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# Optimizing Power Loss and Voltage Stability using the GA and ANN with FACTS Devices

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**Abstract:** In the recent years, the utilization of bio inspired approach in the field of power system has increased rapidly. To optimize the power loss and to increase the voltage stability, we proposed the hybrid model with the combination of artificial neural network along with genetic algorithm. The optimal position is selected for the placement of FACTS devices using the hybrid algorithm. The proposed model is tested using the MATLAB with IEEE 30 bus system. The performances of the proposed techniques are analyzed by increasing the load in the system. The results proved the efficiency of the proposed model in terms of power loss reduction and voltage stability.

**Key words:** Artificial neural network, Genetic algorithm, FACTS devices, optimization, voltage stability, power loss

## INTRODUCTION

In general, power system networks are operated in high load conditions due to the continuous increase in the demand of the power. This sudden increase in the load imposed the risk of managing the required voltage at the bus and the system ultimately faces the voltage instability. The factors like disturbance in the condition of system and increase in the load causes the uncontrollable failure in the voltage.

Kundur (1994) proposed the voltage stability analysis techniques using the time domain analysis, P-V and Q-V analysis. Galiana *et al.* (1996) used the FACTS devices to optimize the active and reactive power control and also to regulate the voltage magnitude. The FACTS devices had the properties of reducing the load in the lines which leads to the desired voltages. By Gerbex *et al.* (2001, 2003), the operations of FACTS devices are more flexible and these devices have the ability to control the phase angle and voltage magnitude at the selected bus and also they optimize the line impedances of the system (Hingorani, 2001; Sode-Yome *et al.*, 2005).

UPFC is treated as the different one in the family of FACTS devices and it has the functionality to control all the parameter of the power flow. FACTS devices can change the parameters to control and optimize the power flow. Therefore, the optimal selection of FACTS devices leads to the effective utilization of the power system. UPFC regulates the bus voltages during different load conditions of the power system. Sode-Yome *et al.* (2005) FACTS devices improve the voltage magnitude and load ability of the power system. The hybrid approaches are used to find the optimal location and sizes of the FACTS devices. Kaur and Kakran (2012) to improve the stability of the power system it is important to select the optimal location, finding the voltage magnitude and angle injection. The proposed work focused on developing the hybrid approach by combining the Artificial Neural Network (ANN) with genetic algorithm. The ANN is used for finding the optimal location. The GA is used for finding the voltage magnitude and angle of injection.

**Literature review:** Many researchers successfully managed to develop the approaches for voltage fluctuation issues in the transmission systems. As per the intention of addressing the voltage stability, various approaches like fuzzy logic, particle swarm optimization, genetic algorithms and other parallel techniques are discussed in this study.

Prasad and Mukherjee (2016) proposed Symbiotic Organic Search (SOS) algorithm for the optimal selection of FACTS devices attach to the transmission line. The SOS algorithm uses evolution process to generate the population. The proposed model was examined with IEEE 30 bus system and IEEE 57 bus system. The proposed model considered the minimization of the fuel cost, active power loss as the objectives. Pradhan *et al.* (2016) presented the firefly algorithm to optimize the voltage using the FACTS devices. This mechanism optimizes the power loss and voltage stability limit. Mondal *et al.* (2012)

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proposed the differential equation method to set the optimal parameters for UPFC. Phadke *et al.* (2012) made an attempt to find the optimal location for placing the Static Var Compensator (SVC) and Thyrister Controlled Series Compensator (TCSC) by using the Particle Swarm Optimization (PSO).

Sirjani *et al.* (2012) enhanced the Particle Swarm Optimization (PSO) to place the FACTS devices in the power system. Due to the heavy loads, the voltage instability is the common problem faced by the power system. Therefore, the PSO (Kennedy and Eberhart, 1995) makes the quick optimal decisions. Sabri *et al.* (2013) proposed Gravitational Search Algorithm (GSA) for optimal placement of FACTS devices. This method is emerged from stochastic based meta-heuristic approach which mimics the newton laws of gravity and motion.

## MATERIALS AND METHODS

**Problem statement:** In the power systems, one of the most challenging tasks is to optimize the voltage stability (Ertas, 2013). This research work concentrates on optimizing the voltage stability and loss minimization using the combination of Genetic Algorithm (GA) and Artificial Neural Networks (ANN) (Sarkar and Roy, 2016; Amroune *et al.*, 2017). The Newton-Raphson method is used to analyze the load flow in the system. The power flow equations are developed based on the UPFC parameters and these equations are used determine the voltage and power angles at the time of power injections. The proposed approach uses ANN and GA for the optimal placement of the UPFC and for calculating the power angle to be injected. The GA is also had the additional advantage of computing the amount of voltage to be injected. The experimental results are compared with the total power loss in terms of normal load and sudden increase in load when connecting the UPFC. The major objective function of the proposed model is to reduce the power loss under different constraints. The formulation for the real power loss is given in Eq. 1:

$$L_P = \sum_{i,\,j=1}^{n} R[\mathrm{conj}((M_V(i))\times(M_V(j))\times Y_{ij}\times B \text{ value}] \quad (1)$$

Where

B = The Base value of MVA

$M_{vol}$ = The voltage magnitude

$Y_{ij}$ = The Y-bus matrix

**Equality constraint:** The load flow equations for the equality constraint are given as follows:

$$PG_i\text{-}PD_i = P_i \quad (2)$$

$$QG_i\text{-}QD_i = Q_i \quad (3)$$

Where:

$PG_i$ and $QG_i$ = The generated real power and generated real load of bus I

$PD_i$ and $QD_i$ = The generated reactive power and generated reactive power load of the bus I, respectively

**Voltage constraint:** Equation 4 shows the voltage magnitude of each node that are of allowable range $M_V^{min}$ and $M_V^{max}$:

$$M_V^{min}(i) \le M_V(i) \le M_V^{max}(i) \quad (4)$$

where, $M_V^{min}$ and $M_V^{max}$ are the limitations of the voltage magnitude.

**Reactive power constraint:** Equation 5 shows the permissible range of reactive power constraints $Q^{min}$ and $Q^{max}$:

$$Q^{min}(i) \le Q(i) \le Q^{max}(i) \quad (5)$$

Where:

$Q^{min}_{(i)}$ = The minimum limit

$Q^{max}_{(i)}$ = The maximum limit of the reactive power

**Newton-Raphson method for power flow calculation:** The power flow calculation is one of the important processes in the power systems. In general, there are different traditional approaches for load flow calculation. Newton-Raphson method is one among them which is used for calculating the power flows and line losses in all the buses. For each bus in the network, the inputs are given as bus voltage, inductance and reactance, power angle, active and reactive power. Then, the power flow and line losses of each bus are calculated. Equation 6 and 7 show the active and reactive power flow calculation in the bus:

$$P(i) = \sum_{k=1}^{n} M_V(i)\times M_V(k)[C(ik)\times\cos\theta_{ik} + S(ik)\times\sin\theta_{ik}] \quad (6)$$

$$Q(i) = \sum_{k=1}^{n} M_V(i)\times M_V(k)[C(ik)\times\sin\theta_{ik} + S(ik)\times\cos\theta_{ik}] \quad (7)$$

Where:

$M_v^{(i)}$ and $M_v(k)$ = The voltage magnitudes of the bus i and k

S(ik) and C(ik) = The susceptance and conductance values

$\Theta_{ik}$ = The angle between the bus i and bus k, respectively

In the Newton-Raphson method as an initial step, the random position is selected for achieving the optimal solution. The smart approaches require the training of the dataset which is developed by incorporating the selective features of the existing methods. ANN is one such technique used to evaluate the information of the bus and then submitted to the Genetic algorithm. Therefore, GA decides the initial solution to the problem based on the fitness function. The flow diagram for the overall procedure is given in Algorithm 1.

**Algorithm 1; Procedure for the proposed model:**

Step 1: implement Newtons-Raphson method to compute the power flow in the buses
Step 2: modeling of Fact Devices to control the voltage magnitude and phase angle
Step 3: generating the training dataset to fix the FACT devices
Step 4: training the Neural Network using the generated dataset
Step 5: training the Artificial Neural Network to fix the FACT devices at the optimal location
Step 6: employ the Genetic algorithm to compute the voltage magnitude and phase angle and to reduce the power loss

**FACTS devices:** To control the voltage magnitude and phase angle and line impedances of the selected buses is done by the FACTS devices. In the recent years, the power demand has been increased rapidly. Therefore, to meet the power requirements, the utilities have to better utilize the capabilities of the power systems. Instead of building new substations and expanding the power lines, it has to use the existing power transmission network in an effective way. UPFC is one of the efficient among the available FACTS devices which regulates the voltage and transient stability for the modern power supply systems.

**Representation of UPFC:** The Unified Power Flow Controller (UPFC) is the efficient multipurpose FACTS controller which handle real and reactive power in the power system networks rapidly and individually. It is modelled based on the combination of Static Synchronous Series Compensator (SSSC) and a Static Synchronous Compensator (STATCOM) that are connected with a DC link. This allows the power flow between the output terminals of the SSSC and STATCOM. These compensators are managed to provide the active and reactive series lines compensation without the external energy source. UPFC is treated as one of the powerful devices among the available FACTS devices. The important functionality of the UPFC is power flow redistribution along transmission lines at steady state and also it can be used to recover the low frequency oscillations. This process is carried by UPFC with the help of damping controller, power flow controller and DC voltage controller. The UPFC is different and complex power equipment that is developed for regulating the power flow in the transmission lines. The existing power flow control techniques controls the parameters selectively or simultaneously in the transmission lines. The UPFC autonomously control the active and reactive power flow in the transmission lines compared to the other controllers.

**Modelling of UPFC controller:** Equation 8 and 11 show the power injections in terms of voltage and angle:

$$L_P = \sum_{i,j=1}^{n} R[\text{conj}((M_V(i))\times(M_V(j))\times Y_{ij}\times B \text{ value}] \tag{8}$$

$$\Delta Q(i) = M_V(k)\times[C(new)\times\sin(\delta(k)-\delta(inj))-B(new)\times\cos(\delta(k)-\delta(inj))]-M_V(i) \tag{9}$$

$$\Delta P(k) = -M_V(k)\times M_V(inj)[C\times\cos(\delta(i)-\delta(inj))-S(new)\times\sin(\delta(i)-\delta(inj))] \tag{10}$$

$$\Delta Q(k) = -M_V(k)\times M_V(inj)[C\times\sin(\delta(i)-\delta(inj))-S\times\sin(\delta(i)-\delta(inj))] \tag{11}$$

where, $\Delta P(i)$, $\Delta Q(i)$, $\Delta P(k)$, $\Delta Q(k)$ are the active and reactive injecting powers for bus i and k. $M_v(inj)$ and $\delta(inj)$ are the voltage magnitude and angle injection.

$$C(new) = C(ij)+C$$
$$S(new) = S(ij)+S$$

Where:

C(new) = The Conductance of the UPFC
S(new) = The Susceptance of the UPFC

**Artificial neural network to fix the UPFC in the optimal location:** The structural and functional aspects of the Artificial Neural Network (ANN) are inspired by the biological neural network model. In this proposed method, the functionality of the ANN is to find the optimal location to fix the UPFC to manage the voltage stability. Usually ANN is operated with two stages: training and testing stages in the initial stage, the training data set is provided to the neural network and in the next stage, the input values has been given to the neural network to get the corresponding output variables.

**Calculate S(i) and S(j) by training the ANN:** In general, the training stage of ANN is composed of three layers such as input, hidden and output layer. The input layer is

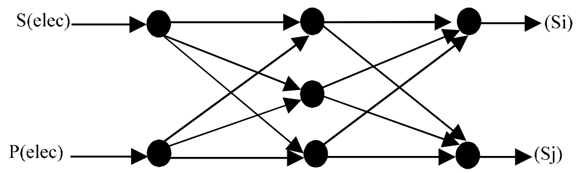


Fig. 1: Artificial neural network for proposed model

associated with two variables called as power error and fault occurred bus number. The output layer is associated with bus locations where the UPFC is fixed. The ANN considers the above parameters to train the neural network and for training back propagation algorithm is used. Figure 1 shows the structure of the neural network which is used for the proposed model. The following steps are used to train the neural network:

- Each neuron is initialized with some input weight
- Apply the sample training set to the neural network

Here, $S_{elec}$ and $P_{elec}$ is the input parameters to the network and $S_i$ and $S_j$ are the output received from the network:

$$S(i) = \sum_{r=1}^{n} W_{2r1} Y(r) \quad (12)$$

$$S(j) = \sum_{r=1}^{n} W_{2r2} Y(r) \quad (13)$$

Where:

$$Y(r) = \frac{1}{1+\exp(-w_{11r} \times (S_{elec}+P_{elec}))} \quad (14)$$

Equation 12-14 represents the activation function performed in the input and output layers, respectively:

- Adjust the weights of the neurons
- Identify the location to fix the fact devices

**Testing phase:** In the testing phase, the input is given as power error and fault bus to the network and the output generated by the network is optimal location to insert the UPFC device. After inserting the UPFC in the optimal location, then the next process is to employ the genetic algorithm to compute the voltage and angle injections.

**Genetic algorithm for optimal voltage injection:** Genetic algorithm is a bio inspired approach which has the functionality of selecting the optimal solution from the global problem search space. The GA always produces the best solution based on the initialization of the population. In 1970's, John Holland developed the GA in the university of Michigan. The GA usually follows the iterative procedure. At each iteration step, the crossover and mutation operations are performed to generate the new population. The chromosomes in the population are evaluated using the fitness function. Based on the combination of different populations with good fitness values, the best population for candidate solution is framed. If the deserved search goal is not achieved, then GA has to be employed again until it achieves the search goal. Algorithm 2 shows how GA will operate:

**Algorithm 2; Genetic algorithm for optimal voltage injection:**

Step 1: specify the input parameters for GA
Step 2: generate the initial population such as voltage $S_n$ and angle $\theta_n$
Step 3: calculate the fitness function based on Eq. 15
Step 4: if the best individual is achieved then
    Select the chromosome as the best population
  Otherwise
  Apply cross over and mutation to the population
  Repeat the process until it reaches to the best population
Step 5: End

**Genetic algorithm to compute the $S_i$ and $Q_i$:** In the proposed method, the genetic algorithm is used to compute the voltage and angle which has to be injected in to the line. The GA uses natural evolution process to develop the search heuristics. GA works with five modules: initialization of the chromosomes, calculation of fitness function, crossover, mutation and termination.

**Initialization of chromosomes:** As an initial step in the genetic algorithm, the chromosomes are generated using the random voltage and angle. In the proposed model, two initial chromosomes are generated. They are given as $S_n = \{S_1, S_2, ..., S_n\}$ and $\theta_n = \{\theta_1, \theta_2, ..., \theta_n\}$ where n is the number of genes in the chromosome. The initial chromosomes are designed based on the minimum and maximum values of the entire population. After chromosomes initialization, the next step is to calculate the fitness function.

**Fitness function:** In GA, fitness function is the major module to select the best population. In the proposed method, the fitness function identifies the total power loss in the system. Equation 15 is chosen as the fitness function to identify the power loss from the generated chromosomes in the initialization module:

$$L_P = \sum_{i,j=1}^{n} R[\mathrm{conj}((M_V(i)) \times (M_V(j)) \times Y_{ij} \times B \text{ value}] \quad (15)$$

**Crossover operation:** The cross operation perform between the two chromosomes which generates the new population. The cross over rate decides the properties of the child chromosome. The proposed method considered 0.8 as the crossover rate $C_r$. Based on this, the new population is evolved. As a next step, the fitness function is calculated to the newly generated population. The mutation process is employed after completing the crossover operation.

**Mutation operation:** The mutation operation changes the combination of the chromosome structure. The Mutation rate decides the quality of the solution. The mutation rate must be low to achieve the best solution. The mutation rate $M_r$ for the proposed model is chosen as 0.02.

**Termination:** The termination stage is the final stage where the GA selects the best chromosome (i.e., the best voltage and angle injection to reduce the power loss). If the optimal chromosome is not obtained, then the GA repeats the above procedure until it reaches to the maximum iterations.

## RESULTS AND DISCUSSION

The proposed model will be simulated in SimPowerSystems or Simulink with MATLAB to study congestion management in deregulated power system by Choice and Allocation flexible AC Transmission Systems (FACTS) optimally using ANN and GA approaches. The proposed model is tested with IEEE 30 bus system. The simulation is carried with different scenarios. The first one is normal method that applies the conventional Newton-Raphson approach. The second one is increasing the load in bus. The third one is inserting the UPFC device at the optimal location using the proposed method. The GA parameters used for the proposed method is given in Table 1.

Figure 2 shows the IEEE 30 bus system that consists of six generator buses (Bus No. 1, 2, 13, 22, 23, 27). Here, the UPFC is connected in the line of bus number 6-8 which is selected as optimal location by the proposed method. Figure 3 and 4 show the performance of the proposed method when compared with the conventional NR method in terms of voltage profile and active power loss.

Figure 3 shows the performance of the proposed model in terms of voltage when compared to the Newton-Raphson method. The two scenarios are tested: one is voltage at normal condition and other one is increase in the load at bus 6. The UPFC is fixed at the line of bus 6-8. It is noticed that the voltage profile is decreased due to the fixing of UPFC compared to the normal condition and also it is identified that the voltage profiles of remaining buses also enhanced.

Table 1: GA parameters

| Parameters | Values |
|---|---|
| Size of the population | 20 |
| Crossover rate | 0.8 |
| Mutation rate | 0.02 |
| Number of iterations | 50 |

Table 2: Performance comparison of active power loss at IEEE 30 bus system

| | Conventional Newton-Raphson | Proposed method | |
|---|---|---|---|
| Bus No. | method (MW) | UPFC bus connection | ANN and GA (MW) |
| 3 | 17.812 | 3--4 | 16.841 |
| 4 | 17.812 | 4--6 | 17.164 |
| 6 | 17.812 | 6--8 | 16.835 |
| 10 | 17.812 | 10--21 | 17.127 |
| 12 | 17.812 | 12--16 | 17.131 |
| 18 | 17.812 | 18--19 | 17.626 |
| 24 | 17.812 | 24--25 | 17.379 |

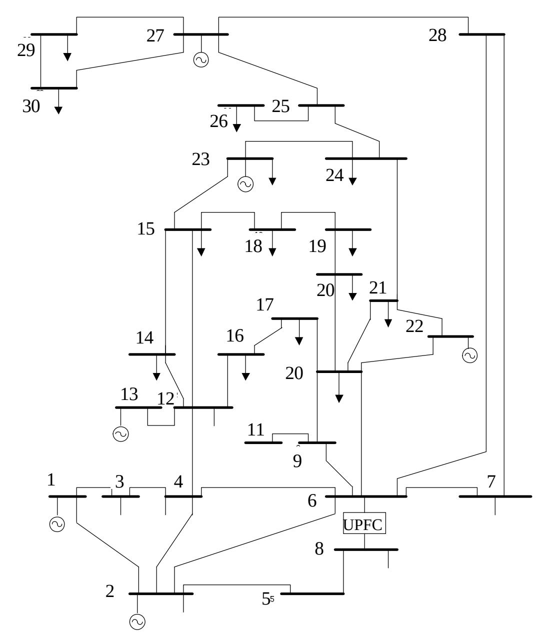


Fig. 2: IEEE 30 bus system connected the UPFC device

Table 2 shows the active power loss of the conventional Newton Raphson Method and the proposed method. The graph representation of the active power loss is given in Fig. 4.

Figure 4 shows the active power loss of the conventional Newton-Raphson method and the proposed method. The active power loss is in the normal load condition is recorded as 17.812 MW for all the buses. After placing the UPFC in the line of bus 6 and 8, the active power loss is recorded as 16.835 MW and also it is observed that the active power loss of all the buses is reduced.

From Table 3, it is observed that the proposed method recorded 4.28% loss reduction compared to the GA (Nikoukar and Jazaeri, 2007), 3.39% loss reduction

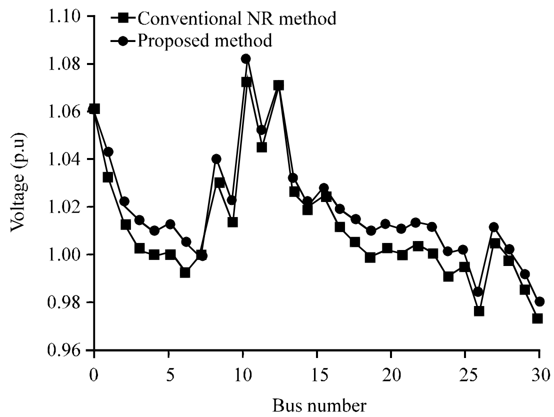


Fig. 3: Performance of the voltage profiles in the IEEE 30 bus system

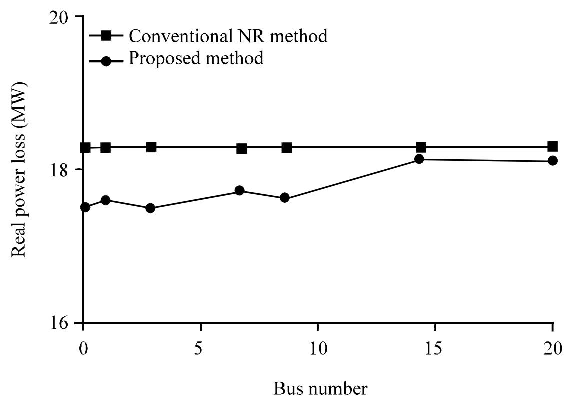


Fig. 4: Performance comparison active power loss in the UPFC

Table 3: Performance comparison of proposed method with existing methods in terms of active power loss

| Methods | Real power loss (MW) |
|---|---|
| GA (Nikoukar and Jazaeri, 2007) | 17.695 |
| GA+PSO (Kalaivani and Kamaraj, 2012) | 17.523 |
| PSO (Raj *et al.*, 2008) | 17.221 |
| ANN+GA | 16.835 |

compared to the GA+PSO (Kalaivani and Kamaraj, 2012), 1.74% compared to the PSO algorithm. This comparison shows the performance of the proposed method that reduces the active power loss compared to the existing methods.

Figure 5 shows the overall performance analysis of the conventional NR method and ant the proposed method in terms of computation time. The proposed method selected the best location in 6.8856 sec and calculated the UPFC capacity in 19.8989 sec. The total computation time of the proposed method is estimated to be 24.3265 sec. It is proved that, the proposed method is efficient compared to the existing method.

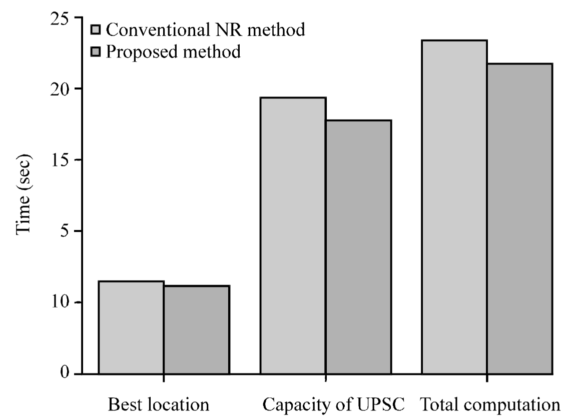


Fig. 5: Performance analysis with respect to computation time

## CONCLUSION

This study proposed a hybrid technique to locate the optimal position for fixing the UPFC device in the system. The ANN is used to calculate the voltage and angle injections in the system for improving the voltage stability. The IEEE 30 system bus is implemented in the MATLAB to test the proposed model. The performance of the proposed method is analyzed in normal condition and sudden increase in the load. It is observe that, the voltage stability is decreased and power loss is increased when there is increase in the load. The proposed method improved the voltage stability and decreased the power loss compared to the existing methods.

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