CHAPTER 3
MODELLING AND ANALYSIS OF D-FACTS DEVICES USING AI TECHNIQUES

Due to economic and environmental constraints, power systems are being operated very near to loadability limit. The rapid increase in load and non-optimal use of transmission lines adversely affect the stability of the power systems. Under this scenario, maintaining a stable and secure operation of power system is a very challenging issue. Therefore, voltage stability by Van Cutsem T, et al., in 1998, is being regarded as one of the main concerns to maintain system security. Voltage stability is the ability of the power system to maintain acceptable voltage profile under normal conditions and even after being subjected to disturbances. Voltage collapse is the process by which the system voltage falls to a low, unacceptable value as a result of an avalanche of events accompanying voltage instability. The approaches for voltage stability assessment can be classified into static and dynamic approaches. Static voltage stability assessment is suitable for operational scheduling problems.

Analysing the system and modelling the system with addition of SMART devices to identify and correct the exact value of demand should reduce or self-heal the system. Accuracy of the data can be determined only by mathematically modelling and to ease the work, computer modelling will add value to the data. This also helps in study by varying the load, injecting the fault into the system, maximising the loading parameters and voltage profile. Load flow analyses are done using both heuristic and computational techniques like Fuzzy, Neural, GA, PSO, and ACO matching the IEEE standards.

3.1 Reactive Power / Voltage Control

During the daily operation, power systems may experience both over-voltage and under-voltage violations that can be overcome by voltage/Var control. Through controlling the production, adsorption, and flow of reactive power at all levels in the system, voltage/Var control can maintain the voltage profile within acceptable limit
and reduce the transmission losses. Transmission connected generators are generally required to support reactive power flow.

3.1.1 Power System Stability

Power system stability is the ability of an electric power system, for a given initial operating condition, to regain a state of operating equilibrium after being subjected to a physical disturbance, with most system variables bounded so that practically the entire system remains intact.

3.1.2 Load Forecasting

Load forecasting is a technique used by power or energy-providing companies to predict the power/energy needed to meet the demand and supply equilibrium. The accuracy of forecasting is of great significance for the operational and managerial loading of a utility company.

3.1.3 General Maintenance Schedule

The maintenance of generating units is related to system reliability. The maintenance schedules of generating units attract great attention in both planning and designing power systems and also in operation management. The power system maintenance schedule is in fact a constrained optimization problem. The scheduled maintenance should be periodically arranged and effectively organized repair work should be carried out after a random fault has occurred. The general aim of these activities is to ensure that equipment is always in or is restored to sound operating condition. In addition, this is expected to reduce equipment faults, to extend the equipment life, and to increase the reliability and economic benefits of power systems.

3.1.4 Thermal / Hydro Scheduling

Hydro-Thermal Scheduling of a power system is required in order to find the optimum allocation of hydro energy so that the annual operating cost of a mixed hydro-thermal system is minimized. Hydro-Thermal Scheduling problem is
decomposed into three sub-problems: maintenance of thermal units, dispatch of thermal units, and dispatch of hydro units.

3.1.5 Economic Dispatch

Economic dispatch control determines the power output of each power plant, and power output of each generating unit within a power plant, which will minimize the overall cost of fuel needed to serve the system load. The economic operation requires power systems to be operated at conditions which will ensure minimum cost of operation meeting all the conditions.

3.1.6 Unit Commitment

Economic dispatch gives the optimum schedule corresponding to one particular load on the system. The total load in the power system varies throughout the day and reaches different peak value from one day to another. Different combination of generators, are to be connected in the system to meet the varying load.

When the load increases, the utility has to decide in advance the sequence in which the generator units are to be brought in. Similarly, when the load decreases, the operating engineer need to know in advance the sequence in which the generating units are to be shut down.

The problem of finding the order in which the units are to be brought in and the order in which the units are to be shut down over a period of time, say one day, so the total operating cost involved on that day is minimum, is known as Unit Commitment (UC) problem. Thus UC problem is economic dispatch over a day. The period considered may a week, month or a year.

3.1.7 Automatic Generator / Load Frequency Control

The main bifurcation between frequency and voltage in power system is on the account of active and reactive power. The dependency of frequency is on active power whereas that of voltage is on the reactive power. The combination of active power and frequency control is generally known as Load Frequency Control (LFC).
The objectives of LFC are maintaining frequency at transient power loads (unknown external disturbance); regulation of tie line power exchanger error; tackling ambiguities in the power system model and the variations.

3.1.8 Voltage stability

Voltage security enhancement can be achieved through preventive or corrective control. Preventive control is applied so as to ensure that operating point is away from point of collapse in anticipation of incredible contingencies. The corrective control action on the other hand is activated only when the contingency has occurred endangering voltage stability. Corrective control is considered as economic one in the market environment, nevertheless preventive control is also needed to reduce system interruption.

Optimal Power Flow (OPF) is used for corrective strategies by determining the optimal settings of control variables to minimize generation cost in the transmission system. OPF is a large scale, nonconvex, nonlinear static optimization problem with both discrete and continuous variables. In 2001, to achieve voltage security enhancement, the contingency state voltage stability index is included as additional constraint in the formulation of OPF problem along with the contingency state constraints proposed by Canizares C. *et al.*

3.2 Power factor

In an AC electrical power system, the power factor is defined as the ratio of the real power flowing to the load, to the apparent power in the circuit and is a dimensionless number in the closed interval of -1 to 1. In the power system, a load with a low power factor draws more current than a load with a high power factor for the same amount of useful power transferred. Therefore, the power system requires both types of power — active and reactive — in order to function properly. Electric generators supply reactive power, in addition to active power, that is consumed by customer load which is shown in Figure 3.1
These three types of power are trigonometrically related to one another. In a right triangle, $P =$ adjacent length, $Q =$ opposite length, and $S =$ hypotenuse length. The opposite angle is equal to the circuit's impedance ($Z$) phase angle.

Real Power - Power dissipated by a load, true power or real power, the capacity of the circuit for performing work in a particular time and symbolized as $P$ and measured in the unit of Watts (W).

Reactive Power - Reactive power is the power merely absorbed and returned in load due to its reactive properties is symbolized as $Q$ and measured as unit of Volt-Amps-Reactive (VAR).

Apparent Power - Total power in an AC circuit, both dissipated and absorbed/returned is apparent power. Apparent power is the product of the current and voltage of the circuit and symbolized by the letter $S$ and measured in the unit of Volt-Amps (VA).

Frequency - Mostly power supplied by large rotating AC generators turn in synch with the frequency of the grid, which is identical and tied directly to the RPM of the generators themselves, i.e., 3600 RPM for gas turbines and 1800 RPM for nuclear plants. Frequency is maintained at desired rate if sufficient power is in the generators i.e. 50Hz or 60Hz depending on the locale and decreases when power is insufficient.
Frequency varies as load and generation change. Automatic generation control (AGC) maintains scheduled frequency and interchange power flows. Temporary change due to changing demand and rapid change due to distribution network operates near its capacity limits, observed shortly before major outages. Small deviations result in automatic load shedding or other control actions to restore system frequency.

3.3. Load Forecasting

Electrical Load Forecasting is the estimation for future load by an industry or utility company. Load forecasting is vitally important for the electric industry in the deregulated economy. It has many applications including energy purchase and generation forecasting, load switching, contract evaluation, and infrastructure development. Load forecasting is a central and integral process in the planning and operation of electric utilities. It involves the accurate prediction of both the magnitudes and geographical locations of electric load over the different periods of the planning horizon, usually hours. Accuracy of load forecasts has significant effect on power system operations. System load, random non-stationary process, behaviour is influenced by economic factors, time, day, season, weather and random effects.

Load forecasting techniques such as Multiple Regression, Exponential Smoothing, Iterative Reweighted Least-Squares, Adaptive Load Forecasting, Stochastic Time Series, ARMAX Models Based on Genetic Algorithms, Fuzzy Logic, Neural Networks, Genetic Algorithm, and Knowledge-Based Expert Systems are used to predict future load demands.

3.4. Reactive Power

Energy stored in capacitive or inductive elements of the network give rise to reactive power flow. Reactive power flow strongly influences the voltage levels across the network. Voltage levels and reactive power flow must be carefully controlled to allow a power system to be operated within acceptable limits. When voltage is placed across the coil, a magnetic field builds up and takes a period of time for the current to reach full value, causing the current to lag behind the voltage in phase. These are
sources of lagging reactive power. When voltage across a capacitor constantly changes, the capacitor will oppose this change causing the voltage to lag behind the current and leads the voltage in phase. These devices are sources of leading reactive power.

From the above said statement, it is clear that the power flow is a function of transmission line impedance, the magnitude of the sending end and receiving end voltages and the phase angle between voltages. By controlling one or a combination of the power flow arrangements, it is possible to control the active, as well as, the reactive power flow in the transmission line.

3.4.1. Sources of Reactive Power

Reactive Power sources are devices that consume reactive capacitive current. Most of the industrial equipment like electric motors, transformers, conductors, chokes, converters, arc furnaces and power electronics, consumes reactive power. In random circuit without source, the reactive power is associated with the frequency. Capacitance and inductance are not variable and offer control only in large steps. Line loaded below surge impedance loading generates reactive power and line loaded above surge impedance loading absorbs reactive power. The reactive power sources consist of Dynamic and Static sources.

Dynamic sources are fast, continuous controllable reactive support. It consists of Synchronous condenser and Power electronics devices such as SVC, STATCOM etc. Static sources consist of Reactor, Capacitor, Transmission lines and Transformer tap changers.

3.4.2. Receivers of Reactive Power

Reactive Power receivers are devices that consume reactive inductive current. Most of the industrial equipment like electric motors, transformers, conductors, chokes, converters, arc furnaces, power electronics, consumes reactive power.
In any electric circuit, the generated reactive energy is equal to the consumed energy. The cooperation of compensating devices with linear circuits causes the reactive component of the supplying current to decrease.

3.4.3. Reactive Power Injection

Reactive power injection is the process of injecting the reactive power in the system by the methods as follows.

- Shunt controller for voltage control.
- Series controller for line flow control.
- Unified controller for power flow control.

Reactive power injections represent the features of the steady state FACTS device. Power injections are temporary result and independent control variables of power flow control. Once the required power injections are obtained, the original control parameters can be derived easily according to the PIM and the corresponding VSM. Figure 3.2 details the voltage compensation using D-FACTS devices.

![Simplified FACTS model](image)

**Figure 3.2 Simplified FACTS model**

Injected voltage converted to its equivalent injection current sources. The current injection model can be easily adopted for the conventional power system simulation programs

3.4.4. Reactive Power Compensation

Reactive power compensation along with phase shifting is applied to increase the stability and the security of the power systems.
3.4.5. Need for Reactive Power Compensation

- Voltage regulation.
- Increased system stability.
- Better utilisation of machines connected to the system.
- Reducing losses associated with the system.

3.4.6. Principle of Reactive Power Compensation

In linear circuit, reactive power is generated by the AC power source is stored in a capacitor or reactor during a quarter of a cycle, and in the next quarter cycle is sent back to the power source. In other words, the reactive power oscillates between the AC source and the capacitor or reactor, and also between them, at frequency equals to two times the rated value. Due to this, it is compensated using VAR generators, avoiding its circulation between the load (inductive) and source, improving voltage stability of the power system. Figure 3.3

![Figure 3.3 Simplified models of Power Transmission Systems.](image)

Two power grids connected by a transmission line is assumed lossless and represented by reactance $X_L$, $V_1$ and $V_2$ as the voltage phasors of the buses with angle $\delta = \delta_1 - \delta_2$ between the two.

The magnitude of the current in the transmission line is given by:

$$I = \frac{V_L}{X_L} = \frac{|V_1 - V_2|}{X_L}$$

3.1
The active and reactive components of the current flow at bus 1 are given by:

\[ I_{d1} = \frac{V_2 \sin \delta}{X_L} \]

\[ I_{q1} = \frac{(V_1 - V_2)}{X_L} \]

The active power and reactive power at bus 1 are given by:

\[ P_1 = \frac{V_1 V_2 \sin \delta}{X_L} \]

\[ Q_1 = \frac{V_1 (V_1 - V_2 \cos \delta)}{X_L} \]

Similarly, the active and reactive components of the current flow at bus 2 can be:

\[ I_{d2} = \frac{V_1 \sin \delta}{X_L} \]

\[ I_{q2} = \frac{(V_2 - V_1)}{X_L} \]

The active power and reactive power at bus 2 are given by:

\[ P_1 = \frac{V_1 V_2 \sin \delta}{X_L} \]

\[ Q_2 = \frac{V_2 (V_2 - V_1 \cos \delta)}{X_L} \]

The above equations indicate that the active and reactive power/current flow can be regulated by controlling the voltages, phase angles and line impedance of the transmission system when phase angle is 90 the active power flow will be maximum and the system will be stable from the transient and dynamic oscillations when the phase angle is small.

3.4.7. Reactive Power Compensation Techniques

The reactive power compensation techniques are as follows:

1. Shunt compensation
2. Series compensation
3. Synchronous condensers
4. Static VAR compensators
5. Static compensators

➢ Shunt Compensation

Shunt connected reactors reduce the line over voltages by consuming the reactive power and shunt connected capacitors maintain the voltage levels by compensating the reactive power to transmission line. This has been widely used in transmission system to

- Regulate the voltage magnitude.
- Improve the voltage quality
- Enhance the system stability, voltage stability.
- Increases transmitted power.

The transmission line is assumed lossless and represented by the reactance $X_L$. At the midpoint of the transmission line, controlled capacitor $C$ is shunt-connected. The voltage magnitude at the connection point is maintained as $E_c$ and phase angle as $\delta$. Figure 3.4

![Figure 3.4 Shunt Compensation](image)

➢ Series Compensation

VAR compensation, series connection type using capacitors, used to decrease the equivalent reactance of power line at rated frequency, which generates reactive power that improves the power transmission system functionality.

- Increased angular stability of the power corridor.
- Improved voltage stability of the corridor.
- Optimized power sharing between parallel circuits.

Series compensation aims to directly control the overall series line impedance of the transmission line by adding a voltage in opposition to its voltage drop reducing the series line impedance. The transmission line assumed lossless and represented by the reactance $X_L$. The voltage magnitude at the connection point is maintained as $E_c$ and phase angle as $\delta$. Figure 3.5

![Series Compensation Diagram]

**Figure 3.5 Series Compensation**

- **Synchronous condenser**

  A device whose main function is the improvement of pf of the electrical system is known as the synchronous condensor. It is installed at the receiving end of the line. When a synchronous condensor is introduced it supplies the kVAR to the system thus reducing the current and losses, improving the efficiency and pf of the system, by delivering more power to the load.

- **Static VAR compensator**

  SVC, an electrical device that provides reactive power on transmission networks and an automated impedance matching device, designed to bring the system closer to unity power factor. The term "static" refers that it has no moving parts except circuit breakers and disconnects, which do not move under normal SVC operation. In power system, when reactive load is capacitive (leading) conditions, SVC uses reactors (as Thyristor Controlled Reactors) to consume vars from the system, to lower the system voltage and when inductive (lagging) conditions, the capacitor banks
are automatically switched in to provide a higher system voltage

- **Static synchronous compensator**

  The compensating devices using SVS’s for generating or absorbing reactive power are constructed with VSC called Static Compensator or STATCOM, which contains a SVS driven from a DC storage capacitor connected to AC system bus through an interface transformer, that steps the AC system voltage down such that the voltage rating of SVS switches are within the specified limit.

### 3.4.8 Benefits of Reactive Power Compensation

- Better efficiency of power generation, transmission and distribution.
- Improvement in voltage.
- Reduced KVA demand.
- Higher load capability.
- Reduced system losses.

### 3.4.9 Flexible Alternating Current Transmission Systems (FACTS)

In electric power system, the flexibility of electric power transmission is the ability to accommodate changes in the electric transmission system or operating conditions while maintaining sufficient steady state and transient margins. IEEE defines FACTS as “a power electronic based system and other static equipment (controllers) that provide control of one or more AC transmission system parameters to enhance controllability and increase power transfer capability of the network”.

### 3.4.10 Objectives of Facts Controllers

1. Regulation of power flows in prescribed transmission routes.

2. Secure loading of transmission lines nearer to their thermal limits.

3. Prevention of cascading outages by contributing to emergency control.

4. Damping of oscillations that threatens security/limits the usable line capacity.
### 3.4.11 FIRST GENERATION FACTS DEVICES

<table>
<thead>
<tr>
<th>FACTS Devices</th>
<th>Attributes of Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Static compensator of VAR’s (SVC, TCR, TCS, TRS)</td>
<td>Voltage control and stability, compensation of VAR’s, muffling of oscillations.</td>
</tr>
<tr>
<td>Thyristor Controlled Series Compensation (TCSC, TSSC)</td>
<td>Current control, muffling of oscillations, transitory, dynamics and of tension stability, limitation of fault current.</td>
</tr>
<tr>
<td>Thyristor Controlled Reactor Series Compensation (TCSR, TSSR)</td>
<td>Current control, muffling of oscillations, transitory, dynamics and of voltage stability, limitation of fault current.</td>
</tr>
<tr>
<td>Thyristor Controlled Phase shifting transformers (TCPST, TCPR)</td>
<td>Control of active power, muffling of oscillations, transitory, dynamics and of voltage stability.</td>
</tr>
<tr>
<td>Thyristor Controlled voltage Regulators (TCVR)</td>
<td>Control of reactive power, Voltage control, muffling of oscillations, transitory, dynamics and of voltage stability.</td>
</tr>
<tr>
<td>Thyristor Controlled voltage Limiter (TCVL)</td>
<td>Limit of transitory, dynamic voltage.</td>
</tr>
</tbody>
</table>

### 3.4.12 SECOND GENERATION FACTS DEVICES

<table>
<thead>
<tr>
<th>FACTS Devices</th>
<th>Attributes of Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Synchronous Static Compensator (STATCOM without storage)</td>
<td>Voltage control, Compensation of VAR’s, muffling of oscillations, stability of Voltage.</td>
</tr>
<tr>
<td>Synchronous Static Compensator (STATCOM with storage)</td>
<td>Voltage control and stability, Compensation of VAR’s, muffling of oscillations, dynamics, transitory and of tension stability.</td>
</tr>
<tr>
<td>Static Synchronous Series Compensator (SSSC without storage)</td>
<td>Current control, muffling of oscillations, transitory, dynamics and of voltage stability, limitation of fault current.</td>
</tr>
<tr>
<td>Static Synchronous Series Compensator (SSSC with storage)</td>
<td>Current control, muffling of oscillations, transitory, dynamics and tension stability.</td>
</tr>
</tbody>
</table>
Unified Power Flow controller (UPFC)  Control of active and reactive power, Voltage control, Compensation of VAR’s, muffling of oscillations, transitory, dynamics and of voltage stability, limitation of fault current.

Interline Power Flow Controller (IPFC) or Back to Back (BtB)  Control of reactive power, voltage control, muffling of oscillations, transitory, dynamics and voltage stability.

3.4.13 Criteria before Installing Facts Devices

- Type of device
- Capacity required
- Optimal location of the device is important.

3.4.14 Benefits of Facts Controllers.

- Better utilization of existing transmission system assets – cost effective.
- Increased transmission system reliability and availability.
- Overcomes voltage fluctuation problems and lower vulnerability to load changes, line faults.
- Increased quality of supply for sensitive industries - through mitigation of flicker, frequency variations.
- Environmental protection - smaller impact than the installation of new lines. No waste production.
- Control of power flow, ensures optimum power flow, minimize the emergency conditions, or a combination thereof.
- Contribute to optimal system operation by reducing power losses and loop flows, and improving voltage profile, allows the lines to carry more active power.
• Increase the loading capability of the lines to their thermal capabilities, including short term and seasonal.

• Increase the system security by raising the transient stability limit, limiting short-circuit currents and overloads, managing cascading blackouts and damping electromechanical oscillations of power systems and machines. Also, Increased dynamic and transient grid stability.

• Provide secure tie line connections to neighbouring utilities and regions thereby decreasing overall generation reserve requirements on both sides.

• Provide greater flexibility in sitting new generation.

Many optimization techniques in Engineering utilizes different algorithm. These algorithms try to emulate the mathematical model which finds it importance according the formulae utilized by the author. Now, it is the need of the hour to compare the best available artificial Intelligence techniques to best fit the compensation techniques that is been utilised in Electrical Network.

Artificial Intelligence emerged as a computer science discipline in the mid 1950’s. Since then, it has produced a number of powerful tools, many of which are of practical use in engineering to solve difficult problems normally requiring human intelligence. Technological developments in the field of Artificial Intelligence has an impact in the engineering include data mining, or the extraction of information and knowledge from large databases and multi-agent systems, or distributed self-organizing system employing entities that function autonomously in an unpredictable environment concurrently with other entities and processes.

3.5 Overview of Artificial Intelligence Techniques

In recent years, AI concept applications are appeared in an increasing attention in many sections of power networks such as planning, control and operation.

AI concepts own an important role in power network control and management. The electric power industry is always looking for methods to enhance the performance
efficiency. Although the conventional concepts of power generation, transmission, and distribution vary in slow rate, the power industry moves quickly to explore new ideas, which can assist the search to show benefits.

The main description owns an effect on the layout of many artificial intelligence systems. Expert planning systems, artificial neural networks, fuzzy logic algorithms, genetic algorithms are applied almost AI benefits in at least prototype form to one or more problem applications in the power networks, and new practical uses of AI are with increasing frequency. In other cases, AI options vary existing techniques. In others, AI options give solutions to problems previously shown only by natural intelligence, creating new computers applications.

3.5.1. Classification of AI Techniques

![Figure 3.6 Classifications of Artificial Intelligence Techniques](image-url)
3.5.2 Need for Artificial Intelligence Techniques

Artificial intelligence (AI) analysis depends on the past history data of a system, the designer should understand and appreciate this data than other theoretical and experimental ways. Power system analysis by conventional techniques becomes more difficult due to reasons as follows,

(1) Complex, versatile, and large amount of information which is used in calculation, diagnosis and learning.

(2) Increase in the computational time period and accuracy due to extensive and vast system data handling.

3.5.3 Artificial Intelligence Techniques Methods

It is the science of making intelligent computer program. Various AI techniques are detailed below.

3.6 Artificial Neural Networks

ANN is an interconnected group of artificial neurons that uses a mathematical model or computational model for information processing based on a connectionist approach to computation. Learning features of an ANN along with conventional power system network solution methodologies to provide real-time control and optimization.

3.6.1 Overview of Artificial Neural Networks

The transmission of a signal from one neuron to another through synapses is a complex chemical process in which specific transmitter substances are released from the sending side of the junction. The effect is to raise or lower the electrical potential inside the body of the receiving cell. If this graded potential reaches a threshold, the neuron fires. It is this characteristic that the artificial neuron model proposed by McCulloch and Pitts (1943) attempt to reproduce.
An ANN has two types of basic components, namely, neuron and link. A neuron is a processing element and a link is used to connect one neuron with another. Each link has its own weight. Each neuron receives stimulation from other neurons, processes the information, and produces an output. Neurons are organized into a sequence of layers. The first and the last layers are called input and output layers, respectively, and the middle layers are called hidden layers. The input layer is a buffer that presents data to the network. It is not a neural computing layer because it has no input weights and no activation functions. The hidden layer has no connections to the outside world. The output layer presents the output response to a given input. The activation coming into a neuron from other neurons is multiplied by the weights on the links over which it spreads, and then is added together with other incoming activations. Figure 30

Artificial Neural Network (ANNs) is a program designed to solve any problem by trying to mimic the structure and the function of our nervous system. Neural networks are based on simulated neurons, which are joined together in a variety of ways to form networks. Applications of neural networks include function approximation, face recognition, handwritten character recognition, speech processing, noise filtering, image compression, stock market prediction, mobile object
path prediction, loan application scoring, automobile autopilot, soccer robot control, travelling salesman problem, medical diagnosis, and many others.

### 3.6.2 Parameters to optimize ANN

In order for the network to mimic a desired behaviour, the parameters of the network should be optimized through the learning process. There are three major learning paradigms: Supervised, Unsupervised, and Reinforcement.

- In supervised learning, there is a desired function that maps an input space to an output space, and the learning process changes the weights or topology of the network in order to make its behaviour as close as possible to the desired function.
- Unsupervised learning is a learning process for cases in which the desired function is unknown. In this case there is usually a cost function to be optimized.
- Finally, Reinforcement learning is used for cases where both input space and the desired function are not given, and the learner interacts with its surroundings to optimize its behaviour.

Neural network resembles the human brain in two ways: a neural network acquires knowledge through learning; and a neural network’s knowledge is stored within the interconnection strengths known as synaptic weight. Figure 3.6 details the ANN sampling process.

![Figure 3.8 Adjusted Neural Networks](image)
Artificial Neural Network can be utilized to control in real time the multi tap capacitors installed on a distribution system for a nonconforming load profile such that the system losses are minimized. The required input data are directly obtained from on-line measurements which include the active and reactive line power flows, voltage magnitudes and the current capacitor settings at certain buses. Inequality constraint consists of limits on capacitors rating. The application of the proposed capacitor control will be limited by the computation time required for the learning process which in turn depends on the number of conforming load groups and capacitor installed rather than the number of system buses.

3.6.3 Learning & Training Methods

Let, \( R, N, \) and \( S \) the numbers of input, hidden neurons, and output respectively; \( {i}_w \rightarrow \) input weights matrices and \( {h}_w \rightarrow \) hidden weights matrices; \( {h}_b \rightarrow \) bias vectors of the hidden layers and \( {o}_b \rightarrow \) bias vectors of the output layers; \( x \rightarrow \) input vector of the network; \( h_o \rightarrow \) output vector of the hidden layer; \( y \rightarrow \) output vector of the network; and \( f \rightarrow \) activation function. Vector, Matrix, and Binary Methods are three ways of encoding and representing the weights and biases of ANN for every solution in an algorithm. The neural network in Figure 31 can be expressed through the following equations:

\[
\begin{align*}
    h_{oi} &= f \left( \sum_{j=1}^{R} (i_{w_{i,j}} \cdot x_j + h_{b_{i}}) \right), \text{for} i = 1, \ldots, N, \\
    y_i &= f \left( \sum_{k=1}^{N} (h_{w_{i,k}} \cdot h_{o_{k}} + o_{b_{i}}) \right), \text{for} i = 1, \ldots, S,
\end{align*}
\]

When implementing a neural network, it is necessary to determine the structure in terms of number of layers and number of neurons in the layers. The larger the number of hidden layers and nodes, the more complex the network will be. A network with a structure that is more complicated than necessary over fits the training data. This means that it performs well on data included in the training set, but may perform poorly on data within a testing set.

Once a network has been structured for a particular application, it is ready for training. There have been three methods of using a heuristic algorithm for training
ANNs. The three methods are: heuristic algorithms \(\rightarrow\) find a combination of weights and biases that provide desired values at the network’s output when presented with different patterns at its input with a minimum error; heuristic algorithms \(\rightarrow\) find a suitable ANN structure in a particular problem; and heuristic algorithms \(\rightarrow\) tune the parameters of a gradient-based learning algorithm, such as learning rate and momentum. When network training is initiated, the iterative process of presenting the training data set to the network’s input continues until a given termination condition is satisfied.

3.6.4 Advantages of Artificial Neural Networks

- It involves human like thinking.
- They handle noisy or missing data.
- They can work with large number of variables or parameters.
- They provide general solutions with good predictive accuracy.
- System has got property of continuous learning.
- They deal with the non-linearity in the world in which we live.

3.7 Fuzzy Logic Method

It is derived from fuzzy set theory dealing with reasoning that is approximate rather than precisely deduced from classical predicate logic. Fuzzy Logic is used directly in very few applications, due to its concept being gradual progression from stability to instability. Most applications of Fuzzy Logic use it as the underlying logic system for decision support systems. It is a generalization of bivalent logic in which everything is, or allowed to be, a matter of degree and provides a foundation for the methodology of computing with words and perceptions.
3.7.1 Overview of Fuzzy Logic Method

This method is based on fuzzy sets theory (FST) was introduced by Zadeh, dealing with reasoning that is approximate rather than classical logic. A fuzzy variable is modelled by a membership function which assigns a degree of membership to a set. Usually, this degree of membership varies from zero to one. Voltages and power loss reduction indices of distribution system nodes are modelled by fuzzy membership functions. A fuzzy inference system containing a set of heuristic rules is designed to determine candidate nodes suitable for capacitor placement in the distribution system. Capacitors are placed on the nodes with highest sensitivity index. Fuzzy-based approach used for the optimal placement and sizing of fixed capacitor banks in radial distribution networks in the presence of voltage and current harmonics. The objective function includes the cost of power losses, energy losses, and capacitor banks. Using fuzzy set theory, a suitable combination of objective function and constraints is generated as a criterion to select the most suitable bus for capacitor placement. The $\alpha$-cut process is applied at each iteration to guarantee simultaneous improvements of objective function and satisfying given constraints.

3.7.2 Features of Fuzzy Logic Method

- Fuzzy Logic is basically easy to understand - theory behind fuzzy learning is very clear. Fuzzy Logic is a better in self-evident methods without complex concepts.

- Flexibility of Fuzzy Logic - In any specific process, it is simple to apply on more flexibility without working from scratch.

- Fuzzy Logic has more clearance to deal with imprecise data - when we work closely enough, everything may be considered imprecise but not always, many issues are imprecise even on care inspection.

- Fuzzy Logic can deal with nonlinear complex functions - design a Fuzzy system to any pattern of input and output data. This process is used particularly simply by adaptive methods as (ANFIS) systems.
- Fuzzy Logic can be integrated with traditional control techniques - Fuzzy systems do not necessarily exchange traditional controllers. In most situations, fuzzy systems link with them and enhance their implementation.

- Fuzzy Logic building depends on natural language - The core of Fuzzy Logic is the core of for people communication, because Fuzzy Logic is structured on the structures of normal language description used in our life, the Fuzzy Logic algorithm is easy to apply.

3.7.3 Strategy of Fuzzy Logic Method

Fuzzy control systems are rule-based systems. The outcome of certain system can be corrected by a set of fuzzy rules that represent the fuzzy logic controller (FLC) technique. The FLC also provides a strategy which can change the linguistic control approach, based on expert knowledge, to automatic control ones. Figure 1 shows the basic pattern of the FLC. It consists of a fuzzification interface, a knowledge base, a decision-making logic, and defuzzification interface.

For the model development of power system dynamics, the power system components - synchronous generators, induction machine and basic commutating machine using Fuzzy Logic approach are developed in Figure 3.9

![Figure 3.9 Generic Structure of Fuzzy Logic Controller.](image)

Criteria to be considered in Fuzzy Logic applications for modelling and simulation of electrical machines as accurately as possible are as follows,
1. Selection of variables and the number of fuzzy sets.

2. Selection of membership functions for each fuzzy set and their overlappings

3. Selection of Intersection operators

4. Selection of Union operators

5. Selection of implications methods

6. Selection of Compositional rule and

7. Defuzzification methods

Global Input Variables → The fuzzy input vector, of each static fuzzy logic controller (SFLC) has two variables → the voltage deviation error (e_v) and voltage deviation change of error (Δe_v).

Fuzzy Logic Systems are based on Fuzzification, Inference, Composition and Defuzzification.

- FUZZIFICATION → Establishes the fact base of the fuzzy system. It identifies the input and output of the system, defines appropriate IF THEN rules, and uses raw data to derive a membership function.

- INFERENCE → Evaluates all rules and determines their truth values. If an input does not precisely correspond to an IF THEN rule, partial matching of the input data is used to interpolate an answer.

- COMPOSITION → Combines all fuzzy conclusions obtained by inference into a single conclusion. Since different fuzzy rules might have different conclusions, consider all rules.

- DEFFUZZIFICATION → Convert the fuzzy value obtained from composition into a “crisp” value. This process is often complex since the fuzzy set might not translate directly into a crisp value. Defuzzification is necessary, since
controllers of physical systems require discrete signals. Defuzzification methods are Centroid and Maximum Methods.

In the Centroid Method, the crisp value of the output variable is computed by finding the variable value of the center of gravity of the membership function for the fuzzy value.

In the Maximum Method, one of the variable values at which the fuzzy subset has its maximum truth value is chosen as the crisp value for the output variable.

### 3.8 Genetic Algorithm

Genetic Algorithms (GAs) are adaptive heuristic search algorithm, powerful, successful problem-solving strategy, based on the evolutionary ideas of natural selection and genetics, especially principles by Charles Darwin of "Survival of the Fittest", representing an intelligent exploitation of a random search used to solve optimization problems by exploiting historical information to direct the search into the region of better performance within the search space.

GA, better than conventional AI, do not break easily even if the inputs are changed slightly. Also, in searching a large state-space, multi-modal state-space, or n-dimensional surface, it offers significant benefits over more typical search of optimization techniques - linear programming, heuristic, depth-first, breath-first, and praxis.

#### 3.8.1 Overview of genetic algorithm

GA is a programming technique that mimics biological evolution as a problem-solving strategy. Given a specific problem to solve, the input to GA is a set of potential solutions to that problem, encoded in some fashion. Each individual is coded as finite length vector components or variables in terms of values like voltage and angle, some binary \{0,1\}. To continue the genetic analogy these individuals are related to chromosomes and the variables are analogous to genes. Thus, a chromosome (solution) is composed of several genes (variables).
Fitness Function quantitatively evaluates each candidate, generated randomly. They select appropriate ones towards solving the problem for reproduction. Multiple copies are made of them, including imperfect copies, random changes are introduced, and digital offspring go on to next generation forming a new pool of candidate solutions, subjected to a second round of fitness evaluation – where worst candidates are deleted again by the changing their code and efficient individuals are selected and copied over into the next generation with random changes, and the process repeats.

Expectation - average fitness of the population increases each round, and by repeating this process for number of rounds, very good solutions to the problem can be discovered. The GA aims to use selective `breeding' of the solutions to produce `offspring' better than the parents by combining information from the chromosomes.

### 3.8.2 Importance of Genetic Algorithm

- It works with the base in the code of the variables group (artificial genetic strings) and not with the variables in themselves.
- Also, works with a set of potential solutions (population) instead of trying to improve a single solution.
- It does not use information obtained directly from the object function, of its derivatives, or of any other auxiliary knowledge of the same one.
- It applies probabilistic transition rules, not deterministic rules.
- Genetic Algorithm process is quite simple involving only a copy string, partial string exchanges or a string mutation, all these in random form.

### 3.8.3 Genetic Algorithm Parameters

- Population size and number of chromosomes.
- Selection rate.
- Crossover probability.
- Mutation probability.
- Maximum number of generations.
3.8.4 Effects of genetic algorithm parameters

- Using selection alone will tend to fill the population with copies of the best individual from the population.
- Using selection and crossover operators will tend to cause the algorithms to converge on a good but sub-optimal solution.
- Using mutation alone induces a random walk through the search space.
- Using selection and mutation creates a parallel, noise-tolerant, hill climbing algorithm.

3.8.5 Strengths of Genetic Algorithm

Genetic Algorithms are intrinsically parallel and have multiple offspring by exploring the solution space in multiple directions at once, if one path turns out as dead end, they easily eliminate it and continue work on more promising paths, giving them a greater chance for each run in finding the optimal solution.

GA can "home in" on the space with the highest-fitness individuals and find the overall best one from that group, as in evolutionary algorithms context, Schema Theorem, central advantage over other problem-solving methods.

In a linear problem, the fitness of each component is independent, so any improvement to any one part will result in an improvement of the system as a whole. In non-linearity changing one component may have ripple effects on the entire system, and in multiple changes individually are detrimental leading to much greater improvements in fitness when combined.

3.8.6 Genetic Algorithm an Optimization Technique

Optimization, a mathematical process, involves the process of modifying the characteristics of a device, including cost function, fitness function, to obtain minimum or maximum of the output, the fitness function of the system. Its goal is to utilize the best of the existing transmission lines by determining the best location of FACTS controllers with a defined criterion to maximize the system load-ability with
thermal and voltage constraints and to enhance the power system stability, reduce generation cost, reduce the total system losses in the transmission lines.

The main objective of the proposed algorithm GA determines the best fitness value, the amount of voltage and angle to be injected in the system, in order to place the FACTS controllers using Mat Lab 2012Ra and ultimately minimize the generation cost and/or minimize the total real and reactive power losses in the transmission lines of the system using ETAP Power Station 4.0 software.

3.8.7 Computing Voltage and Angle Injecting Values Using Genetic Algorithm

Genetic algorithm is one of the most salient evolutionary algorithms, often used for optimization process. In this project, GA is used to compute the voltage and angle injecting values. To determine the amount of voltage and angle value to be injected and to find the best fitness (capacitance) value for placing the FACTS controller, GA, a global search technique is used, without any prior knowledge or special properties of the objective function and thus produce high quality solutions. Fitness evaluation is lowering power losses of the system.

Normally, GA consists of five stages namely, generation of initial chromosomes, fitness function, crossover operation, mutation operation, and termination. Figure 3.10 details flow chart representation of genetic algorithm.

- GENERATION OF INITIAL CHROMOSOME

The initial step in genetic algorithm is initializing the chromosome. Number of genes used here is two they are, voltage and angle injecting values. Each gene is generated based on a certain limit. After the generation of initial chromosome, the next step is to compute the fitness function.

Note: Population size is a crucial factor. Smaller population - risk of converging prematurely to a local minima and larger population - greater chance of finding the global optimum at the expense of more CPU time. The population size remains constant from generation to generation.
FITNESS FUNCTION

Fitness function, determined by an objective function or by a subjective judgement, is used to find the optimum chromosome generated in the above stage. In the proposed method, total power loss is considered as the fitness function. The fitness function is computed for all the initial chromosomes and then ordered based on the lowering the power loss.

CROSSOVER OPERATION

The next process after calculating the fitness function is crossover, a prime factor GA. In crossover operation, a new set of chromosomes are generated from the above chromosomes based on the crossover rate. Subsequently, fitness function is applied for the new set of chromosomes generated and then ordered based on the low power loss.

Figure 3.10 Flow Chart Representation of Genetic Algorithm
MUTATION OPERATION

Here, mutation operation is applied to the above chromosomes. The purpose of mutation operation is to maintain diversity within the population and inhibit premature convergence. The mutation operation is performed based on the mutation rate by arbitrarily selecting the genes in the chromosome. Mutation alone induces a random walk through the search space. Mutation and selection, without crossover create a parallel, noise-tolerant, hill-climbing algorithms. The next step after the completion of mutation operation is termination.

TERMINATION

In this stage, the best chromosome i.e., voltage and angle injecting values is selected based on the fitness function. The above process is repeated until it reaches the maximum number of iterations. After completing the process, a best set of chromosome is obtained based on fitness function, lowering power loss.

These operations are repeated until the best individual is found. In order to ensure that there is only one FACTS device on each transmission line. This process of Arrangement of the FACTS locations is necessary.

3.8.8 Benefits of Genetic Algorithm

- Supports multi-objective optimization.
- Flexible building blocks for hybrid applications.
- Always an answer; answer gets better with time.
- Easy to exploit previous or alternate solutions.

3.9 Miscellaneous AI Methods

Expert System & Parallel Tabu Search – compared with Simulated Annealing, GA & Tabu Search methods.
3.9.1 Simulated Annealing

Simulated annealing (SA) is based on annealing of materials which involves heating and controlled cooling of a material to increase the size of its crystals and reduce their defects. The heat causes the atoms to become unstuck from their initial positions (a local minimum of the internal energy) and wander randomly through states of higher energy; the slow cooling gives them more chances of finding configurations with lower internal energy than the initial one. By analogy with this physical process, each step of the SA algorithm attempts to replace the current solution by a random solution. The new solution may then be accepted with a probability that depends both on the difference between the corresponding function values and also on a global parameter $T$ (called the temperature), that is gradually decreased during the process. The optimization techniques based on SA to search the global optimum solution to the capacitor placement problem, to determine the locations where capacitors are to be installed, the types and sizes of capacitors to be installed, and the control settings of these capacitors at different load levels. SA reduces the cost function related to which includes the energy and the capacitor installation cost. The practical aspects of capacitors, load constraints and operational constraints at different load levels are considered in which are solved by a powerful simulated annealing approach.

3.9.2 Expert System

In artificial intelligence, an expert system is a computer system that emulates the decision-making ability of a human expert. Expert systems are designed to solve complex problems by reasoning about knowledge, represented primarily as if–then rules rather than through conventional procedural code. The first expert systems were created in the 1970s and then proliferated in the 1980s. Expert systems were among the first truly successful forms of AI software.

- Software architecture of expert system.
An expert system is divided into two sub-systems: the Inference Engine and the Knowledge Base. The Knowledge Base represents facts and rules. The Inference Engine applies the rules to the known facts to deduce new facts and also includes explanation and debugging capabilities.

The Knowledge Base represents facts about the world, represented as classes, subclasses, and instances and assertions were replaced by values of object instances. The rules worked by querying and asserting values of the objects.

The Inference Engine is an automated reasoning system that evaluates the current state of the knowledge-base, applies relevant rules, and then asserts new knowledge into the knowledge base. The inference engine may also include capabilities for explanation, so that it can explain to a user the chain of reasoning used to arrive at a particular conclusion by tracing back over the firing of rules that resulted in the assertion.

As Expert Systems evolved many new techniques were incorporated into various types of Inference Engines, which are as follows.

Truth Maintenance Systems → record the dependencies in a Knowledge-Base so that when facts are altered dependent knowledge can be altered accordingly.

Hypothetical Reasoning → the knowledge base can be divided up into many possible views, via. worlds. This allows the inference engine to explore multiple possibilities in parallel.

Fuzzy Logic → One of the first extensions of simply using rules to represent knowledge was also to associate a probability with each rule.

Ontology Classification → With the addition of object classes to the knowledge base a new type of reasoning was possible. Rather than simply reason about the values of the objects the system could also reason about the structure of the objects as well. These types of special purpose Inference Engines are known as classifiers. Although
they were not highly used in expert systems, classifiers are very powerful for unstructured volatile domains and are a key technology for the Internet.

➢ Advantages of Expert System

1. With an expert system the goal was to specify the rules in a format that was intuitive and easily understood, reviewed, and even edited by domain experts rather than IT experts.

2. The benefits of this explicit knowledge representation were rapid development and ease of maintenance.

➢ Disadvantages of Expert System

1. The most common disadvantage cited for expert systems in the academic literature is the knowledge acquisition problem.

2. Performance was especially problematic because early expert systems were built using tools such as Lisp, which executed interpreted rather than compiled code.

➢ Applications of Expert System

Hayes-Roth divides expert systems applications into 10 categories: Interpretation, Prediction, Diagnosis, Design, Planning, Monitoring, Debugging, Repair, Instruction, and Control.

3.10 Ant Colony Optimization

It is based on the ideas of ant foraging by pheromone communication to make path. The ant colony optimization algorithms are novel and very effective in solving some very hard global optimization problems which can’t even be touched using the traditional algorithms. Ants teach us that there is strength in numbers and coordinated effort. Some real time implementations can be found in route finding, vehicle routing, job scheduling, data mining and in electronic network optimization applications.
3.10.1 Overview of Ant Colony Optimization

Ant algorithm has been inspired by the behaviour of real ant colonies. Real ants are capable of finding the shortest path from food sources to the nest without using visual cues and bring them back to their colony by the formation of unique trails. Therefore, through a collection of cooperative agents called ants, the near-optimal solution to capacitor placement problems can be effectively achieved. Ant Colony Optimization approach solves the capacitor placement problems and minimizes the total active losses in electrical distribution systems.

3.10.2 Strategy of Ant Colony Optimization

Ant colony optimization algorithm as follows:

STEP 1 ➔ START

STEP 2 ➔ Initialization

• time: t = 0
• number of cycles: NC = 0
• pheromone: $\tau_{ij}(t) = c$
• Initial positioning of $m$ ants to $n$ cities

STEP 3 ➔ Initialization of tabu lists

STEP 4 ➔ Ants’ action

• Each ant iteratively builds its route
• Calculate length of the routes $L_k$ for all ants $k \in (1,...,m)$
• update the shortest route found
• Calculate $\Delta \tau_{ijk}$ and update $\tau_{ij}(t+n)$

STEP 5 ➔ Increment discrete time

• $t = t+n$, $NC = NC + 1$

STEP 6 ➔ If (NC < NCmax) then goto step 2

STEP 7 ➔ else STOP
3.10.3 Applications of Ant Colony Optimization

- ACO can run continuously and adapt to changes in real time.

- ACO gives the shortest path in a graph, between two points A and B, built from a combination of several paths.

- ACO algorithms are applied to both Dynamic Network routing and Static problems → Traveling salesman, Quadratic assignment, Job-shop scheduling, Vehicle routing, Graph colouring, Shortest common super sequence.

3.11 Artificial Bee Colony Algorithm

The Artificial Bee Colony (ABC) algorithm was proposed by DervisKaraboga for optimizing numerical problems in 2005. It simulates the intelligent foraging behaviour of honey bee swarms. It is a very simple, robust and population based stochastic optimization algorithm which requires less control parameters to be tuned.

3.11.1 General Scheme of the ABC Algorithm

- Initialization Phase
- REPEAT
- Employed Bees Phase
- Onlooker Bees Phase
- Scout Bees Phase
- Memorize the best solution achieved so far
- UNTIL(Cycle=Maximum Cycle Number or a Maximum CPU time)

3.11.2 Four Main Phases of ABC Algorithm

The ABC algorithm has four phases:

- Initialization phase
- Employed Bee
- Onlooker Bee
- Scout Bee
3.11.3 Initialization Phase

The initial food sources are randomly produced via the expression

\[ x_{i,j} = x_{j}^{\text{min}} + \lambda [x_{j}^{\text{max}} - x_{j}^{\text{min}}] \]  

\( i=1,2,\ldots,D \)

\( x_{i,j} \rightarrow j^{th} \) dimension of \( i^{th} \) employed bee

\( x_{j}^{\text{min}} \text{ and } x_{j}^{\text{max}} \rightarrow \) lower and upper bounds of \( j^{th} \) parameters

\( \lambda \rightarrow \) random number in range of \([0,1]\)

\( N \rightarrow \) number of employed bee

\( D \rightarrow \) dimensionality of the optimization problem

3.11.4 Employed BEE Phase

The neighbour food source \( v_{i,j} \) is determined and calculated by the following equation.

\[ v_{i,j} = x_{i,j} + \varphi [x_{i,j} - x_{k,j}] \]  

\( i,k \in \{1,2,\ldots,N\} \)

\( j \in \{1,2,\ldots,D\}, i \neq k \)

\( v_{i,j} \rightarrow j^{th} \) dimension of \( i^{th} \) candidate solution

\( x_{i,j} \rightarrow j^{th} \) dimension of \( k^{th} \) employed bee

\( x_{k,j} \rightarrow j^{th} \) dimension of \( k^{th} \) employed bee

\( \varphi \rightarrow \) random number in range of \([-1,+1]\)

\( N \rightarrow \) number of employed bee

\( D \rightarrow \) dimensionality of the optimization problem
The fitness is calculated by the following formula (3.7), after that a greedy selection is applied between \( x_m \) and \( v_m \).

\[
fit_i = \begin{cases} 
\frac{1}{1 + f_i}, & \text{if } f_i \geq 0 \\
1 + |f_i|, & \text{if } f_i < 0 
\end{cases}
\]

\( fit_i \) \( \Rightarrow \) fitness value of the \( i \)th employed bee

\( f_i \) \( \Rightarrow \) objective function value of \( i \)th employed bee is replaced with the candidate solution \([v_i=x_i]\) and the AC counter of the employed bee is reset, otherwise AC is increased by 1.

\[
AC = AC + 1
\]

AC \( \Rightarrow \) Abandonment Counter

### 3.11.5 Onlooker BEE Phase

The quantity of a food source is evaluated by its profitability and the profitability of all food sources. \( p_i \) is determined by the formula

\[
p_i = \frac{fit_i}{\sum_{j=1}^{N} fit_j}
\]

\( p_i \) \( \Rightarrow \) probability of being selected \( i \)th employed bee

Onlooker bees search the neighbourhoods of food source according to the expression:

\[
v_{i,j} = x_{i,j} + \varphi(x_{i,j} - x_{k,j})
\]

### 3.11.6 Scout BEE Phase

The new solutions are randomly searched by the scout bees. The new solution \( x_i \) will be discovered by the scout by using the expression:

\[
x_i = x_{\min} + \text{rand}(0,1). (x_{\max} - x_{\min})
\]

\( x_{\max}, x_{\min} \) \( \Rightarrow \) upper and lower bounds of dimension \( j \)
3.11.7 Main Steps of ABC Algorithm

The main steps of the ABC algorithm in the form of Pseudo-code are given below:

Step 1: Initialize the population of solutions $x_{i,j}$, $i = 1,...,SN$, $j = 1,....D$

Step 2: Evaluate the population

Step 3: Cycle = 1

Step 4: Repeat

Step 5: Produce new solutions (food source positions) $V_{i,j}$ in the neighbourhood of $x_{i,j}$ for the employed bees using the formula $V_{i,j} = x_{i,j} + \phi_{i,j}(x_{i,j} - x_{k,j})$ (k is a solution in the neighbourhood of i) and evaluate them.

Step 6: Apply the greedy selection process

Step 7: Calculate the probability values $P_i$ for the solutions $x_{i,j}$ by means of their fitness values using Eq.

$$p_i = \frac{fit_i}{\sum_{m=1}^{SN} fit_m}$$

In order to calculate the fitness values of solutions, the following Eq.

$$fit_i = \begin{cases} 
\frac{1}{1 + f_i}, & \text{if } f_i \geq 0 \\
1 + |f_i|, & \text{if } f_i < 0 
\end{cases}$$

Normalize $P_i$ values into $[0, 1]$. $f_i$ is obtained separately for each individual $i_{th}$ solution through Eq.

Step 8: Produce the new solutions (new positions) $v_{i,j}$ for the onlookers from the solutions $x_{i,j}$ selected depending on $P_i$ and evaluate them.

Step 9: Apply the greedy selection process.
Step 10: Determine the abandoned solution (source), if it exists, and replace it with a new randomly produced solution $x_{i,j}$ for the scout using

$$x^l_i = x^l_{\text{min}} + \text{rand}(0,1). (x^l_{\text{max}} - x^l_{\text{min}})$$

Step 11: Memorize the best food source position (solution) achieved so far.

Step 12: Cycle = Cycle + 1

Step 13: Until Cycle = MCN.

3.11.8 Control Parameters

There are three control parameters used in the ABC-based algorithm. They are:

- Number of the food sources which is equal to the number of employed or onlooker bees.
- value of limit
- MCN.

In ABC, providing that a position cannot be improved further through predetermined number of cycles, then that food source is assumed to be abandoned. The value of predetermined number of cycles is an important control parameter of the ABC algorithm; this is termed the ‘‘limit’’ for abandonment.

3.11.9 Selection Process

The ABC algorithm employs four different selection processes. They are:

1. A global selection process used by the artificial onlooker bees for discovering promising regions.

2. A local selection process carried out in a region by the artificial employed bees and the onlookers depending on local information for determining a neighbour food source around the source in the memory.

3. A local selection process called greedy selection process carried out by all bees.

4. A random selection process carried out by scouts.
Figure 3.11 Voltage profile before and after compensation.

In Figure 3.11 the red line indicates the voltage profile before compensation and the blue line indicates the voltage profile after compensation. From the graph it can be concluded that the voltage profile for the system has increased significantly and the minimum p. u. voltage has increased values.

3.12 Applications of Artificial Intelligence Techniques in Power System

(i) Operation of power system like unit commitment, hydro-thermal coordination, economic dispatch, congestion management, maintenance scheduling, state estimation, load and power flow.

(ii) Planning of power system like generation expansion planning, power system reliability, transmission expansion planning, reactive power planning.
(iii) Control of power system like voltage control, stability control, power flow control, load frequency control.

(iv) Control of power plants like fuel cell power plant control, thermal power plant control.

(v) Control of network like location, sizing and control of FACTS devices.

(vi) Electricity markets like strategies for bidding, analysis of electricity markets.

(vii) Automation of power system like restoration, management, fault diagnosis, network security.

The percentages of some significant AI researches on applications to power systems are shown. Figure 3.12

![Figure 3.12 Applications of AI in Power Systems.](image-url)
Summary

Many optimization techniques in Engineering that utilizes different algorithm were analysed and found that these algorithms try to emulate the mathematical model which finds it importance according the formulae utilized. Now, it is the need of the hour to compare the best available artificial Intelligence techniques to best fit the compensation techniques that is been utilised in our Electrical Network.

A number of research articles which have appeared recently indicate the applicability of AI methods to power networks for wider operating cases with uncertainties. Most of these methods are still under researching, however, there already current many practical applications of AI systems. Because of multiple AI systems, they can be applied as a general methodology to provide knowledge or theory into controllers and decision makers. There are analytical solution techniques for power system problems. However, the mathematical formulations of power systems problems are derived during specific restrictive assumptions and even with these assumptions, the solution of large-scale power system problems is not simple.

The various uncertainties in power system problems, like large-scale, complex, wide spread in geographical places which are affected by unplanned conditions are the validated reasons that lead to difficulty in handling many power systems problems through strict mathematical formulations alone. Therefore, AI approach that owns the complement tool to mathematical approaches for solving power system problem can be utilized to model our system. Since expert knowledge, experience, and intuition are essential in power systems operations, AI can be effectively used in power system problems to represent uncertainties based on preferences and/or experience.

After studying and modelling the various compensation methods and tools utilized for power system analysis, it is the need of the hour on designing a system that can handle voltage stability using D-FACTS devices comparing various algorithms that are utilized to best fit the devices for best compensation.