i.e. *Voltage* ≤ *V_set*.
- ii. Generate three random numbers, variables x_1, x_2 and x_3. They are termed as the *parents*.
- iii. Find for constraints violations. If violated, go to step ii, otherwise go to the next step (iv).
- iv. Fill in the population pool according to the required value.
- v. If the pool is not full, go back to step ii; otherwise go step vi.
- vi. Determine the *x_min* and *x_max*.
- vii. Assign the x_1, x_2 and x_3 in the system line-data.
- viii. Calculate fitness 1 by running the load flow program in order to evaluate the voltage values.
- ix. Determine the *voltage_min* and *voltage_max*.
- x. Clone the *parents*. This creates 200 populations for 20 populations of *parents*.
- xi. Mutate the *parents*. This will breed *offsprings*.
- xii. Recalculate fitness using the *offsprings*.
- xiii. Selection of *offsprings*.
- xiv. Define next generation to be the parents for next evolution.
- xiv. If solution converges, stop the process otherwise; repeat step x to xiv.
- xv. Stop the AIS process.

5 Results and Discussion

Voltage profile improvement based on the optimization technique by using the UPFCs as the control variables was conducted. Tests were performed at 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, 10, 15 and 20.

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.

Table 1: Results For Voltage Profile Improvement at Bus 9

Loading Condition (MVar)	Voltage (p.u.)	
	Without UPFC	With UPFC
10	1.0430	1.0442
20	1.0291	1.0305
30	1.0167	1.0223
40	1.0000	1.0058
50	0.9913	0.9932
***60**	**0.9750**	**0.9771**
70	0.9640	0.9661
80	0.9547	0.9557

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. For instance, at Q_{d9} = 60 MVar, the voltage 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 improved the voltage profile in the system. The size of UPFCs are determined by the AIS.

The results for voltage profile improvement when loading condition variation is subjected to bus 9 are illustrated in Fig. 3. With UPFC installed in the system, voltage at bus 9 had been increased significantly.

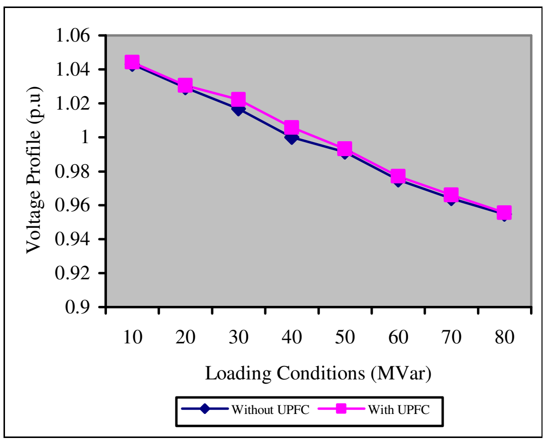

Fig.3: Results for voltage profile improvement with and without UPFC at bus 9

On the other hand, the results for voltage profile improvement for bus 17 are tabulated in Table 2.

Table 2: Results for Voltage Profile Improvement at Bus 17

Loading Condition (MVar)	Voltage level (p.u.)	
	Without UPFC	With UPFC
10	1.0328	1.0348
20	1.0156	1.0178
30	0.9996	1.0021
40	0.9806	0.9834
50	0.9577	0.9632
60	0.9272	0.9304
***70**	**0.9046**	**0.9083**
80	0.8728	0.8769

From the table, it is observed that voltage at bus 17 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. For instance, at Q_{d17} = 70 MVar, the voltage has been increased from 0.9046 p.u. into 0.9083 p.u.. The results for voltage profile improvement when loading condition variation is subjected to bus 17 are illustrated in Fig. 4. However, the difference in voltage profile improvement is not graphically obvious. Detail results can be referred to Table 4.

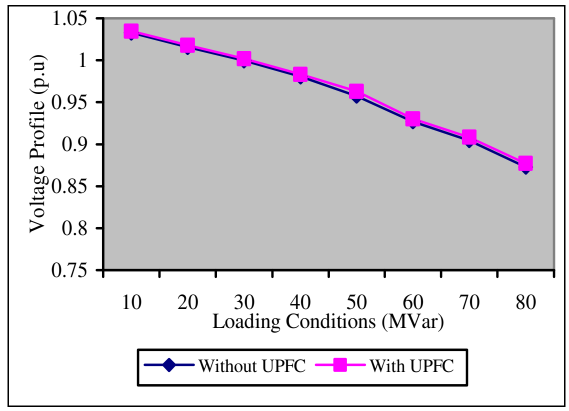

Fig. 4: Results for voltage profile without UPFC and with UPFC at bus 17

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 increases accordingly as the reactive power loading is increased. For instance, at Q_{d24} = 80 MVar, the voltage has been increased from 0.7877 p.u. to 0.8551 p.u..

Table 3: Results for Voltage Profile Improvement at Bus 24

Loading Condition (MVar)	Without UPFC	With UPFC
10	1.0149	1.0348
20	0.9921	0.9964
30	0.9703	0.9797
40	0.9451	0.9622
50	0.9111	0.9383
60	0.8748	0.9049
70	0.8367	0.8738
***80**	**0.7877**	**0.8551**

The results for voltage profile improvement when loading condition variation is subjected to bus 24 are illustrated in Fig. 4.

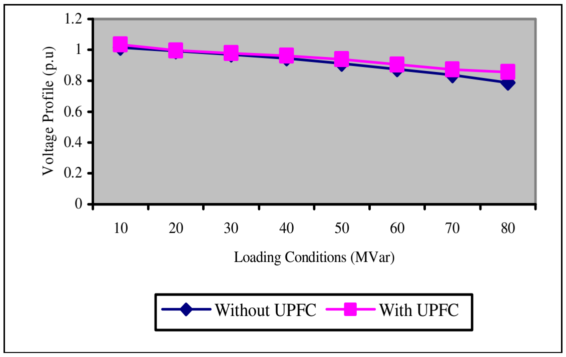

Fig 5: Results for voltage profile without UPFC and with UPFC at bus 24

From the figure, the installation of UPFC has significantly increased the voltage profile 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. The effect of population size to voltage profiles when reactive load variation was subjected to bus 9 are tabulated in Table 4.

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

Pop. Size	Voltage Value at Bus 9 for Several Loading Conditions			
	$Q_9 = 10$ Mvar	$Q_9 = 14$ Mvar	$Q_9 = 26$ Mvar	$Q_9 = 30$ 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. For instance, at population size of 5, the voltage profile at $Q_9 = 10$ 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.

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 $Q_{17} = 10$ 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.

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

Pop. Size	Voltage Value at Bus 17 for Several Loading Conditions			
	$Q_{17} = 10$ Mvar	$Q_{17} = 14$ Mvar	$Q_{17} = 26$ Mvar	$Q_{17} = 30$ 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 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. However, Therefore, it is better to have 20 populations size for all buses in order to achieve better voltage profile improvement in the system.

6 Conclusion

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 UPFC 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. Minor alteration in the developed engine can be implemented in order to solve other optimization problems.

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