CHAPTER-I

Introduction to the Status of Power System And its Associated Requirements

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1.1 INTRODUCTION

The total installed electrical power generating capacity and per capita electrical energy consumption are the indices of development of a country. Electrical energy has been accepted as the most feasible form of energy because it can be generated in bulk, transmitted conveniently over long distances and applied efficiently to various purposes including industrial, agricultural and domestic etc. Electrical power system is a system comprising of generators, transformers, bus bars, transmission lines, loads etc. inter-connected in a particular manner. Several power systems are interconnected together to ensure uninterrupted power supply to the consumers [168,108].

The generated electricity cannot be stored. At the same time, it is difficult to precisely predict the demand beforehand. The generated electricity is required to chase the demand, maintaining the quality power supply by means of providing power at constant voltage and constant frequency [75, 86]. Maintenance of such a balance is not easy although it is essential for satisfactory and stable operation of the power system. A great deal of planning and control of operations required achieving this balanced condition. The entire power system is highly sensitive to its operating conditions and susceptible to loss of synchronism [108, 161]. The problems of dynamic and steady state stabilities, voltage and frequency regulations, optimization of active and reactive power are the major challenges before power engineers.

The traditional manual and semi-automatic techniques could not survive long due to ever increasing size and complexity of power systems [66,71]. From 1929 onwards the analog computers were used. From 1956 onwards digital computers replaced them. Since then the extensive and complex computations of interdependent nonlinear algebraic simultaneous equations, representing power systems, are being solved by the digital computers. During past two decades, the attempts have been
made to explore the possibility of introducing Artificial Intelligence as an alternative tool to solve the lengthy and complex power system problems with fewer efforts.

The important task of power system engineers is two folds [168, 61, 71, 161, 149]. One is the procurement of knowledge of the current status of a power system in terms of the complex voltages at all the buses, generation and load, and the line flows. The load flow study of power system study provides such information, which is then used for the purpose of planning the expansion and control of operation of the power system. The other second area of concern is to decide whether the system currently is safe, critical or unsafe. If the system is safely operating, it is of further interest to know whether following an unforeseen outage of one or more components, the power system will still remain within safe operating limits. The short circuit study, which includes the fault calculations and stability studies, facilitates the adequate designing of the protective schemes so as to remove the unhealthy part at the earliest and continue the supply to the unaffected parts [168].

There has been a remarkable progress in terms of development of computational facilities and software for study of the activities like power system planning, design, analysis and control [66]. However, much still depends on the judgment by human experts. The experienced planning and design personnel make efficient intuitive decisions on the basis of the comprehensive knowledge of the prevailing circumstances.

In recent years Artificial Neural Network has been developed as an alternative tool for quick assessment of the performance of power system. The work reported so far is much scanty and leaves a scope for further investigation.
1.2 OBJECTIVE

Studies in the area of power system engineering are focused at ensuring uninterrupted supply of quality electric power to the consumers. The quality supply means constant frequency and constant voltage power supply under normal operating conditions. For planning the improvement or expansion and for controlling the operation of the power system, the power engineer needs to assess the status of power system under varying operating conditions. The controls of power system are required to be quick and robust enough so as to withstand the sudden unforeseen variations of load and/or generation and accordingly adjust the generation and/or load respectively such that the continuity of the supply of quality power is maintained. Quick assessment of voltages at different buses, power flow through lines, effect of changing loads on generation scheduling etc. are some of the important issues which help the engineer in decision making.

The second objective is that in case of abnormal operation or fault, the protective system should be quick in sensing the fault. The removal of the faulty part should be made decisively such that the normal operation is maintained at the remaining healthy part of the power system and at the same time the system is restored quickly.

It is complicated to satisfy aforesaid dual objectives especially because of the operating constraints, unpredictable load variations and the power system operating conditions. Moreover, some of the operating quantities are nonlinearly interdependent to a great extent. With the advent of interconnected grid systems and increasing size of power systems, the analyses of power systems are becoming more and more complicated and time consuming. Hence, one of the important aims of the ongoing research in the field of power system engineering is to reduce the power system status assessment time. The main objective of the work reported in this thesis is focused at
exploring and establishing the viability of using Artificial Neural Network as a powerful tool to assess the status of the power lines quickly.

1.3 STATUS OF POWER SYSTEM

The power lines operate in their steady state mode under normal operating conditions. The calculation carried out to determine the steady state operating characteristics of the power lines, for given combination of the bus bars and the interconnecting lines, is termed as Power Flow or Load Flow [86].

While a power system is in operation, it may be subjected to one or more of the following conditions [86, 71].

- Change in load,
- Change in generation,
- Elimination of one or more lines
  (For maintenance or due to operation of protective system against fault),
- Tripping due to overloading.
- Line outage

The above conditions affect the status of the power lines and hence, the operation of the power system and may result in instability, fault or collapse of the system due to one or more of the following reasons [122].

- Violation of voltage limits at one or more load buses,
- Violation of reactive power generation limits at one or more generator buses,
1.4 POWER SYSTEM REQUIREMENTS

For reliable and economic operation of power system, it is essential to monitor and control the status of the entire power lines in a control center. The modern control centers are equipped with on line computers performing variety of signal processing in a hierarchical manner ensuring satisfactory operation of power system under normal as well as abnormal conditions. Every control center has a control console, operated by an experienced personal. Various computers are there in the control center to raise alarm on occurrences of deviations from normal operation. The control room personal makes judgments and decisions according to the functional requirements of the power system and then executes the corrective measures through computers on the basis of his expertise and the intuitive skill. The existing computational techniques use sequential or serial computations. Advanced software packages, written in user-friendly high level languages, are available to perform fast calculations and produce results which are required for decision making.

AC calculating boards, having small - scale single – phase replicas of actual systems were used which provided the power system solutions consuming larger time. Digital computers facilitated much faster calculations of the complex problems like load flow of the power systems having hundreds of transformers and thousands of buses and lines [168]. The different approaches to solve power system problems involve detailed mathematical modeling of the power system components, proper interfacing of these models and then the development of an algorithm to represent the problem exactly [80, 141]. An appropriate computational tool is then applied to obtain the desired solutions describing the status of the power system under varying operating conditions to ensure that the power system operates within safe and stable limits of operation.
1.5 LOAD FLOW ANALYSIS

Various system components are mathematically modeled to suit the type of study to be carried out, and then appropriately interfaced to represent the power system [78, 80]. The network contains hundreds of nodes and lines with impedances specified in per unit on a common MVA base. The equations describing the network are normally in the node-voltage form. The nodal admittances give the node currents in the form of complex linear simultaneous algebraic equations [66, 71]. The power system equations become nonlinear because for load flow solutions, the power flow equations are used instead of the current flow equations. Solutions of the equations thus obtained require iterative numerical computational techniques. The Power Flow (Load Flow) study is carried out to determine the status of the power system in terms of the complex bus voltages, complex line flow and the line losses. The Load Flow study is the most important study for a power system and is essentially performed at all stages of power system planning, operation and control.

A power system is assumed to be normally operating under balanced conditions. For Load flow studies, single-phase representation of the power system is used. The analysis is carried out using four quantities related to the system [86, 71, 161].

Voltage magnitude $|V|$, 
Phase Angle $\delta$, 
Real Power $P$, and 
Reactive Power $Q$.

The buses are classified as follows.
### Bus Type

<table>
<thead>
<tr>
<th>Bus Type</th>
<th>Known Quantities</th>
<th>Unknown Quantities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slack Bus (Reference Bus)</td>
<td>$</td>
<td>V</td>
</tr>
<tr>
<td>Load Bus (PQ Bus)</td>
<td>$P$ $Q$</td>
<td>$</td>
</tr>
<tr>
<td>Voltage Controlled Bus (PV Bus)</td>
<td>$P$ $</td>
<td>V</td>
</tr>
</tbody>
</table>

The Load Flow problem, in general, can be stated as follows.

**Given**: $V_1, S_2, S_3, \ldots, S_m; P_{m+1}, |V_{m+1}|; \ldots; P_n, |V_n|$

**Find**: $S_2, V_3, V_4, \ldots, V_n; Q_{m+1}, \delta_{m+1}, \ldots; Q_n, \delta_n$

Where suffix ‘1’ is used for Slack bus, ‘2 to m’ for Load (PQ) bus and ‘(m+1) to n’ for Generation (PV) bus quantities.

With the above information the equations are developed [122] such that,

$$f(x, y) = 0; \quad \ldots. 1.1$$

Where ‘$f$’ is a vector function, ‘$x$’ is a vector of $(2n+1)$ independent variables, and ‘$y$’ is a vector of $(2n+1)$ dependent variables.

The values of ‘$x$’ that are used to control some of the ‘$y$’ variables are called Controlled parameters. These are the adjustable independent variables like $|V|$ on Load bus, $P_g$ at generation bus having controllable power etc. The remaining independent variables are called the fixed variables. However, all the independent variables must remain within specified limits decided by the physical and the operating conditions of the given power system.

The conventional methods of solving the above-discussed simultaneous equations for obtaining the unknown quantities use iterative numerical methods like Gauss Siedel method, Newton Raphson methods or Fast Decoupled method. The
study is started with certain assumptions and the whole calculation is iterated for a
number of times so that the following power balance is satisfied.

\[
( \text{The total system demand} + \text{The system losses}) \sim (\text{Specified power at
voltage controlled bus}) = (\text{Power supplied by the Slack bus})
\]

or

\[
P_g - P_d - P_i (|V_i|, \delta_i) = 0, \quad \text{and} \quad \ldots \ldots 1.2
\]

\[
Q_g - Q_d - Q_i (|V_i|, \delta_i) = 0 \quad \ldots \ldots 1.3
\]

Where, \( i = 1, 2, \ldots, n \)

\( n \) = number of buses in the system

\( P_g, Q_g = \text{Active and reactive generation at bus 'i'} \)

\( P_d, Q_d = \text{Active and reactive demand at bus 'i'} \)

\( P_i, Q_i = \text{Active and reactive power injected by lines connected to bus 'i'} \)

\( |V| = \text{Bus voltage magnitude} \)

\( \delta = \text{Bus voltage angle.} \)

At the same time it is important that the following voltage and power
constraints, called the Inequality Constraints, are followed [122, 71].

1. Normally, \( |V_i| \) must satisfy the constraint

\[
|V_i|_{\text{max}} < |V_i| < |V_i|_{\text{max}} \quad \ldots \ldots 1.4
\]

The permissible limit of variation, from stability study point of view, is +/- 5%
of the rated values.

2. The bus voltages normally do not have a range of phase wider than 30° and
the difference between the successive bus voltages is less than 10°. Often it is even
less than this value.
3. Due to physical constraints at generating power plants the following constraints are also imposed.

\[ \left| \delta_i - \delta_j \right| < \left| \delta_i - \delta_j \right|_{\text{max}} \] ........1.5

\[ P_{g_{\text{min}}} < P_{g_i} < P_{g_{\text{max}}} \quad \text{and} \quad Q_{g_{\text{min}}} < Q_{g_i} < Q_{g_{\text{max}}} \] ........1.6

The Load Flow study is performed for changing supply and demand conditions and the variation of the line flows and the bus voltages is observed critically. In case of violation of the constraints, the operator takes necessary appropriate decisions to maintain a secured and stable operation of the power system. It is, therefore, important for the operator to have fast operating tools that may provide him with quick results enabling him to take the necessary steps quickly. Although the existing techniques are sufficiently fast, but the technique developed in this thesis can produce results even faster.