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Electrical Network Equivalent Modeling Method with Boundary Buses Interconnected

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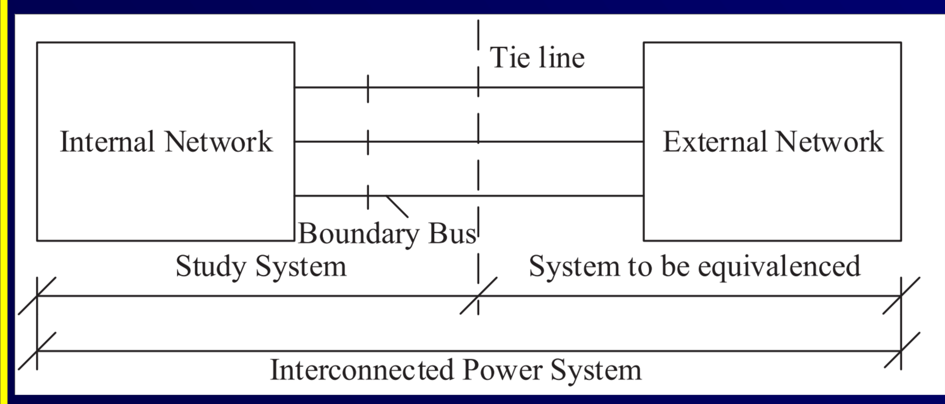
Abstract

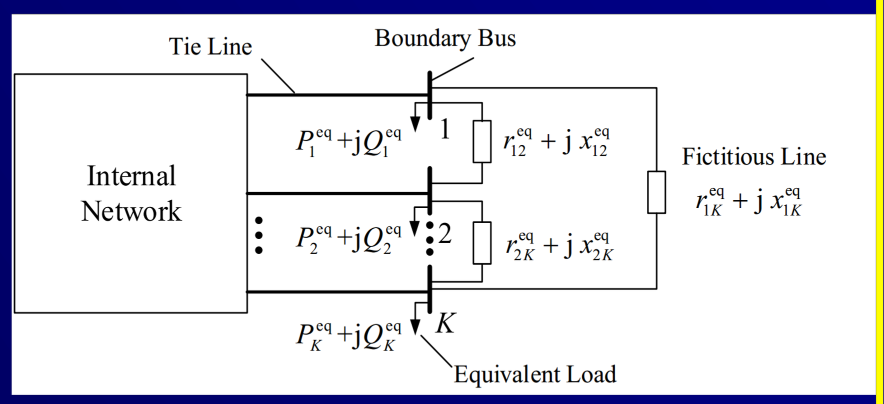
This paper proposes an equivalent modeling method (EMM) based on system measurements to reduce the scale of electrical network. In this method, the equivalent network model adopts a novel framework with boundary buses interconnected in order to improve the accuracy of equivalent network while maintaining the simplicity of the network structure. Obtaining the unknown parameters of equivalent network is regarded as a parameter identification problem in EMM, which is actually a nonlinear programming problem (NLP). The objective function of this NLP is built upon the predictive errors without the weight tuning and the unknown parameters are then identified using interior-point method. Simulation studies on a five-bus system and an IEEE 30-bus system demonstrate the efficiency and the practicability of the EMM under different operation states.

Overview

Generally, the electrical network to be equivalenced can be separated into three parts, including internal network, boundary bus and external network. With respect to equivalent network, it is composed of the following parts: internal network, tie lines, boundary buses, equivalent load and fictitious lines. Among these five parts, the internal network, tie lines, boundary buses are inherited from the original network, while equivalent loads and fictitious lines are constructed based on data of system measurements.



Original Network



Equivalent Network

Highlight of EMM framework:

- All pairs of boundary buses are mutually interconnected by fictitious lines.
- No fictitious bus which was adopted by prevenient equivalent methology.
- Equivalent load model considers the static voltage characteristics of loads.

Parameter Identification of EMM

Unknown parameters

- Impedance of fictitious lines.
- Coefficients of equivalent load.

The collected data from measurement apparatus is used to identify the unknown parameters. Using the squared errors between measured data and calculated value as objective function, parameter identification problem is actually a least-square estimation problem.

Objective function

The objective function is formed based on the root-mean-square errors of measured value and calculated value of current at boundary buses.

$$F(R,X,a^{\mathrm{eq}})=\sqrt{\frac{\sum_{j=1}^{J}\sum_{i=1}^{K}\left|\dot{I}_{ic}^{j}-\dot{I}_{im}^{j}\right|^{2}}{J}}$$

$$\dot{I}_{ic}^{j}=\left(\frac{P_i^{eq}+jQ_i^{eq}}{\dot{V}_{im}^{j}}\right)^{*}+\sum_{l=1,l\neq i}^{K}\frac{\dot{V}_{im}^{j}-\dot{V}_{lm}^{j}}{r_{il}+\mathrm{j}x_{il}}$$

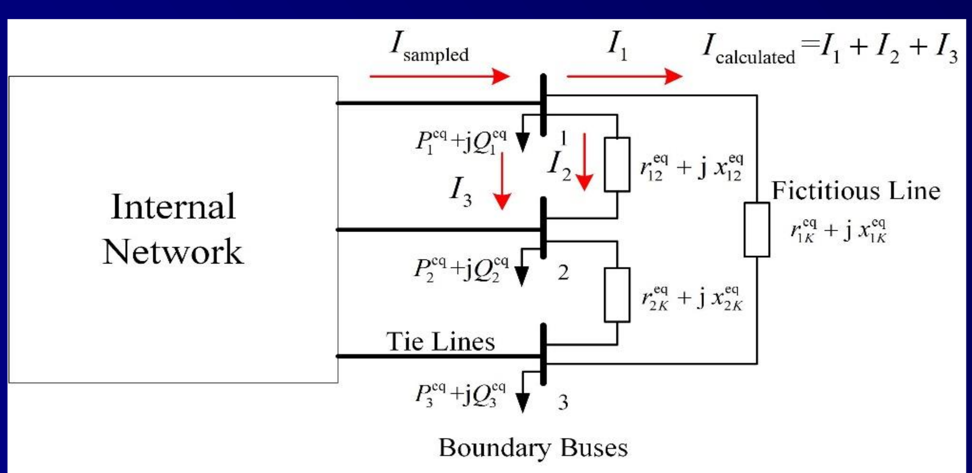


Fig. 1. An illustrative example of calculated value of current at boundary buses.

Flowchart

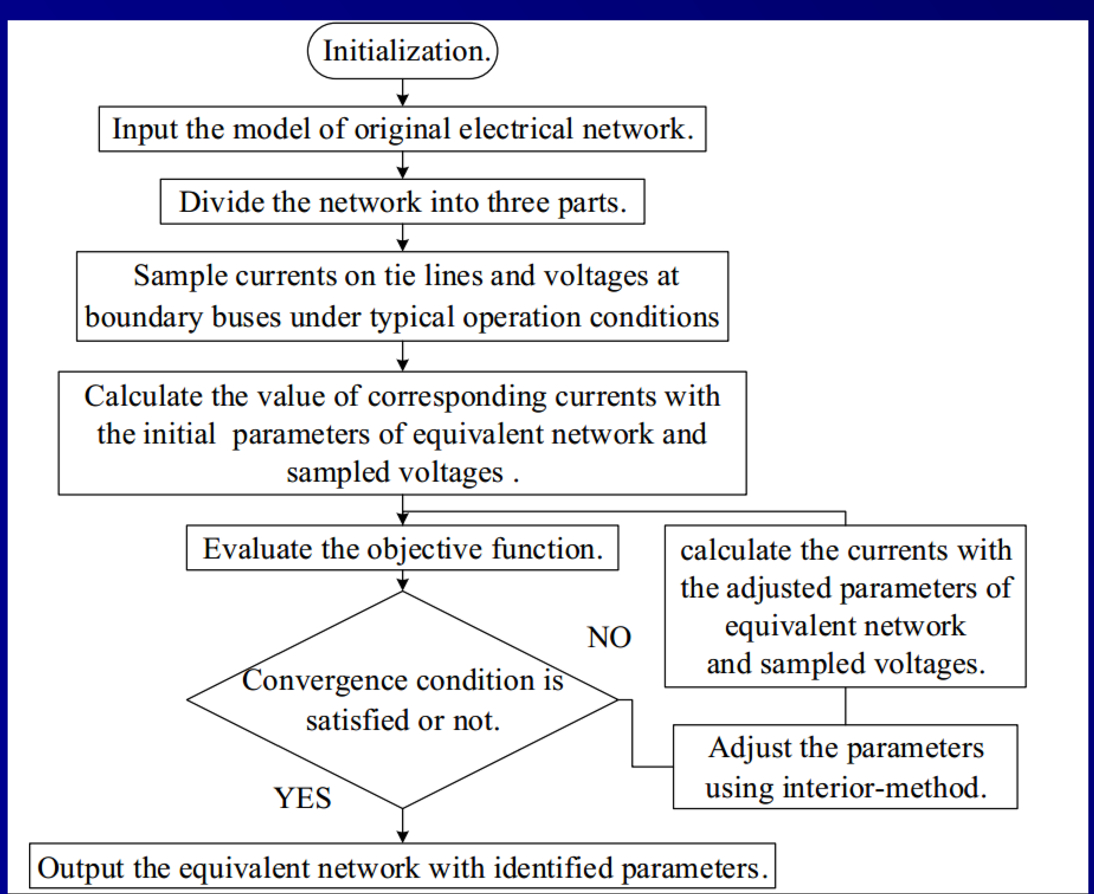
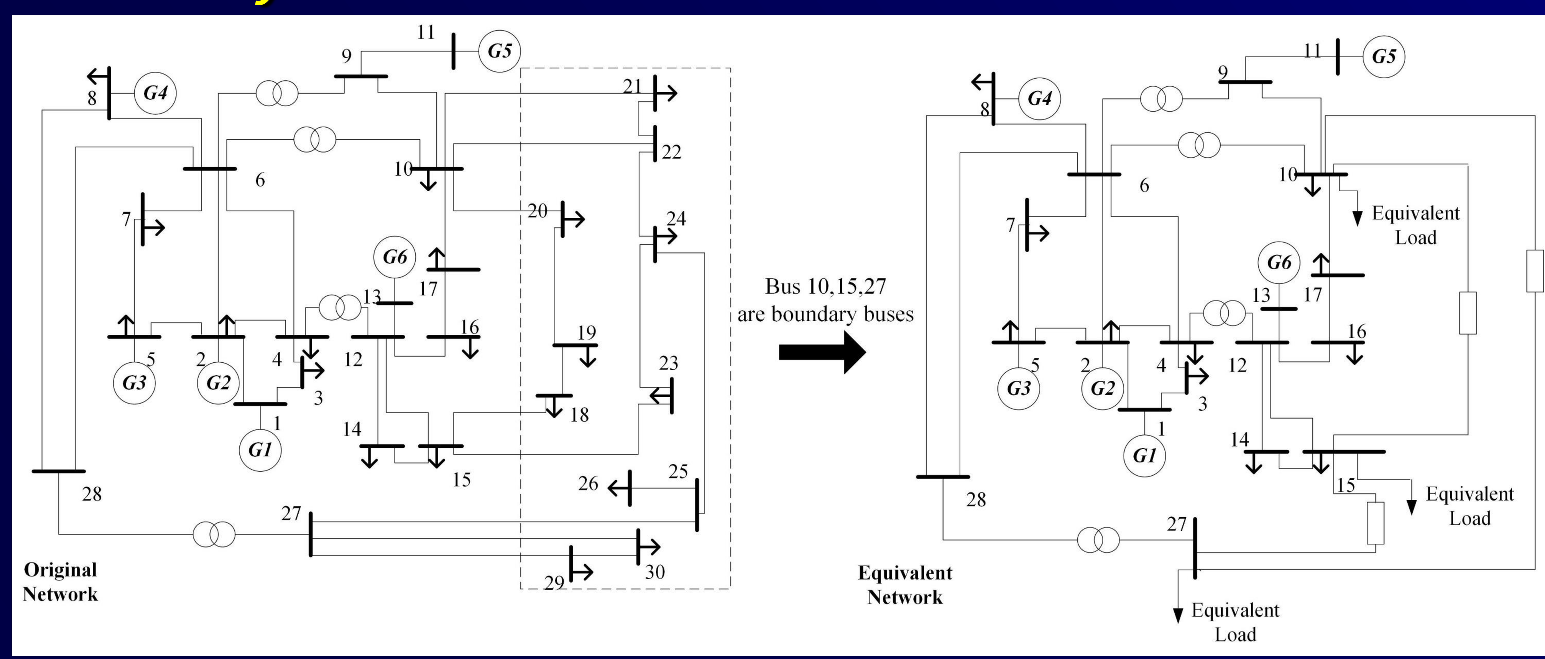


Fig. 2. Flowchart of proposed algorithm.

Case Study

IEEE 30 bus system



Identificated parameters

The parameters of equivalent load at boundary buses

	a_1^{eq}	a_2^{eq}	a_3^{eq}	a_4^{eq}	a_5^{eq}	a_6^{eq}
Bus 10	1.6253	0.0060	-1.4676	-0.4865	0.0936	0.6195
Bus 15	-1.8144	0.1379	1.9382	0.2302	0.0021	-0.2091
Bus 27	1.1128	0.0216	-1.0170	-0.0352	0.0148	0.0621

The parameters of fictitious lines

from bus	to bus	r(p.u.)	x(p.u.)
10	15	4.7594	0.7343
15	27	4.7131	1.2262
10	27	5.0879	-0.1101

Series test

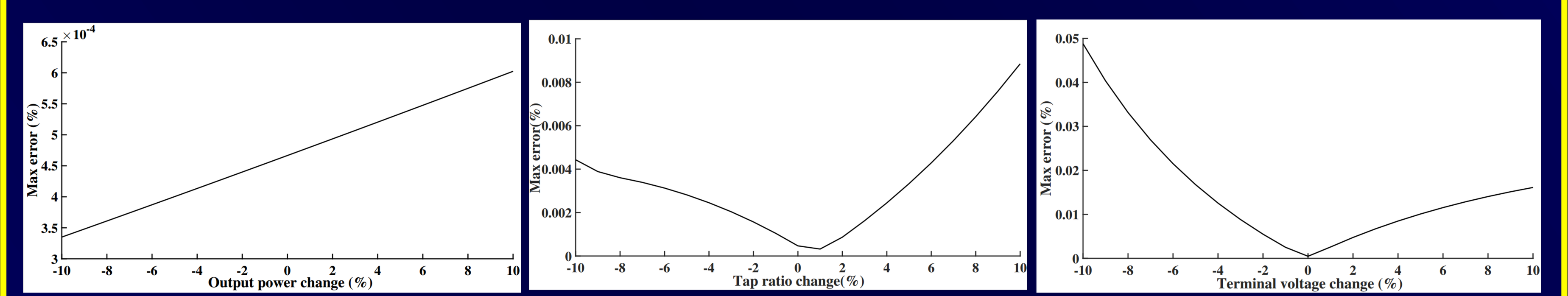


Fig. 3. Maximum relative error of voltage under different operation states.

Conclusion

- This paper has proposed EMM for reducing the scale of electrical network.
- A novel framework with boundary buses interconnected has been employed in EMM.
- The objective function based on predictive errors has been simplified to avoid the weight tuning and then the unknown parameters have been identified together using interior-point method.
- Simulation studies have been taken on a five-bus system and an IEEE 30-bus system. The results of simulation studies indicate that though the equivalent network obtained from EMM is much smaller than the original network, it can represent the characteristic of the original network in pretty high accuracy and well adapt to different operation states.
- The equivalent model derived from EMM can be employed in the applications such as static security analysis, long-term planning, and optimal power flow.