Projects
- Load Flow
- P. Qual/harm.

S.C. Study results.
- Protective Relaying
- Bus bar design
- Interrupting Ratings
  - Fuses
  - CBs
  - Other interrupters
- CT Accuracy Concerns
- CCVTs: Subsidence transients
and then to

\[ V_{\text{out}} = \left( \frac{K \cdot T_2}{T_1} + \frac{K(1 - T_2/T_1)}{1 + T_1 \cdot p} \right) V_{\text{in}} \]

which can be represented by the block diagram in Fig. 6.11, and is a lag circuit in parallel with a gain.

It is important to remember that the time constant \( T_1 \), must be nonzero even if the integration method can accommodate zero time constants.

### 6.4 LOADS

Early transient stability studies were concerned primarily with generator stability, and little importance was attached to loads. In the two-machine problem for example, the remainder of the system, generators and loads were represented by an infinite busbar. A great deal of attention has been given to load modelling since then.

![Figure 6.12](image)

Characteristics of different load models: (a) active and reactive power against voltage; (b) current against voltage
Table 6.1
Typical values of characteristic load parameters [9]

<table>
<thead>
<tr>
<th>Load</th>
<th>$p_v$</th>
<th>$q_v$</th>
<th>$p_f$</th>
<th>$q_f$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Filament lamp</td>
<td>1.6</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Fluorescent lamp</td>
<td>1.2</td>
<td>3.0</td>
<td>-1.0</td>
<td>2.8</td>
</tr>
<tr>
<td>Heater</td>
<td>2.0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Induction motor half load</td>
<td>0.2</td>
<td>1.6</td>
<td>1.5</td>
<td>-0.3</td>
</tr>
<tr>
<td>Induction motor full load</td>
<td>0.1</td>
<td>0.6</td>
<td>2.8</td>
<td>1.8</td>
</tr>
<tr>
<td>Reduction furnace</td>
<td>1.9</td>
<td>2.1</td>
<td>-0.5</td>
<td>0</td>
</tr>
<tr>
<td>Aluminium plant</td>
<td>1.8</td>
<td>2.2</td>
<td>-0.3</td>
<td>0.6</td>
</tr>
</tbody>
</table>

Much of the domestic load and some industrial load consist of heating and lighting, especially in the winter, and in early load models these were considered as constant impedances. Rotating equipment was often modelled as a simple form of synchronous machine and composite loads were simulated by a mixture of these two types of load.

A lot of work has gone into the development of more accurate load models. These include some complex models of specific large loads which are considered in the next chapter. Most loads, however, consist of a large quantity of diverse equipment of varying levels and composition and some equivalent model is necessary.

A general load characteristic [8] may be adopted such that the MVA loading at a particular busbar is a function of voltage ($V$) and frequency ($f$):

$$P = K_P (V)^{p_v} (f)^{p_f}$$  \hspace{1cm} (6.4.1)

$$Q = K_Q (V)^{q_v} (f)^{q_f}$$  \hspace{1cm} (6.4.2)

where $K_P$ and $K_Q$ are constants which depend upon the nominal value of the variables $P$ and $Q$.

Static loads are relatively unaffected by frequency changes, i.e. $p_f = q_f = 0$, and with constant impedance loads $p_v = q_v = 2$.

The importance of accurate load models has been demonstrated by Dandeno and Kundur [8] when considering voltage-sensitive loads. Figure 6.12 demonstrates the power and current characteristics of constant power, constant current and constant impedance loads. Berg [9] has identified the characteristic load parameters for various homogeneous loads and these are given in Table 6.1. These characteristics may be combined to give the overall load characteristic at a busbar. For example, a group of $n$ homogeneous loads, each with a characteristic of $p_v j$ and a nominal power of $P_j$ may be combined to give an overall characteristic of

$$p_v^\text{(overall)} = \frac{\sum_{j=1}^{n} (p_v j) P_j}{\sum_{j=1}^{n} (P_j)}$$  \hspace{1cm} (6.4.3)

The other three overall characteristics may be similarly determined.

6.4.1 Low-voltage Problems

When the load parameters $p_v$ and $q_v$ are less than or equal to unity, a problem can occur when the voltage drops to a low value. As the voltage magnitude decreases,
the current magnitude does not decrease. In the limiting case with zero voltage magnitude, a load current flows which is clearly irrational, given the nondynamic nature of the load model. From a purely practical point of view, the load characteristics are only valid for a small voltage deviation from nominal. Further, if the voltage is small, small errors in magnitude and phase produce large errors in current magnitude and phase. This results in loss of accuracy and with iterative solution methods poor convergence or divergence.

These effects can be overcome by using a constant impedance characteristic to represent loads where the voltage is below some predefined value, for example 0.8 p.u.

6.5 THE TRANSMISSION NETWORK

It is usual to represent the static equipment which constitutes the transmission system by lumped ‘equivalent-π’ parameters independent of the changes occurring in the generating and load equipment. This representation is used for multi-machine stability programs because the inclusion of time-varying parameters would cause enormous computational problems. Moreover, frequency, which is the most obvious variable in the network, usually varies by only a small amount and thus the errors involved are small. Also, the rates of change of network variables are assumed to be infinite which avoids the introduction of differential equations into the network solution.

The transmission network can thus be represented in the same manner as in the load-flow or short-circuit programs, that is by a square complex admittance matrix.

The behaviour of the network is described by the matrix equation

\[ [I_{\text{inj}}] = [Y][V] \]  \hspace{1cm} (6.5.1)

where \([I_{\text{inj}}]\) is the vector of injected currents into the network due to generators and loads and \([V]\) is the vector of nodal voltages.

Any loads represented by constant impedances may be directly included in the network admittance matrix with the injected currents due to these loads set to zero. Their effect is thus accounted for directly by the network solution.

6.6 OVERALL SYSTEM REPRESENTATION

Two alternative solution methods are possible. The preferred method uses the nodal matrix approach, while the alternative is the mesh matrix method.

Matrix reduction techniques can be used with both methods if specific network information is not required, but this gives little advantage as the sparsity of the reduced matrix is usually very much less.

6.6.1 Mesh Matrix Method

In this method, the system-loading components are treated as Thévenin equivalents of voltages behind impedances. The network is increased in size to include these impedances and the mesh impedance matrix of the increased network is created. This is then inverted or the factorised form of the inverse determined.
Faults:

\[ V_{TH} \]

\[ X/R \]

RL Ckt:

\[ Z = \frac{L}{R} = \frac{X}{\omega R} \]

345-kV:

\[ 12 < \frac{X}{R} < 20 \]

69-kV:

\[ 1 < \frac{X}{R} < 8 \]

dist: \[ \frac{X}{R} < 1 \]
Ex: HV Substation

25 ft between supports (~ 8 m)

Parallel Conductors:
- Steel Pipe or I-beam
- Anchor bolts
- Foundation
- Concrete
- Rebar cage

L-L 3Ø Fault, 40,000 Arms = 56,570 A peak

What is max induced force?

\[ f = i (\mathbf{I} \times \mathbf{B}) N \]

\[ f_{\text{insul}} = (56,570 \times 8 \text{m}) \times 0.0377 \]

\[ = 1706 \text{ N} \times \frac{kN-f}{7.8N} \times \frac{2.21b}{kN} \]

\[ = 383165 \text{ (max)} \]

Max Groundline Moment:

\[ (383)(12) = 4600 \text{ ft-lbs} \]

Note:

\[ H = \frac{I}{2\pi r} \]

\[ B = \mu_0 H = \frac{\mu_0 I}{2\pi r} \]

\[ = \frac{(4\pi \times 10^{-7})(56,570)}{2\pi (8 \text{m})} \]

\[ \approx 0.00377 T \]
Resonant freq. of insulator

Avoid not freq. of 120 Hz or harmonics.

\[ f(t) \int t^n \]