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GENETICALLY OPTIMIZED UPFC CONTROLLER FOR IMPROVING TRANSIENT STABILITY

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***Abstract*— An electrical power system is a complex network which consists of numerous generators, transformers, transmission lines and variety of loads. The power demand should be equal to the power generated then the system will be stable. Transient stability is a complicated problem in the power system transmission lines for maintaining synchronism. Sometime the total power losses, cascading outage of transmission lines, etc, are increased due to power loadability in lines and the system leads to collapse. In order to avoid this, the power system will be analyzed with various optimization methods. New voltage stability index is method used to determine the critical line on the transmission lines. In order to improve transient stability in power system, FACTS device can play important role on it. UPFC is one of the FACTs controllers which can control both real and reactive power of transmission lines. UPFC is needed to be locate on optimal location of system and this effective control strategies is achieved by genetic algorithm. PID controller is employed for controlling UPFC and the results obtained are by placing the UPFC in optimal location on the transmission lines. The transient stability of seven bus system is studied under some external disturbance in MATLAB/SIMLINK environment.**

***Index Terms*— Flexible AC Transmission system (FACTS), Unified Power Flow Controller (UPFC), New Voltage Stability Index (NVSI), Genetic Algorithm (GA)**

I. INTRODUCTION

An electric power system is a network of electrical components that is used to supply and transfer the power to the load for satisfying the required demand. The transmission lines get overloaded when the demand of the lines gets increases due to which the system becomes complex and this leads to serious stability issues. The most important stability issue is transient stability [1]. The stability problems of power system can be effectively reformed by the use of FACTS devices. The FACTS device is employed here in order to transfer the exceeding power from generator to the system.

FACTS are the most multifarious devices [2] used for controlling reactive power and real power in transmission line for economic and flexible operation. The main objective of FACTS devices are:

- Increases power transfer capability
- Controls power flow in specified routes
- Realize overall system optimization control

FACTS devices include Static Var Compensator (SVC), Static Synchronous Compensator (STATCOM), Thyristor Controlled Series Capacitor (TCSC), Thyristor Controlled Phase Shifter (TCPS), Static Synchronous Series Compensator (SSSC) and Unified Power Flow Controller (UPFC) etc., UPFC is used for voltage control applications. UPFC helps to maintain a bus voltage at a desired value during load variations. The UPFC can be made to generate or absorb reactive power by adjusting firing angle. The major problem in the FACTS controllers is identifying [2] the location for fixing and the amount of voltage and phase angle to be injected. The stochastic algorithms can be used for locating the FACTS devices on the transmission lines. There are several stochastic algorithms such as Genetic Algorithms, Differential Evolution, Tabu Search, Simulated Annealing, Ant Colony Optimization, Particle Swarm Optimization and Bees Algorithm. Each of these algorithms has its own advantages. Genetic Algorithms (GA), Particle Swarm Optimization (PSO) and Bees Algorithm (BA) are a few efficient and well— known stochastic algorithms.

II. UPFC OPERATION AND MATHEMATICAL MODEL

Unified Power Flow Control is a combination of parallel and series branches, each consists of separate transformer, power electric converter which is capable of turning on and off with semiconductor device and dc circuit [5].

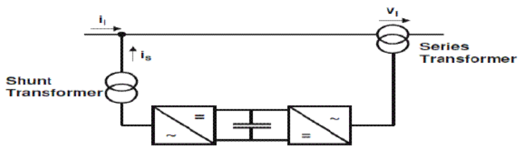

Fig no 1: Principal Configuration of UPFC Model

The DC-circuit allows the active power exchange between shunt and series transformer to control the phase shift of the series voltage, this setup is shown in Figure 1. The DC link in UPFC is used for filter the ripple content. Fig 2 shows a UPFC equivalent circuit, the parameter are connected between bus i and bus j, the voltages and angles at the buses i and j are V_i , V_j, θ_i and θ_j respectively. The main advantage of the UPFC is to control the active and reactive power flows in the transmission line.

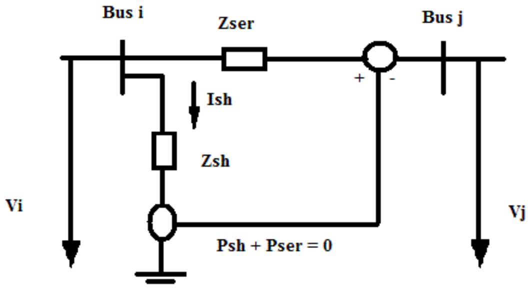

Fig no 2: UPFC Equivalent Circuit

The real power (P_{ij}) and reactive power (Q_{ij}) flow between the buses i to j can be written as follows,

$P_{ij} = V_i^2 g_{ii} - V_i V_j (g_{ij} \cos(\theta_i - \theta_j) + b_{ij} \sin(\theta_i - \theta_j)) - ViVser(gij\cos\theta i-\theta ser+bij\sin(\theta i-\theta ser))$
$V_i V_{sh}(g_{sh} \cos(\theta_i - \theta_{sh}) + b_{sh} \sin(\theta_i - \theta_{sh}))$ ----------- (1)

$Q_{ij} = V_i^2 b_{ii} - V_i V_j (g_{ij} \sin(\theta_i - \theta_j) - b_{ij} \cos(\theta_i - \theta_j)) - ViVser(gij\sin\theta i-\theta ser-bij\cos(\theta i-\theta ser))-ViVsh(gsh\sin\theta i-\theta sh-bsh\cos(\theta i-\theta sh))$ -------------- (2)

The real (P_{ji}) and reactive power flow between the buses j to i can be written as

$P_{ji} = V_j^2 g_{jj} - V_i V_j (g_{ij} \cos(\theta_j - \theta_i) + b_{ij} \sin(\theta_j - \theta_i)) + ViVser(gij\cos\theta j-\theta ser+bij\sin(\theta j-\theta ser))$ ---------- (3)

$Q_{ji} = -V_j^2 b_{jj} - V_i V_j (g_{ij} \sin(\theta_j - \theta_i) - b_{ij} \sin(\theta_j - \theta_i)) + ViVser(gij\cos\theta j-\theta ser-bij\sin(\theta j-\theta ser))$ ---------- (4)

Where

$g_{ij} + jb_{ij} = {}^1/_{Z_{ser}}$, $g_{ii} = g_{ij} + g_{sh}$, $b_{ii} = b_{ij} + b_{sh}$,
$g_{jj} = g_{ij}$, $b_{jj} = b_{ij}$, i and j = 1, 2 ...n

The operating constraint of the UPFC (the active power exchange via the dc link) is

$PE = P_{sh} + P_{ser} = 0$ ------------- (5)

Where PE is active power exchange, P_{sh} is Real power on shunt transformer and P_{ser} is real power on series transformer. The value of P_{sh} is found from $Re(V_{sh} I_{sh}^*)$ and value of P_{ser} is found from $Re(-V_{ser} I_{ser}^*)$. The UPFC absorbs and generates reactive power by adjusting firing angle so in the operating constraint of UPFC the real power of series transformer and shunt transformer is made as equal to zero.

III. LOCATION CRITERIA OF UPFC

The location of FACTs devices are based on several criteria which include sensitivity based approach, artificial intelligence methods, point of voltage collapse method frequency response, stability index and control theories [6]. FACTS device will be placed in power network for different reasons and their locations can be determined by applying different techniques. New voltage Stability Index is proposed techniques to locate device.

A. NEW VOLTAGE STABILITY INDEX

Figure 3 consists of two buses which is bus 1 and bus 2. The apparent power of bus 1 and bus 2 are $P_1 + jQ_1$ and $P_2 + jQ_2$. The current (I) passed through the impedance of transmission line. NVSI can be mathematically explained as follows by fig (3).

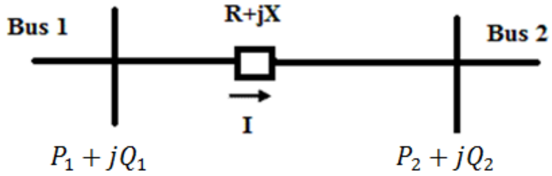

Fig No 3: Line Model

The real power can be calculated by following equation:

$P_2 = -\left(\frac{V_1 V_2}{X}\right) \sin\delta$ --------- (6)

The reactive power can be calculated by following equation:

$Q_2 = -\frac{V_2^2}{X} + V_1 V_2 \cos\delta$ --------- (7)

Rewrite the above equation as follows:

$$P_2 + \left(\frac{V_1 V_2}{X}\right) \sin\delta = 0$$
$$P_2 X + V_1 V_2 \sin\delta = 0$$
$$P_2 X + V_1 V_2 \left((1 - \cos^2\delta)^{\frac{1}{2}}\right) = 0$$

Squaring on both sides,

$P_2^2 X^2 + V_1^2 V_2^2 - V_1^2 V_2^2 \cos^2\delta = 0$ --------- (8)

Rewrite the reactive power equation as follows,

$$Q_2 + \frac{V_2^2}{X} - V_1 V_2 \cos\delta = 0$$

Squaring on both sides,

$Q_2^2 + \frac{V_2^4}{X^2} - V_1^2 V_2^2 \cos^2\delta = 0$ --------- (9)

By subtracting equation 8 and 9, we can eliminate δ and get equation as

$V_2^4 + (2Q_2 X - V_1^2) V_2^2 + X^2 (P_2^2 + Q_2^2) = 0$ -------- (10)

This is an equation of order two of V_2. The condition to have at least one solution is:

$(2Q_2 X - V_1^2)^2 - 4X^2 (P_2^2 + Q_2^2) \geq 0$ ---------- (11)

$\frac{2X\sqrt{(P_2^2 + Q_2^2)}}{(2Q_2 X - V_1^2)} \leq 1$ ---------- (12)

With taking the suffix "i" as sending end bus and "j" as the receiving bus. NVSI can be defined by as follows

$NVSI_{ji} = \frac{2X\sqrt{(P_2^2 + Q_2^2)}}{(2Q_2 X - V_1^2)}$ ---------- (13)

Where NVSI is new voltage stability index, V_1 is the magnitude of bus 1, P_2 and Q_2 is the real and reactive power of bus 2. If the equation (13) is equal to 1.00 then the respective line is said to be maintain stable in transmission lines.

IV. GENETIC ALGORITHM

Genetic algorithm is proposed by Darwin in the 19th century and it is developed based on the evolutionary theories [9]. The genetic algorithm is used to solve complex optimization problems. It is a global search technique which is based on the mechanisms of natural selection and genetics, it also can search several possible solution simultaneously. The GA start with random generation of initial population Figure 4 shows the flow chart of genetic algorithm. The first step is to initialize of variables that need to taken into account. Here the optimal solution is nothing about fitness solution it is used to find the best solution that suited to the system if it is not satisfied then it goes to selection process where thousands of solution is being produced. Reproduction is the core of the evolution process where generational variations of a population are determined by genetic crossover and by random mutations that may occur. Reproduction is process of mixing genetic material from parent and it generates a quicker evolution which is compared to the one that would result if all descendants will contain a copy of their parents. The possible solution of a problem is done with a chromosome by a bit string which is codified by 0 and 1. Individuals are evaluated through a function which measures their ability of problem solving. The new population evolves based on random operators using reproduction, mutation, crossover and the evolution exits the cycle when the stop criterion is reached. The main application of genetic algorithm is to tune the controller parameter that being viewed during the optimization problem [10 - 12] and here it is done by the defined objective function and time domain simulation. Here the genetic algorithm works on chromosome which is encoded version of potential parameter of solution rather than the parameters of themselves. It overcomes problems that occur in analytical solution. Figure 4 represents the flow chart of genetic algorithm.

ALGORITHM

Step 1: Start the algorithm to find effective solution.
Step 2: Initialize the parameter that are required such as population size, number of population, number of generation.
Step 3: From the initialized parameter the possible solution are generated. It consists of thousands of solution for estimated optimization problem.
Step 4: At T=0, the condition is checked whether it is optimum solution for problem. The optimum solution is selected from possible solution which is generated through fitness function.
Step 5: If optimum solution is found then go to stop or else go to next step.
Step 6: Here the selection process is done where it selects one individual that is suited to problem.
Step 7: Then the selected individual reproduce various chromosomes which is called as child chromosome.
Step 8: Here it combine Childs chromosome with parent chromosomes and from various child chromosome suitable solution is selected. Each and every chromosomes consists of various solution
Step 9: The duration of time T is increased by 1 which leads to T+1.
Step 10: Again the optimum solution is checked with the problem and same process is repeated until solution is being found.
Step 11: Stop the algorithm when optimum solution is found.

Tuning the controller parameter can be viewed as an optimization problem in power system because setting of the controller will yield good performance. Genetic algorithm is most used algorithm. Some of the traditional method of tuning doesn't give guarantee to optimal parameter and in most cases the tuned parameter needs improvement through trial and error where as in genetic algorithm the tuning process is depend on the optimality concept through the objective function and the time domain simulation. In present study genetic algorithm is employed for the optimal tuning of UPFC controller. Table 1 shows the specified parameter for GA algorithm.

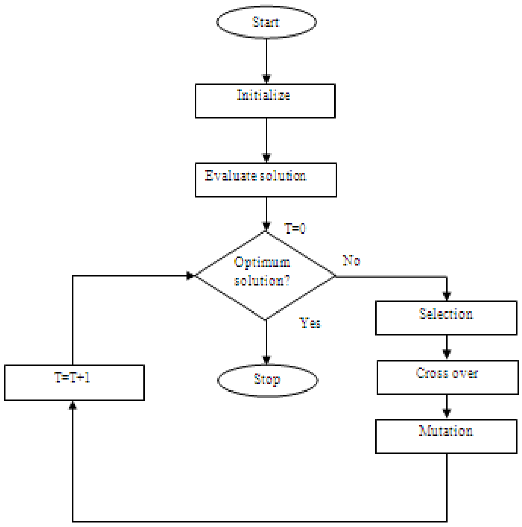

Fig no 4: Flow Chart of Genetic Algorithm

Table 1: parameter used in genetic algorithm

PARAMETER	TYPE OR VALUE
Population size	1000
Type of chromosome	1/1000
Type of crossover	uniform
Type of mutation	Bit inversion

V. UPFC PARAMETER FOR OPTIMIZATION

In this section, it explains about the UPFC parameters that are need to be considered during optimization.

1. The series angle and voltage source (θ_{ser}, V_{ser}) and the shunt angle and voltage source (θ_{sh}, V_{sh}) for UPFC are considered as the variables. These variables are adjusted as per the operation.
2. The main idea of these UPFC variables is to optimize indirectly by adjusting the active and reactive power on the line and also the bus voltage magnitude of specified line on the system. The main aim of the optimization is to determine the critical line where the instability of exist transmission lines.

VI. DESIGN OF DAMPING AND INTERNAL UPFC CONTROLLERS PARAMETER

UPFC has two internal controllers. They are Bus voltage controller and DC voltage controller which is used for controlling the internal parameter of UPFC. Here the PID controller is used for controlling UPFC control problems. The power system stabilizer is provided to improve the damping of power system oscillations [8, 13]. The feedback is controlled by controller called as proportional integral derivative control. It continuously calculates an error value. The error valve is defined as the difference between a measured process variable and desired set point. The output of PID controller will be equal to input of plant in terms of time domain. It is represented as follows:

$$u(t) = K_p e(t) + K_i \int e(t)\,dt + K_d \frac{de}{dt} \qquad \text{------- (14)}$$

Where, e is tracking error, K_p is proportional gain, u is control signal and K_i is integral gain

The equation 14 explains that PID controller is combination of P, I and D because $K_p e(t)$ is the transfer function of proportional and $K_i \int e(t)\, dt$ is transfer function of integral where as d denotes derivates on the equation.

The transfer function of PID controller for UPFC is found by taking Laplace transfer of equation (14)

Laplace transfer,

$$K_p + \frac{K_i}{s} + K_d s$$

------------- (15)

$$\frac{K_d s^2 + K_p s + K_i}{s}$$

------------- (16)

The PID controller is co-dependent on each separate function in order to update the derivative which is from the integral function as supplied data. By using PID controller the following advantage exist on the system.

- Fast in operation
- Low offset
- Low overshoot

VII. SYSTEM DESCRIPTION

The three phase, seven bus system is taken in account to show the performance of UPFC with behaviour of power system. The two buses in the system are used as generator bus while the remaining five buses in the system are used as load bus. In the simlink model, the three phase winding transformer is used for delivering the power to load. The one of block in model is used for each bus in order to view the real and reactive power of the lines.

VIII. SIMLINK MODEL

The simulated model of three phase seven bus system is used and the model is simulated and corresponding results of voltage magnitude, phase angle, real and reactive power is shown in figure respectively. Figure 5 shows simlink model of seven bus system.

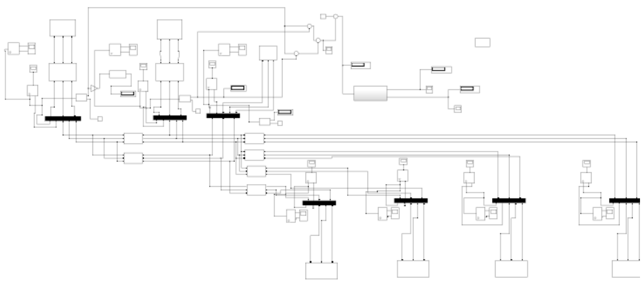

Fig no 5: Simlink model of seven bus system

In simlink model each bus in system consists of phase locked loop, phase sequence analyzer, three phase instantaneous active and reactive power. Phase locked loop (PLL) is used for synchronize on the set of variable frequency. The terminator is the most important block which is used for terminating the output signal within the simulating time. Here RLC series branch is used. The two generator bus is used as sources of system.

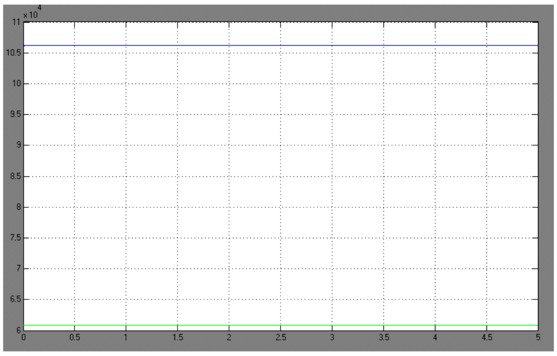

Fig no 6: real and reactive power of source bus

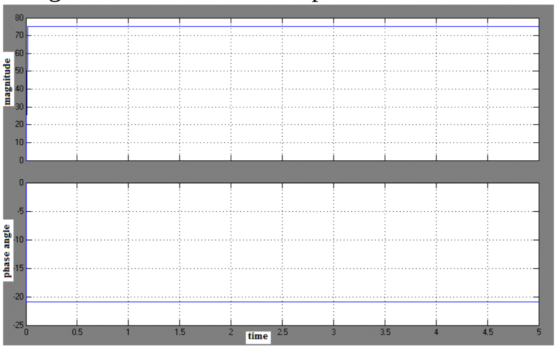

Fig no 7: magnitude and phase angle of source bus

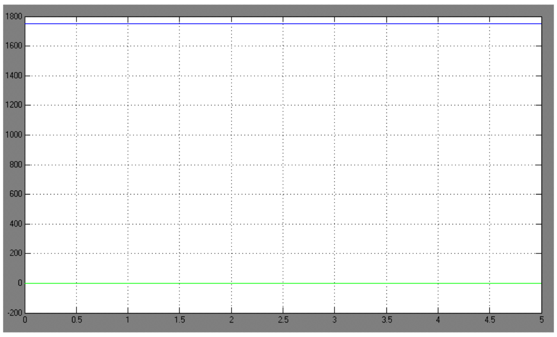

Fig no 8: real and reactive power across load bus

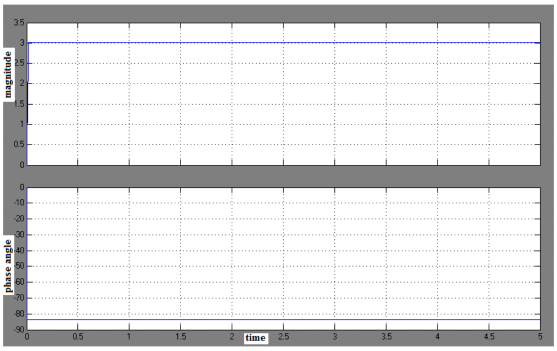

Fig no 9: magnitude and phase angle of load bus

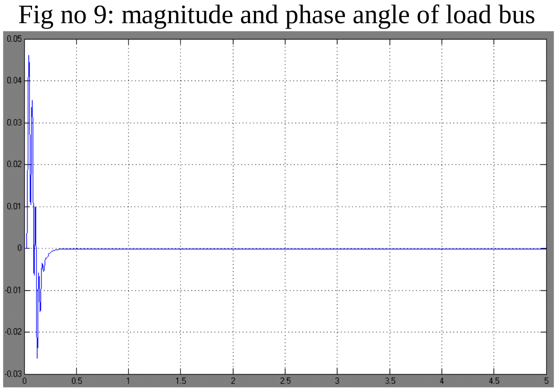

Fig no 10: frequency comparison of buses in system

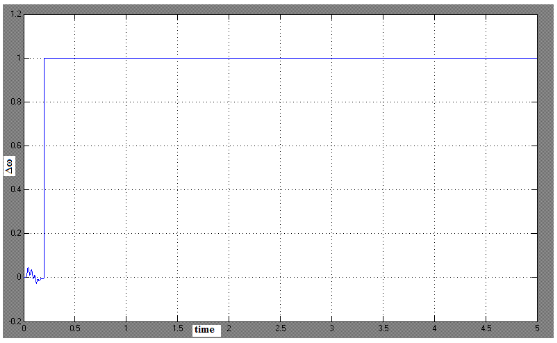

Fig no 11: system without UPFC

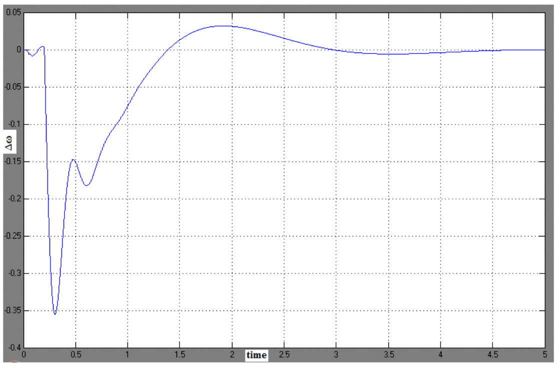

Fig no 12: bus system with UPFC (when external disturbance applied)

Figure 5 and 6 represents the real and reactive power and magnitude and phase angle of source bus where as remaining five buses are used as load bus where the corresponding graph is shown in figure 7 and 8. Here the frequency of these bus systems are compared to each other and it is shown in figure 9. Firstly the bus system operated without any fault, so in order to evaluate the improvement of transient stability the external disturbance is being applied on system. The system is simulated for the duration of 5 seconds. The genetic algorithm is most important technique which is used for solving optimization problems. UPFC detects the disturbance that occurs on the system and it is solved by the UPFC due to which the transient stability of the system improved. The external disturbance exists in system from 0.1second to 0.6second. The fault is cleared above 2 second and stability of system is maintained at the time period of 3second and it maintains same till the system is operated. The optimal location of UPFC is done by New Voltage Stability Index where it is maintained at 1.00 for making the system stable. When compared to existing system, it is cleared that UPFC plays very important role in improvement of transient stability because when TCSC controller is used it takes 6seconds to maintain system at stable and fault is cleared around 3second. When fuzzy controller is used it takes 5 to 6 second to maintain stability. So this method is more efficient when compared to other methods.

IX. CONCLUSION

This paper presents the modelling and optimizing of UPFC controller for improving the transient stability. Then simple transfer function for UPFC controller is developed and the various parameters are optimally tuned. The minimization of the rotor speed deviation from the external disturbance is formulated as the optimization problem and optimal location of UPFC controller are achieved by Genetic algorithm. The simulation results clarify that, the efficiency of the proposed algorithm and optimal location of FACTS device. This algorithm is suitable to search several possible solutions simultaneously and it is well suited for transient stability. Further this algorithm is practically easy to be implemented in power system. Here the PID controller helped in improving damping and enhancing the transient stability in the system.

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