CONTENTS

POWER SYSTEM NETWORK REDUCTION TECHNIQUES
Network Reduction (Kron Reduction)
Dynamic Equivalents of External Electric Power Systems
power system Network Matrices

\[ I = Y_{bus} \ V \]

where

- \( I \) = vector of injected node currents
- \( Y_{bus} \) = Bus admittance matrix
- \( V \) = vector of node voltages

**Network Reduction (Kron Reduction)**

- In a power system, the current injection is always zero at buses where there are no external loads or generators connected.
- Such nodes may be eliminated.
- For an \( n \)-bus system, if node \( k \) has zero current injection (i.e., \( I_k = 0 \) in the nodal equations), then we can obtain the reduced admittance matrix by eliminating node \( k \) by using the formula...
\[ Y_{ij}^{(new)} = Y_{ij} - \frac{Y_{ik} Y_{kj}}{Y_{kk}} \quad 1, 2, \ldots, n \quad i, j \neq k \]

- The superscript (new) distinguishes the elements of the new \((n-1) \times (n-1)\) \(Y_{bus}\) from the original \(n \times n\) \(Y_{bus}\).
- In stability studies, normally we eliminate all the nodes except for the internal generator nodes and obtain the \(Y\) matrix for the reduced network.

\[ I = YV \]

Where

\[ I = \begin{bmatrix} I_n \\ 0 \end{bmatrix} \]

\[
\begin{bmatrix} I_n \\ 0 \end{bmatrix} = \begin{bmatrix} Y_{nn} & Y_{nr} \\ Y_{rn} & Y_{rr} \end{bmatrix} \begin{bmatrix} V_n \\ V_r \end{bmatrix}
\]

\[ I_n = (Y_{nn} - Y_{nr} Y_{rr}^{-1} Y_{rn}) V_n \]

- The matrix is the desired reduced matrix \(Y\). It has the dimensions \((n \times n)\) where \(n\) is the number of the generators.
• If the loads are not considered to be constant impedances, the identity of the load buses must be retained.
• Network reduction can be applied only to those nodes that have zero injection current.
Equivalent (Reduced) Networks

• An equivalent represents a network, which contains many buses but only a few boundary buses, by a reduced network that contains only the boundary buses and a few of the original buses.

• Equivalents are used in two circumstances: both to allow larger areas of major interconnected systems to be represented in studies and also to achieve improved computational speed in simulations by removing buses and branches that influence system behavior, but are not of specific interest.
<table>
<thead>
<tr>
<th>Study System</th>
<th>A group of buses under detailed study; all components are represented explicitly.</th>
</tr>
</thead>
<tbody>
<tr>
<td>External System</td>
<td>A group of buses and branches that connect to and influence a study system, but do not need to be represented in detail.</td>
</tr>
<tr>
<td>Boundary Buses</td>
<td>Buses from which branches run into either a study system and one or more external systems, or into more than one external system.</td>
</tr>
<tr>
<td>Source System</td>
<td>A power system representation which contains all components of an external system as a subset of its own components. It is used to solve for the base conditions within the external system. The source system does not need to include the study system, but must recognize flows between the external and study system.</td>
</tr>
<tr>
<td>Electrical Equivalent</td>
<td>An artificial group of branches and buses which represents the behavior of the external system as seen from its boundary buses.</td>
</tr>
<tr>
<td>Retained Bus</td>
<td>A bus of the external system which is also a bus of the electrical equivalent. A retained bus is not necessarily a boundary bus, but all boundary buses are retained buses.</td>
</tr>
<tr>
<td>Deleted Bus</td>
<td>A bus of the external system which is not a bus of the electrical equivalent, but whose effect is represented by the equivalent.</td>
</tr>
<tr>
<td>Tie Branch</td>
<td>A branch with one end in one system (study or external) and the other end in a different system.</td>
</tr>
<tr>
<td>Area</td>
<td>A group of buses designated in load flow input data for interchange control purposes. An area may, but does not necessarily, coincide with a study or external system.</td>
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</tbody>
</table>
Defining Boundaries and Boundary Buses

A boundary cuts a set of tie-lines between areas or otherwise identifiable sections of a network but passes through no buses. A boundary bus is part of only one area.
Figure 9-1. Separation of Complete Network into Study System and External Systems by Boundaries
An equivalent makes more efficient use of storage when the ratio of branches to buses in the equivalent is reduced.

The relative efficiency of different equivalents of a given system is best determined by trial and error.

As a general rule, however, reducing a system into a number of small equivalents is more efficient than reducing of a large system in one step to produce a single equivalent.
Three special bus type codes are used to designate boundary buses at various stages of the equivalent construction processes:

Type 5  As for Type 1 (load bus); boundary bus or a bus that is not to be deleted by equivalencing, retained bus.

Type 6  As for Type 2 (generator bus); boundary bus.

Type 7  As for Type 3 (swing bus); boundary bus.

It can be seen in Figure 9-1 that the area designated as the "Study System" there are three buses (buses 198, 78 and 77) which are the terminals of lines incoming from the other two areas and there
are four boundary buses in the external systems. If the external systems bus were to be reduced to an equivalent network, it is possible that boundary 914 could be eliminated.

But it would probably be important for the user to retain this bus because of its strategic position in the network.

It is important to note that type codes 5, 6, 7 are valid only during equivalent construction and system data processing operations.
Handling DC Lines

The equivalencing process automatically retains converter buses of unblocked DC transmission lines.

Hence, all buses that are affected by DC transmission must become part of a study system before commencing the construction of an equivalent.
Creating a Network Equivalent

The primary purpose in constructing equivalents is to represent a portion of a network containing many buses but having only a few "boundary buses" by a reduced network containing only the boundary buses and, perhaps, a few selected buses from within the original sub-network.

The equivalent constructed gives an exact reproduction of the self and transfer impedances of the external system as seen from its boundary buses.

The net total of load, generation, and losses in the equivalent matches this total in the complete external system if the bus voltages in the working case were a valid power flow solution.

However, the load, generation, and loss totals in the equivalent may not individually match those of the complete external system.
When voltage conditions at the boundary buses of the study system are changed, the equivalent gives an approximation to the change in power flow into the external system.

This approximation is good as long as the changes are small, but may become unreliable when boundary bus voltages and power flows into the external system (or its equivalent) deviate from the base values by large amounts.

An electrical equivalent is, therefore, correctly applied when it represents an external system in which disturbances or switching operations under study produce only minor effects.

Equivalents should not be applied to network segments in the close vicinity of the disturbances or switchings.
Constructing the Network Equivalent

The task of constructing and using an electrical equivalent can be separated into three steps:

1. Isolating an external system in the working case. The process temporarily discards from the open power flow case all other subsystems (study and external) contained in the source system except the one to be equivalenced. Boundary and retained buses are identified and, if desired, selected generators are replaced by negative load.

2. Constructing the electrical equivalent by performing the required matrix reduction operation on the external system remaining in the working case.

3. Combining system sections together to form a valid system model in the working case. In this step, detailed representations of selected external systems are replaced with their electrical equivalents.
Electrical equivalents are constructed on the following basis:

That is, it constructs an equivalent of a subsystem of the working case with its interior type one buses eliminated.

The equivalent construction process automates many of the data handling tasks required in preparation for, and following the execution of, the equivalent construction calculation.
Dynamic Equivalents of External Electric Power Systems

• In large power systems, normally it is desirable to consider only the local system under study in detail, and to represent the external systems by equivalents.
• Static equivalents for load flow studies are fairly well developed.
• Development of the dynamic equivalents for dynamic studies requires more attention.
• Primary concern is the dynamic interacting effect of the external system on the local system under investigation.
• Dynamic equivalents are used for stability analysis, stabilizer design, and investigation of the electric power transfer limits among areas.
• Ward type equivalents based on Distribution Factors used in power flow studies were extended for Dynamic Studies.
• Model reduction based on Modal Analysis requires computation of eigenvalues & eigenvectors.

• Coherency based equivalents involve a two-stage procedure:
  (a) Identification of coherent groups in the external system;
  (b) Dynamic aggregation of a coherent group of generating units into an equivalent generating unit that exhibits the same speed, voltage, and total mechanical and electrical power as the group during any disturbance where the units in the group remain coherent.
• A coherent group of generating units is defined as a group of generators oscillating with the same angular speed and terminal voltages in a constant complex ratio for a set of disturbances.

• All the units in a coherent group can be attached to a common bus, if necessary through a complex ratio (involving phase shift) transformer.

• Identification of coherency can be based on heuristics such as the concept of electrical distance or utilizing a simplified and linearized power system model.
Major approaches of dynamic equivalencing for stability studies:

- The modal approach, which keeps the main eigenvalues of the external system;
- The coherency approach, which separates machines in groups and combines machines within each group closely swinging together into one equivalent.
- The estimation approach, which derives the equivalents for the external system through estimation.

REFERENCES:

THANK YOU