CHAPTER – 1

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1.1 Introduction to the power quality factors

In modern power system networks are complicated with hundreds of generating stations and load centers being interconnected through power transmission lines. The basic structure of a power system is shown in Figure.1.1.1 containing a generating plant, a transmission system, a sub transmission system and a distribution system. These systems are interconnected through transformers T1, T2, T3.

![Figure 1.1.1 A typical power system](image)
Earlier, the main concern of consumers of electricity was the reliability of supply, which is nothing but the continuity of electric supply. Even though the power generation in the most advanced countries is fairly reliable, the distribution is not always so. The transmission system compounds the problem further as they are exposed to the vagaries of Mother Nature. However, these days it is not only reliability, the consumer wants; quality of power too is very important to them. Also there are very sensitive loads such as Hospitals, Processing plants, Air traffic control, Financial institutions and numerous other data processing and service providers that require clean and uninterrupted power. In several processes such as Semiconductor manufacturing or Food processing plants, a voltage dip of very short duration can cost them a substantial amount of money [104]. Even these short dips of voltage are sufficient to cause conductors on motor drives to drop out from system. Stoppage in a portion of a process can destroy the condition for quality control of the product and require restarting of production. Thus in this changed scenario in which the whole system increasingly demand quality power, the term POWER QUALITY (PQ) attains increased significance [49].

Transmission lines are exposed to the forces of nature. Also, each transmission line has its loadability limit that is often determined by stability considerations or by thermal limits. Even though, the PQ problem is a distribution side problem, transmission lines often have an impact on the quality of power supplied [73]. Along with these, individual customer is responsible for a more substantial fraction of the power quality problems of power system.

1.1.1 Interest in Power-Quality (PQ)

The fact that PQ has become an issue recently does not
mean that it was not important in past. All over the world utilities have worked on
the improvement of power quality for decades [66, 93]. Even the term Power-
Quality has been in use for a rather long time already [1], which detailed a study
by the U.S. Navy after specifications for the power required by electronics
equipments, giving a remarkably good overview of the power quality field,
including the use of monitoring equipment and even the suggested use of a static
transformer switch.

The causes of power quality deteriorating problems are
generally complex and difficult to detect. Customers often describe tripping of
equipments due to disturbances in the supply voltage as 'bad power quality'. On
the other side, utility often view disturbances due to end users equipments as the
main power quality problem.

Modern power electronic equipments are not only sensitive
to voltage disturbances; they also cause disturbances to other customers [47].
The increased use of converter driven equipment has led to a large growth of
voltage disturbances (fortunately not yet to a level, where equipment becomes
sensitive)[80].

The ideal ac line supply, by the utility system should be a
pure sine wave of fundamental frequency (50/60Hz). In addition, peak of the
voltage should be of rated value. Unfortunately the ac line supply that we actually
receive not only contains power frequency components but also so-called
harmonic components with frequencies equal to a multiple of the power
frequency. Equipments have been introducing harmonic distortion since last
many decades, but recently the amount of load, fed via power electronic
converters has increased enormously, causing more harmonic voltage distortion.
Each individual device does not generate much harmonic current but all of them
together cause a serious distortion of the supply voltage [52,108].

Various power quality problems and their details [70, 73,119] have
been listed in Table no. 1.1.1 as:

### Table 1.1.1 Power quality problems and their causes

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<td></td>
<td>Oscillatory</td>
<td>Peak magnitude, frequency component</td>
<td>Line or capacitor or load switching</td>
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<td>Sag</td>
<td>Magnitude, duration</td>
<td>Ferroresonant transformer, SLG fault</td>
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<td>Magnitude, duration</td>
<td>Ferro resonant transformer, S-L-G fault</td>
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<td>Magnitude, duration</td>
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<td>Magnitude, duration</td>
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<td>Duration</td>
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<td>Harmonics</td>
<td>THD, Harmonic spectrum</td>
<td>ASD and other nonlinear loads</td>
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<td></td>
<td>Notching</td>
<td>THD, Harmonic spectrum</td>
<td>Power electronic converter</td>
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<td>DC offset</td>
<td>Volts, amps</td>
<td>Geomagnetic disturbance, half-wave rectification</td>
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<td>Frequency of occurrence, modulating Frequency</td>
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<td>Arc furnace, arc lamps</td>
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Impulsive transient does not travel very far from their point of entry, but can give rise to an oscillatory transient, which lead to transients over voltage and consequent damage to the power line insulators. Impulsive transients are usually suppressed by surge arrestors [76]. Single-Line-Ground faults on the utility distribution or transmission system are often the cause of voltage sags (dips) [96]. Voltage sags can trip a motor or cause its controller to malfunction so as to cause loss of production [60,130]. It can also force a computer system or data processing system to crash, which can be prevented by an Uninterruptible Power Supply (UPS), but it in turn generate harmonics [72, 75,87].

During voltage swell, the protective circuit of an Adjustable Speed Drive (ASD) can trip the system. The lives of computer and many home appliances may be shortened by the stress put on them. A temporary interruption lasting a few seconds will cause loss of production, erasing of computer data etc. During peak hours it may cost much amount [78, 95,118].

The long duration voltage variation has greater impact than short duration voltage variation. A sustained over voltage lasting for few hours can cause damage to household appliances without their own knowing, until it is too late. The under voltage has the same effect as that of voltage sag. The termination of process is sudden in sag and normal operation can be resumed after the normal voltage is restored. However in case of sustained under voltage, the process cannot be even restarted or resumed. A sustained interruption is usually caused by faults.

Voltage imbalance can cause temperature rise in motors and even cause a large motor to trip [6].

Harmonics, DC offset and Notching cause waveform distortions.
Harmonics are the periodic disturbances in voltage and current. They can be integer multiple of fundamental frequency, fraction of the fundamental frequency (sub harmonics) and at frequencies that are not integer multiple of fundamental frequency (interharmonics). Unwanted harmonic currents flowing through the network (system) can cause needless losses. Harmonics can also cause malfunction of ripple control or traffic control systems, losses and heating in transformers, electromagnetic interference (EMI) and interference with the communication systems. Ripple control refers to the use of a 300 to 2500Hz signal added to distribution lines to control switching of loads such as hot water heaters or street lighting. Interharmonic voltages can upset the operation of fluorescent lamps and television receivers. They can also produce acoustic noise in power equipment [58, 67, 92, 120, 122]. DC offsets can cause saturation in the power transformer magnetic circuits. A notch is a periodic transient that rides on the supply voltage. Because of high rate of rise of voltage at the notches, it can damage capacitive components connected in shunt [23, 113, 116].

Voltage flickers are frequent variations in voltage that can cause the light intensity from incandescent lamps to vary. This can have adverse effects on human health as the high frequency flickering of light bulbs; fluorescent tubes or television screen can cause strain on the eyes resulting in headaches or migraine. The voltage flickering can also reduce the life span of electronic equipment, lamps etc. [110, 111, 114, 115].

Thus the lack of standard quality power can cause loss of production, damage of equipment or appliances or can even be detrimental to human health. It is therefore imperative that a high standard of power quality is maintained.

The definition of power quality in the IEEE dictionary originates in IEEE standard 1100 as:
Power quality is the concept of powering and grounding sensitive equipment in a manner that is suitable to the operation of that equipment. The international standard setting organization in electrical engg. (IEC) does not yet use the term power quality in any of its standard documents. Instead they use the term Electromagnetic-Compatibility (EMC), defined as the ability of an equipment or system to function satisfactorily in its electromagnetic environment without introducing intolerable electromagnetic disturbances to anything in that environment [4]. Recently the IEC has also started a project group on power quality [54]. For describing the scope of the project group power quality was defined as: Set of parameters defining the properties of the power quality as delivered to the user in normal operating conditions in terms of continuity of supply and characteristics of voltage (symmetry, frequency, magnitude, waveform etc.).

From the many publications on this subject and the various terms used, the following terminology related to Power Quality has been extracted: [47, 82,100,102,103,105]:

**VOLTAGE QUALITY:** concerns with deviations of the voltage from the ideal, which is a single-frequency sine wave of constant frequency and constant magnitude, and is interpreted as the quality of the product delivered by the utility to the consumers.

**CURRENT QUALITY:** concerns with deviations of the current from the ideal. An additional requirement for an ideal current is that this sine wave is in phase with the supply voltage, and concerns with what the consumer takes from the utility. IF EITHER VOLTAGE OR CURRENT DEVIATE FROM THE IDEAL, IT IS HARD TO BE IDEAL FOR OTHER [107]. As shown in Figure 1.1, the distortion in
current will result in distortion of voltage shown in Figure 1.1.3. Similarly distortion of voltage shown in Figure 1.1.5 is the result of the distortion in current shown in Figure 1.1.4.

**POWER QUALITY:** is the combination of above two quantities (i.e., concerns with deviations of voltage and/or current from the ideal) IT HAS NOTHING TO DO WITH DEVIATIONS OF THE PRODUCT OF VOLTAGE AND CURRENT (POWER) FROM ANY IDEAL SHAPE.

Figure 1.1.2 Distorted current leading to the voltage distortion shown in Fig. 1.1.3
Figure 1.1.3 Distorted voltages, with mainly lower-order harmonic distortion.

Figure 1.1.4 Distorted current leading to the voltage distortion shown in Figure 1.1.5.
It is clear from the previous text and Table 1.1 that the majority of events currently of interest are associated with either a reduction or an increase in the voltage magnitude [90]. A straightforward classification is given in Table 1.2.
**Table 1.1.2** Suggested classifications of voltage magnitude events

<table>
<thead>
<tr>
<th>Event magnitude</th>
<th>Very short overvoltage</th>
<th>Short overvoltage</th>
<th>Long overvoltage</th>
<th>Very long overvoltage</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>110%</strong></td>
<td><strong>Normal operating voltage</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>90%</strong></td>
<td>Very short undervoltage</td>
<td>Short undervoltage</td>
<td>Long undervoltage</td>
<td>Very long undervoltage</td>
</tr>
<tr>
<td><strong>1-10%</strong></td>
<td>Very short interruption</td>
<td>Short interruption</td>
<td>Long interruption</td>
<td>Very long interruption</td>
</tr>
<tr>
<td></td>
<td>1-3 cycles</td>
<td>1-3 min</td>
<td>1-3 hours</td>
<td></td>
</tr>
</tbody>
</table>

The voltage magnitude is split into three regions:

**Interruption:** the voltage magnitude is zero

**Undervoltage:** the voltage magnitude is below its normal value

**Overvoltage:** the voltage magnitude is above its normal value

In duration, a distinction is made between

- very short: corresponding to transient and self-restoring events;
- short: corresponding to automatic restoration of the pre-event situation;
- long: corresponding to manual restoration of the pre-event situation;
- very long: corresponding to repair or replacement of faulted
components.

1.1.2 Characterization of Electric power quality

There are two different categories of causes for deterioration in power quality [99]

* Natural causes:

# Faults or lighting strikes on transmission lines or distribution feeders.

# Falling of trees or branches on distribution feeders during stormy conditions

# Equipment failure.

* Man made causes:

# Transformer energization, capacitor or feeder switching.

# Power electronic loads such as UPS, ASD, converters etc.

# Arc furnaces and induction heating systems

# Switching on or off of large loads.

1.1.3 Factors relating the power quality:

Power quality variations are classified as either disturbances or steady state variations [5]. Disturbances pertain to abnormalities in the system voltage or current due to fault or some abnormal operations. Steady state variations refer
to rms deviations from the nominal quantities or harmonics. Since poor power quality affects almost all consumers so here we list the terms and definitions that are used with power quality:

**Transients:** the part of change in a system variable that disappears during transition from one steady state operating condition to another. Transients can be either impulsive or oscillatory. A sudden, non-power frequency change in voltage or current, unipolar in nature is an impulsive transient. It has a very fast rise/decaying time: mainly caused by lightning strikes. An example is shown in Figure 1.1.6.

![Figure 1.1.6 System responses to a voltage impulse](image_url)

Figure 1.1.6 System responses to a voltage impulse
As shown in Figure 1.1.7 an oscillatory transient is usually bipolar in nature. These transients are classified in accordance with their frequency. With a primary frequency more than 500 kHz is high frequency transients. Within the frequency range of 5 kHz to 500 kHz is termed as a low frequency transient. The typical causes of oscillatory transients are capacitor or transformer energization and converter switching. An impulsive transient may also cause an oscillatory transient. The most common causes of transients are lightning, which results in impulsive transient and switching of electrical equipment resulting in oscillatory transients [79].
**Short duration voltage variations:** any variation in the supply voltage for duration not exceeding one minute is a short duration voltage variation and is further classified as voltage sag, swells and interruptions as shown in Figure 1.1.8.

![Figure 1.1.8 Short duration voltage variations](image)

Voltage sag is a fundamental frequency decrease in the supply voltage for a short duration. Its duration varies between 5 cycles to a minute [51, 107, 128]. Voltage swells are the increase of fundamental frequency voltage for a short duration. These are not as common as sags. An interruption occurs when the supply voltage (or load current) decreases to less than 1 per unit for a period of time not exceeding 1 minute [2,3]. The time duration depends upon the
operating time of the protective device.

**Long duration voltage variations:** are defined as the rms variations in the supply voltage at fundamental frequency for periods exceeding 1 minute. These are further classified as overvoltage, undervoltage and sustained interruptions. An overvoltage/ undervoltage are 10% or more increase/ decrease in rms voltage for more than one minute. If the supply voltage is zero for a period more than one minute, the long duration voltage variations are called sustained interruptions. Human intervention is required during sustained interruptions for repair and restoration.

**Voltage Imbalance:** is the condition in which the voltages of the three phases of the supply are not equal in magnitude and they may not even be equally displaced in time. The primary cause is the single-phase loads in three-phase circuits.

**Waveform distortions:** are the steady state deviations in the voltage or current waveform from an ideal sine wave and classified as harmonics, DC offset and notching. Geomagnetic disturbances and half wave rectification are the major causes of dc offsets in power systems. Poor grounding can also result in dc offsets. In the secondary of a distribution transformer, a load drawing dc current will result in a dc component of the current [7, 8, 9]. Power electronics loads like UPS, ASD etc. usually cause harmonics in power system [62,123]. A measure of harmonic content in a signal is the total harmonic distortion (THD). The percentage THD in a voltage is given by [17, 112]

$$\text{THD} = \frac{\sqrt{\sum_{n=2}^{\infty} V_n^2}}{V_1}$$

Where $V_n$ is the magnitude of $n$th harmonic voltage and $V_1$ is the magnitude of the fundamental voltage. For good quality power it is recommended that the THD
be less than 3% [73]. Notching is a periodic voltage distortion due to the operation of power-electronic converters when current commutates from one phase to other. As shown in Figure 1.1.9 during this period there is a momentary short circuit between the two phases that distorts voltages.

![Graph showing Terminal Voltage (V) and Line Current (A) over time](image)

**Figure: 1.1.9 Notch in voltage due to rectifier action**

**Voltage Fluctuations:** are systematic random variations in supply voltages. A very rapid change in the supply voltage is called voltage flicker, caused by rapid variations in current magnitude of loads, such as Arc furnaces.

**Power Frequency Variations:** are usually caused by rapid changes in the load connected to the system. The maximum tolerable variation in supply frequency is often limited within ± 0.5 Hz.
1.1.4 Power Outages:

The most common cause of an outage is equipment or component failure, e.g. loss of a generator, transformer or feeder due to faults. Sometimes utilities have scheduled outages to maintain the power equipment, which involves changing of transformer oil, replacement of a section of feeder conductors or changing of old and faulty switchgear or other equipment. During scheduled outages, a power distribution company may be able to cater to the large majority of the customers by channeling power through alternate feeders or supply transformers wherever available, but this may not be always possible. Such scheduled outages occur only occasionally and usually prior notice is given to customers that are affected by the outages.

It is the unscheduled outages that cause major problems to both utilities and customers alike. These cause higher financial loss to the customers. The impact of even short outages in semiconductor plants can be very severe, so such outages must be minimized. Amongst the unscheduled outages, natural disasters and accidents like earthquakes, floods, blizzards, tornadoes, fires, arsons, terrorist activities etc cause some. Even if some of these causes can be predicted, it is rather difficult to entirely prevent their impact on the power system.

To define the response of the system to the outages, there are various reliability indices [53, 130]:

SAIFI (System Average Interruption Frequency Index): is the total no. of customer interruption events that have occurred over a period of time (usually one year) divided by the total number of customers i.e. it gives average interruption per customer over a year.
SAIFI = \[ \frac{\text{Total number of customer interruptions}}{\text{Total number of customers in the system}} \]

CAIFI (Customer Average Interruption Frequency Index)

\[ = \frac{\text{Number of customer interruptions}}{\text{Number of customers who had at least one interruption}} \]

The index SAIFI gives the average interruptions per customer, but all customers in the system may not face an equal amount of interruptions, so we use CAIFI, which normalizes the number of interruptions w.r.t. to the total no. of customers facing interruptions. Numerical value of CAIFI will be greater than or at the most equal to that of SAIFI. Thus a comparison of these two indices can give us an insight into the system.

SAIDI (System Average Interruption Duration Index) -

gives the averages duration of all interruptions per customer i.e.

\[ \text{SAIDI} = \frac{\text{Sum total of the duration of all customer interruptions}}{\text{Total number of customers in the system}} \]

CAIDI (Customer Average Interruption Duration Index):

The total interruption duration over a year is averaged amongst the customers who had at least one interruption i.e.

\[ \text{CAIDI} = \frac{\text{Sum total of duration of all customers interruption}}{\text{Number of customers with at least one interruption}} \]

As in the case of SAIFI and CAIFI, a large difference between SAIDI
and CAIDI indicate that the outages are connected on a limited set of customers and hence further investigation will be required.

MAIFI (Momentary Average Interruption Frequency Index):

This index deals with momentary or short duration interruptions. In general the utilities do not treat the short duration interruptions as outages and hence momentary interruptions are not classified under SAIDI or CAIFI.

\[
\text{MAIFI} = \frac{\text{Total number of customer momentary Interruptions}}{\text{Total number of customers}}
\]

The frequency indices tell us how often faults occur, giving an indication about system equipment and network layout. Whereas duration indices are functions of the organization ability of the utility to limit the faulted section to the smallest number of customers and the ability to control the repair time.

1.1.5 Economic Impacts of Power Quality:

The cost associated with power outages can be tremendous. Manufacturing facilities have costs ranging from Rs.4, 00,000 to millions of rupees associated with a single interruption to the process. Momentary interruptions or voltages sags lasting less than 100 ms can have the same impact as an outage lasting many minutes. If an interruption costs Rs.16, 00,000, the total costs associated with voltage sags and interruptions would be Rs.2, 70,40,000/-year. (The total cost is approx. 17 times the cost of an interruption) [85].
1.2 Introduction and application of Artificial Neural Network for performance assessment of power system
1.2.1 Introduction

Artificial neural networks are the result of academic investigations that use mathematical formulations to model nervous system operations. The resulting techniques are being successfully applied in a variety of every day business applications.

Neural Networks (NNs) represent a meaningfully different approach of using computers in the work place. A neural network is used to learn patterns and relationships in data. Regardless of the specific involved, applying a neural network is substantially different from traditional approaches. Traditionally a programmer or an analyst specifically "codes" for every facet of the problem for the computer to "understand" the situation. Neural Network does not require explicit coding of the problem [128].

In principle NNs can compute any computable function. However NNs are as of now, difficult to apply successfully to problems that concern manipulation of symbols and memory.

Neural networks are of interest to quite a lot of people from different fields; such as computer scientists, engineers of many kinds, genitive scientists, neurophysiologists, physicists, biologists, philosophers etc. The human brain is made up of a vast network of computing elements called neurons, coupled with sensory receptor (affecters) and effectors. The average human brain, roughly 1.36 Kg. in weight and 1.35*10^-3 cubic meters in volume in estimated to contain about 100 billion cells of various types. A Neuron is a special cell that conducts an electrical signal and there are about 10 billion neurons in the human brain. The remaining 90 billion cells are called glue cells or glial and serve as support cells for the neurons. Neurons interact through contacts called synapses. On the average each neuron receives signals from thousands of synapses. The brain organizes this huge number of neurons, each with weak computing power, into a massively parallel complex
network in which these neurons interact with each-other dynamically to produce a powerful information processor [59]. Thus in the brain, each neuron takes input values from other neurons, applies a transfer function, and sends its output onto the next layer of neurons, which in turn send their output to other layers of neurons in a cascading fashion [32]. In a similar manner ANNs are usually formed from many hundreds or thousands of simple processing units, connected in parallel and feeding forward in several layers.

Thus a neural network may be defined as:

A massively parallel-distributed processor made up of simple processing units, which has a natural propensity for starting experiential knowledge and making it available for use. It resembles the brain in two respects.
1. Knowledge is acquired by the network from its environment through a learning process.
2. Inter neuron connection strengths; known as synaptic weights are used to store the acquired knowledge [81].

1.2.1. 1 - Historical Development:

The development of Artificial Neural Network started 50 years ago, when in 1958, Rosen Blatt proposed a perceptron model, having weights adjustable by the perceptron learning law. But actually in 1943, Warren McCulloch and Walter Pitts proposed a model of computing element, named as McCulloch-pitts neuron performing a weighted sum of the input to the element followed by a threshold logic operation. Combinations of these computing elements were used to realize several logical computations but the weights were fired and hence the model could not learn from examples. In 1949, Donald Hebb proposed a learning scheme for adjusting a connection weight based on pre and post synaptic values of the variables. Hebb's law became a fundamental learning rule in neural network literature [129]. Some significant contributions in this field that have put the field on strong theoretical and conceptual foundations, as it exists today, has been listed and shown in Table 1.2.1.
Table 1.2.1 Historical Development of Neural Network Principles

<table>
<thead>
<tr>
<th>Key developments</th>
<th>Other significant contributions</th>
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<tr>
<td>McCulloch and Pitts (1943)</td>
<td>von Neumann (1946)- General purpose electronic computer</td>
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<td>Model of neuron</td>
<td>Norbert Weiner (1948)- Cybernetics</td>
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<td>Logic operations</td>
<td>Shannon (1948)- Information theory</td>
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<td>Lack of learning</td>
<td>Ashby (1952)- Design for a Brain</td>
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<td>Synaptic modifications</td>
<td>Uttley (1956) Theoretical machine</td>
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<td>Hebb’s learning law</td>
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<td>Learning machines</td>
<td>Steinbuch (1961)- Learnmatrix</td>
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<td>Rosenblatt (1958)</td>
<td>Minsky and Selfridge (1961)- Credit assignment problem</td>
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<td>Perceptron learning and convergence</td>
<td>Nilsson (1965) Learning machine</td>
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<td>Linear separability constraint</td>
<td>Amari (1967) Mathematical solution to credit assignment</td>
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<td>Widrow and Hoff (1960)</td>
<td>Kohonen (1971) Associative memories</td>
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<td>Adaptive signal processing</td>
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<td>Minsky and Papert (1969)</td>
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<td>Perceptron (MLP)</td>
<td>Tikhonov (1973) Regularization theory</td>
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<td>Hard problems</td>
<td>Little (1974) Ising model and neural network</td>
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<td>No learning for MLP</td>
<td>Grossberg (1976)- Adaptive resonance theory</td>
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<td>Error backpropagation</td>
<td>Little and Shaw (1978)- Stochastic law for NN, spin glasses</td>
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<td>Energy analysis</td>
<td>Kohonen (1982) Feature mapping</td>
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<td>Boltzmann machine</td>
<td>Kirkpatrick (1983)- Simulated annealing</td>
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<td>Generalized delta rule</td>
<td>Amit (1985)- Statistical machines and stochastic networks</td>
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<td>Klopf (1986)- Drive reinforcement learning</td>
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<td></td>
<td>Hecht-Nielsen (1987)- Counterpropagation</td>
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<td></td>
<td>Information preservation</td>
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<td></td>
<td>Kosko (1988)- BAM, Fuzzy logic in ANN</td>
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<td></td>
<td>Broomhead (1988)- Radial basis functions (RBF)</td>
</tr>
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<td></td>
<td>Poggio and Girosi (1990)- RBF and regularization theory</td>
</tr>
</tbody>
</table>
1.2.1. 2 - The Artificial Intelligence:

A neural network consists of a set of processing nodes, connected together. The connections bear weight whose value is adjusted during the process of training and is fixed after the training is over. These nodes can be arranged in two (input and output) or more (hidden) layers. Each node receives input information either from an external source or from other nodes in the net as shown in Figure1.2.1. The input that any node receives from previous one is a function of the output of that node and the weight of the connection between those two nodes. If there is more than one input to a node they all are combined in a particular manner to produce the corresponding output. The architecture of an ANN is decided by the arrangement of nodes and their interconnections in the network. Each node has an activation value. The input to a node and its current state of activation are passed through a function “f” to produce an output value for the node. After fixing the architecture for a specific neural network, set of input information and the corresponding known output information are fed at its input layer and the output nodes respectively. The initial weights and biases are arbitrarily chosen and the network is trained. An algorithmic computation is carried out during training by which the network adjusts the weights and the threshold values such that the error between the targeted output and the actual output (the output obtained during training) matches the predecided error goal. While training the weight and bias attributes get readjusted so as to produce the desired output values. The network gets trained only after the attained output is within the prescribed limits of error. The weights and the biases are then memorized and the network is then used to simulate new output corresponding to the given change(s) in the input values. The network thus establishes an input output mapping.

The process of learning i.e. the process of adjustment of the weights and the thresholds, however, requires a specific algorithmic approach. A variety of learning algorithms are available for training a network. Statistical soundness of training data, the network structure, and the size of the neural network.
number of hidden layer neurons, initial weights and biases and the learning strategy affect the accuracy of the results obtained through ANN.

1.2.1. 3 - Definitions [42, 46, 126] –

**Perception:**

is a single layer neural network whose weights and biases can be trained to produce the correct response.

**Layers:**

The input and the output set of nodes in a neural network constitute minimum two layers (in some texts input is not considered as a layer, we also do so). There can be one or more hidden layer(s) in neural network. Single layer networks (no hidden layer) can solve only linearly separable classification problem. So multilayer (1 or more hidden layer(s)) network is proposed, which is quite powerful, but excessive hidden layers beyond a certain limit do not improve the network performance (1 to 3 hidden layers are preferred) [89].

**Mapping:**

fixing up of a complex empirical co-relation establishing interdependence of the input and output variables.

**Learning:**

The process of adjustment of weights and biases for obtaining the desired results during training.

**Training:**

The user provides training to a neural network while the network learns.

**Function Approximation:**

The task performed by a network to get trained in order to respond to input to give the designed output e.g. purelin, hardlim, logsig, tansig etc.
Transfer function:
maps the input of a neuron to its corresponding output.

Learning Rate:
is a training parameter, controlling the change in the sizes of weights and biases. It decides the minimum of a function. Its for small value results in smooth trajectory in the weight space, but takes long time to converge, while too large value may increase the speed of learning but will result in large random fluctuations in the weight space, leading to an unstable situation.

Local minima:
for limited range of input.

Global minima:
over the entire range of input.

Momentum Constant:
is a training parameter that prevents back propagation process to get caught into shallow minima

Learning Rule:
is the technique applied for adjustment of weights and biases during training some of which are:

Delta Rule:
Widrow Hoff rule of learning

Generalized Delta Rule:
Makes use of gradient of error with respect to the weight and is used in back propagation algorithm.

HEBB Rule:
The adjustment of the weight and the biases is proportional to the multiplication of output of pre and post epochs.

Kohenen Rule:
The weights of the selected neurons are taken as the values of the input
1.2.1.4-Neural Network Learning:

Learning is acquiring new knowledge/skill or enhancing and/or refining it. NN. Learning may be supervised, unsupervised or reinforcement. Reinforcement is most suited to control system, in which grad is provided instead of target. In unsupervised learning the ANN self organizes the data without a teacher (No target). Mostly perform some kind of clustering operation. The data is partitioned in clusters and every cluster is related to a different sub-concept. In supervised learning the process incorporates environmental information and an external teacher (l/p with a set of correct output (target)). It was demonstrated by Rumelhart et al that feed forward network, with one or more internal layers, was capable of training itself autonomously, if analytic functions were used for activation function and if a Generalized Delta Rule (GDR) was used to modify the weight of the connections and the thresholds at the activation function until the proper results were obtained. A feed forward network and a back propagation technique are shown in Figure 1.2.1 and Figure 1.2.2 respectively.

Back propagation is the most popular technique for training ANN [31, 88].

A multi layer feed-forward network with back propagation is superior than a perception. The error at the output layer propagates back ward to the hidden layer, until it reaches the input layer.
Figure 1.2.1 Feed forward Network
Although an associative neural network alternative to back propagation CMAC (Cerebellar Model Arithmetic Computer) has been reported [21] but for off line applications the back propagation technique is more popular. The FBNNs have been found to be more effective than Radial Basis Function Nets (RBFN$s$) for distinguishing the power system problems belonging to one class.

It should be noted that there are no guidelines for the choice of network architecture except for the experience of the user and a trial and error mechanism. Also, ANN$s$ are never 100 percent correct, but in practical applications, it is usually...
better to have a solution, which is 99 percent correct in few milliseconds, rather than
have a 100 percent correct solution in tens of hours [32, 66].

In Figure 1.2.1 let the input for $j^{th}$ node at the II hidden layer is $\text{net}_j^{II}$
and the output of I hidden is $0^I$ then

$$\text{net}_j^{II} = \sum w_{ij} 0^I_i, \text{ where } i = 1, 2 \ldots p \text{ for } 1^{st} \text{ hidden layer}$$

and

$$j = 1, 2 \ldots q \text{ for } 2^{nd} \text{ hidden layer}$$

\[\text{Figure 1.2.3 sigmoidal transfer function}\]

The most common activation (transfer) function - A sigmoid function is shown in
Figure 1.2.3 and given as

\[f(a) = 1/(1+\exp(-a))\]

for $j^{th}$ node of hidden layer II the effective input is

\[a = (\text{net}_j^{II} + 0^I_j)/\theta_0\]

where $\theta_0$ is the shape modifier of the activation function, deciding the
abruptness of transition. Thus
output of $j^{th}$ node

$$0_j^{(l)} = \frac{1}{1 + \exp[-(\text{net}_j^{(l)} + \theta_j)]}$$

### 1.2.1.5 - Steepest Descent Rule of Back Propagation:

Let the actual output is $Y_m$ and the target output is $t_m$, then for obtaining the minimization of error function the sum squared error is given by

$$E = \frac{1}{2} \sum (t_m - Y_m)^2$$

The searching of solution is done along the negative of the gradient and is find by iteratively applying the following algorithm until convergence

$$w_i^{(k+1)} = w_i^{(k)} - n \delta_j^{(k)} w_j^{(k)}$$

Where $w_j$ - arbitrarily chosen vector

$w_i^{(k)}$ - criterion function at $k^{th}$ iteration

$w_i^{(k+1)}$ - solution vector at $(k+1)^{th}$ iteration

$n$ - positive scale factor that sets up the step size and

$\delta$ - the error gradient operator.

For the output layer $\delta_m = Y_m (1-Y_m) (t_m - Y_m)$

For hidden layer $\delta_i = o_i (1-o_i) \sum n^k \delta_j^{k+1} o_j^{k}$

Weight correction - the weight is corrected by training the error backward as

$$w_i^{(k+1)} = w_i^{(k)} - \Delta w_i^{(k)}$$

and $\Delta w_i^{(k)} = n^k \delta_j^{k+1} 0_j^{(k)}$ where $n$ is an independent learning rate $(0<n<1)$

The connection weights between the nodes of all successive layers are updated in all the iterations. The thresholds values are also modified considering them as connections variable weights connected to fictitious nodes of previous layers having unity output [74].
1.2.1.6 - Software used:

MATLAB is a product of the math works, Inc. and is an advanced interactive software package specially designed for scientific and engineering computation. Originally it is written by Dr. Cleve Moler, chief scientist at math works, Inc to provide easy access to matrix software developed in the LINPACK and EISPACK projects in late 1970 for matrix theory, linear algebra and numerical analysis. MATLAB thus, was a foundation of sophisticated matrix software, in which the basic data element is a matrix that does not require predimensioning [128]. It basically works as a spreadsheet that calls upon the routines of Fortran and C languages. Matlab has been facilitated with several tool boxes such as control system, communications, signal processing, system Identification, robust control, simulink, neural network, fuzzy logic, Image processing, Analysis, optimization, spline, symbolic user interface utilities etc. For this thesis, the neural network toolbox of MATLAB has been used, which makes easy to build and train many types of artificial neural networks MATLAB is best suited for working with neural network algorithms compared to other general purpose systems and adept at executing them. Most neural net algorithms are readily described by matrix equations and demand elaborated computations. Neural network toolbox meets these requirements. The algorithm can tackle many classifications, interpolations, probability estimations, forecasting and recognition.

MATLAB is not hard to integrate into larger systems. It connects with C and FORTRAN function libraries for accessing MATLAB data files. Windows dynamic data exchange is supported allowing a MATLAB script to open spreadsheet, take out some data, operate on it and send it back. Under window, UNIX or VMs it can be used as a background 'Engine'. C or FORTRAN programs can send any MATLAB command by a call to a simple function.
1.2.1.7 - Designing ANN:

The performance of an ANN greatly depends on its appropriate and adequate design. However, the design of a network requires sufficient acquaintance with the different features of neural networks. There is no rule available for designing a network. The designer has to make efforts by hit and try, to develop a suitable design of the network to get the best possible results [66, 32, 61]. The following steps are included in the design of an ANN:

**Selection and preparation of input and output**

Before selecting the input features, we must have sufficient knowledge of the system and its behavior. There are two types of features that basically govern the performance of any system under consideration. Firstly, the features directly affect the system performance; there exists a mathematical correlation between the input and the output parameter defining the system problems. Secondly, some features may have an effect on or a relation with the given problem but they may not bear any direct mathematical relationship with the parameters defining the problem. The mapping property of ANN is harnessed to solve such problems. The input data may be selected as such or there can be a procedure made on input data. A large number of input features assure meaningful categorization.

After selecting the desired input and the output features, it is essential to prepare data for presenting to the neural network, which can be done by either scaling or by normalizing the data. Preparation of data has a very important role to play in the overall performance of the NN.

1.2.1.8 - Selection of ANN Architecture:

The arrangement of neurons into layers and the pattern of connection within and in-between layers are the architecture of the net. The number of layers in the net can be defined to be the number of layers of weighted interconnected links between the particular slabs of neurons. A single layer network (no hidden layer) is
shown in Figure 1.2.4(a). If two layers of inter connected weights are present, it is found to have hidden layers as shown in Figure 1.2.4(b).

![ANN Architecture](image)

(a) Single layer feed forward  
(b) Multi layer feed forward

**Figure 1.2.4 A N N Architecture**

As mentioned a multi layers feed forward with back preparation is the best-suited architecture [129]. Selection of ANN structure requires understanding of the computational procedure and the limitations of a particular type of NN. It is not necessary that all the types of available structure can solve a given problem. Again a befitting NN architecture is chosen by trial and practice to solve the given problem.

Commonly one input vector is presented to a network as the input and an algorithm is applied to compute the corresponding output. Sigmoid and linear functions can deal with a wide range of problems. A large number of input vectors however can be simultaneously fed to get the network response against each of them called batching the input. This provides consistent training of the network and better accuracy of results if sufficient knowledge base is available.
1.2.1.9 - Selection of Training parameters:

For the efficient operation of the back propagation network it is necessary for the appropriate selection of the parameters used for training. The effects of parameters affect the training. Initialization of the training weight and biases, change of error goal and that of learning rate, number of hidden layers and the number of nodes in each hidden layer all affects the training. Except for purely linear network, more number of neurons in the hidden layer makes the network powerful up to a certain level. Too many numbers may result in the development of internal noise and unacceptably large residual error. One or two hidden layers provide required result [60].

It is not necessarily advantageous to continue training until the error reaches a minimum value. As long as the error for validation decreases training continues. Whenever the error begins to increase, the net is starting to memorize the training patterns; at this point training is terminated [129].

1.2.2 - Applications:

The electrical power system has been increasing in complexity at a rapid rate in the last few decades. Present day power systems are dynamic in nature, where the network topology frequently changes with load demand. Many measures have been introduced to improve its reliability and security [64,88]. However, the system is more and more polluted owing to the increasing use of power electronic converters and controllers for industrial processes and drives, among other types of disturbing loads. The effect is the contamination of the 50 Hz supply by a wide range of frequencies up to the radio frequencies and thus power system monitoring becomes a necessity to check the state of health of the power network [13] i.e.

POWER-QUALITY
Power quality has become an issue of increasing interest since late 1980s. The interest in PQ involves all three parties concerned with the power business: utility companies, equipment manufacturers and electric power customers [66].

Electric power quality problems are many and are largely dependent on the system configuration and the system equipment. The proper diagnosis of power quality problems requires a high level of engineering expertise and the required expert knowledge in not in one area, but is rather in many areas of power knowledge.

New powerful tools of interest to PQ diagnosis are those of artificial intelligence (AI). The use of AI technique in electric power has received extensive attention from many researchers. The AI tools of interest to the electrical power community include expert system (ES) artificial neural net- works (ANNs), fuzzy logic (FL) and the newer techniques of Adaptive Neuro-Fuzzy systems (ANF5) etc.

ANN is an advanced and fast upcoming AI technique finding applications in various fields of engineering including power system engineering. An ANN does not precisely represent the inherent intricate mathematical nonlinear relationship among the input - output parameters constituting the power system equations, however if has got the unique feature of mapping the input-output relationship differently through its weighted links and the thresholds. The learning process of ANN is termed as training of the network. Back propagation is the most popular technique used for training ANN. A well-trained ANN provides the desired results within permissible range of accuracy, practically with in no time. So ANN has come up as a power full tool for solving complicated engineering problems. A lot of work has been reported in literature in the area of application of ANN in power system problems like load forecasting, assessment of static and dynamic stability, assessment of security etc. In the present work the ANN is used in assessing the power quality of IEEE 30-bus system.
1.2.2.1- ANN applied to power system problems: A review

Among the many applications of ANN in power system engineering, some are listed below.

R. Khosla et al [41] suggested a neuro-expert system approach to represent and analyze a power system. In order to minimize the power system losses using real and reactive line flows, bus voltages and the capacitor settings, the Artificial Neural Network model proposed by N. Iwan Santosa et al [16] gave real time cost effective control of capacitor setting under varying load conditions. AI based demand side management has been developed by I.F. Hopley et al [29] and A.S.Zadgaonkar [63] to support energy management in power system during abnormal situations.

A lot of work has been reported in the area of power system security using ANN. K. Shantiswarup et al [88] demonstrates the feasibility of classification of load patterns for power system static security assessment using Kohonen self organizing feature map. R. Fischl [34] has reported an over view of application of ANN to power system security assessment from ANN design point of view. For assessment of large power system static security S. Weerasooriya et al [26] used the property of ANN for synthesizing a map between input and output variables using pattern recognition perspective. Soumen Ghosh et al [39] have suggested Hopfield neural network based optimization technique for obtaining security constrained active power.

Stability is a very important area where sufficient work using ANN has been reported. ANN has been successfully applied by D.Venkataraman to predict the voltage stability margin [50]. Sushil Chauhan et. al. [40] have found the transient stability of a power system in terms of transient energy margin using ANN and the results obtained from Liapunov function method are compared. Liang Zhong Yao et al [30. 37] used ANN for non linear mapping of the transient energy margin and generator power at different fault clearing time to give transient stability limit for the generator at different critical clearing time.
For power system state estimation, conventionally the non-linear power system equations are liberalized and then solved using Newton Raphson method. Badrul H. Chowdhury et al [28] used real and reactive power generation and load as information to ANN in order to obtain complex bus voltages of a power system as a fast load-flow solution. D.M. Vinod kumar tested various ANN models and their different algorithms for state estimation, observability analysis, network to topology and static state estimation of power system. Pourbeik el al [48] trained ANNs for fault diagnosis as well. A.G. Jogepier et al [27] have described ANN based scheme for distance protection of a double circuit line.


Much work has been reported on application of ANN to analyze the performance of rotating machines. Bekir Karlic [44] suggested the performance analysis of induction motors using ANN. An ANN based alternative to conventional field oriented decoupling control of induction motor has been reported by A-Ba-Razzquk [43] using MATLAB/SIMULINK/NN toolbox.

P.K. Hota et al [65] tested the ANN approach for economic generation scheduling. During last three decades the expert system and ANN based load forecasting models have been developed. Alireza khotanzad et al [55] shows the ANN as a powerful tool for load forecasting. D.C. Park et al [24] found that ANN is suitable to interpolate among the load and temperature pattern data of training sets to provide the future load pattern. Dunae D. Highley at al [32] proved that there is a huge potential for using an ANN to perform short-term load forecasting.

D.K Chaturvedi et al [56] developed the Generalized Neural Network (GNN) to accommodate the dependency of load forecast on nature of event, load demand, type of load, seasonal variance, day of the week etc. GNN approach
required less number of neurons, less hidden layers, less training data and less
convergence time also less error in the results. A.K. Azad et al [57] have developed
a multi layer feed forward neural network using back propagation training method to
forecast the monthly load of a large institute using different models. S.P.Singh et al
[38] used one neural network to predict loads of week days, weekend and holidays
for all seasons. Jeff kohlback [33] and Vincent E. Findley [45] established the
suitability of ANN for daily peak demand.

Power quality is the latest burning topic for electrical engineers. J.V.
Wijayakulasooriya et al [82] and K.A. Ghosh et al [47] gave the power quality
disturbance classification using ANN. Various works, researches, experiment have
done for several years and are in progress in this field [77, 83, 84, 86, 91, 97, 98,
109, 117, 121, 124, 127].

Thus load scheduling, power system stability, power-system security,
frequency predication etc. are the areas of great interest. And considerable efforts
are needed for the assessment of power quality e.g. bus voltage (both magnitude
and phase), frequency and so harmonics (total harmonic distortion THD), therefore
in the thesis power quality assessment using ANN for the IEEE standard system is
presented.