CIRED
21-22 SEP 2022
SHANGHAI , CHINA

Operating State Assessment in Distribution Network Based on Empirical Spectral Analysis

Yun Chen[1] Ciren Ouzhu[1] Lei Tang[1] Chaoran Fu[1] Xin Shi[2]
1.State Grid Shanghai Electric Power Co. Ltd., China; 2. North China Electric Power University, China

Introduction

Operating state assessment is a fundamental task in distribution grid which faces three major challenges:

1) The anomalies exhibit complex, nonlinear and dynamic characteristics;

2) It's difficult to build up-to-date models for distribution feeders without any assumption or simplification;

3) It's difficult to build accurate dynamical models.

Therefore, demand for data analytics being more sensitive to the abnormal behavior of distribution grid has been increasing. This paper focuses on a data-driven approach for real-time operating state assessment of distribution grid. The main advantages of it include:

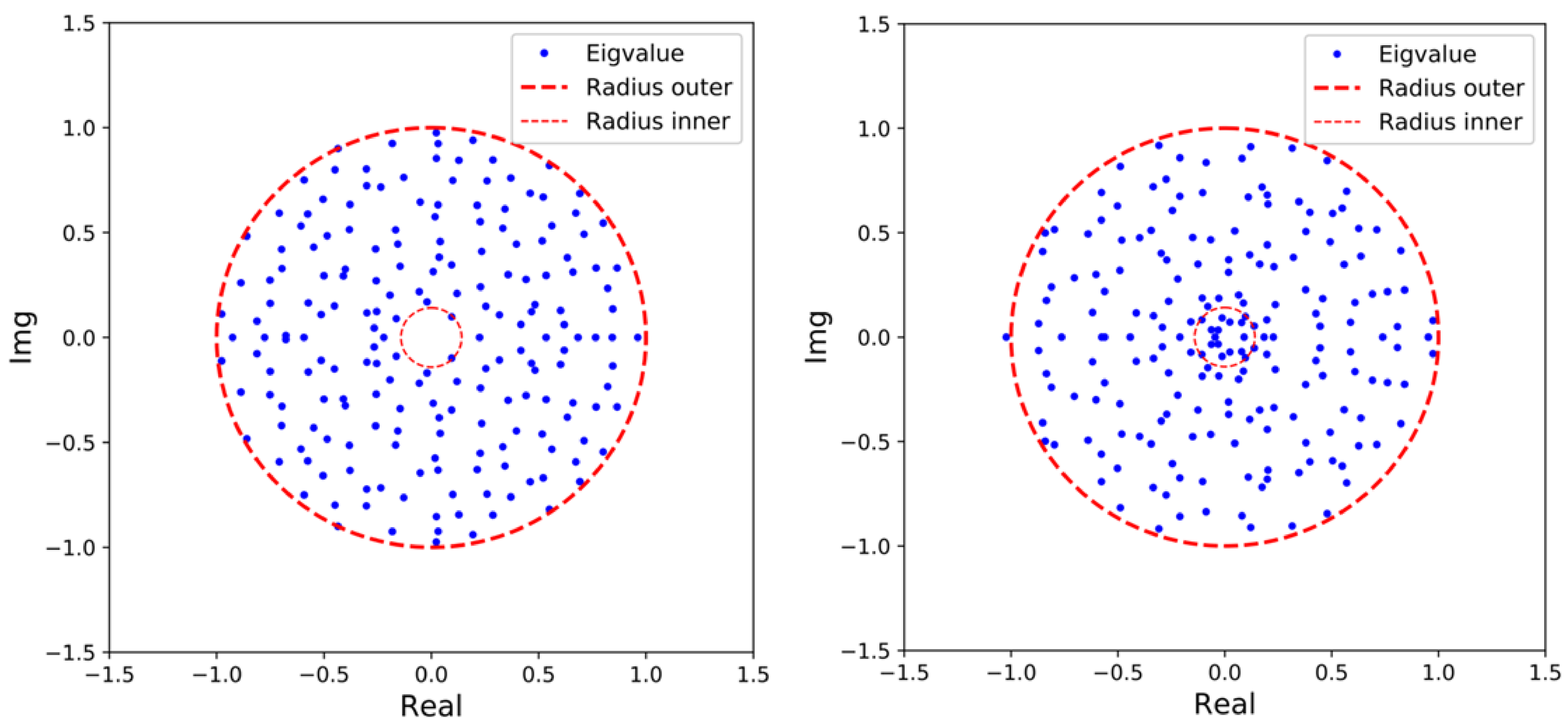
1) It is purely data-driven, avoiding making simplifications for the complex topology of the distribution grid;

2) It is sensitive to the abnormal behavior in distribution grid;

3) It is robust against random fluctuations and measurement errors;

4) It is unsupervised, overcoming the problems like data label lack or inaccuracy.

Methods



1 (a) normal system state 1 (b) abnormal system state

In normal system operating state, the empirical spectral density of the measurement data converges to the limit with probability density function

$$f_{RL}(\alpha)=\begin{cases}\dfrac{1}{\pi cl}|a|^{(\frac{2}{L}-2)}, & (1-c)^{\frac{L}{2}}\leq|\alpha|\leq 1\\ 0, & \text{others}\end{cases}$$

as shown in Figure (a). In abnormal system operating state, the empirical spectral density of the measurement data does not converge to its theoretical limits and some outliers caused by fault signals are out of the inner circle of the ring, as shown in Figure (b).

The empirical spectral density of high-dimensional measurement data matrix corresponding to different operating states of the distribution system are different. The mean spectral radius is the average distribution radius of the eigenvalues in the complex plane, defined as

$$\kappa_{MSR}=\frac{1}{p}\sum_{i=1}^{p}|\lambda_i|$$

The mean spectral radius can reflect the distribution of the empirical spectrum and it can be used as the statistical index for indicating the distribution system states quantitatively.

Steps for the data-driven operating state assessment approach can be summarized as follows:

1) Measurement data standardization;

2) Calculate the singular value equivalent of measurement data matrix;

3) Calculate the product of L measurement data matrix;

4) Convert the product into standard form;

5) Obtain the empirical eigenvalues and the statistical index.

Results

The synthetic data generated from IEEE 141-bus system was used to validate the effectiveness and advantages of the approach. In the simulations, two fault signals were set by changing the active loads at bus 20 and others stay unchanged, as in Table I. The voltage magnitude measurement curves

Table I Fault signals set at bus 20

Bus	Sampling time	Active power(MW)
	t_s=1~300	20
20	t_s=301~700	200
	t_s=701~1000	200→400
others	t_s=1~1000	unchanged

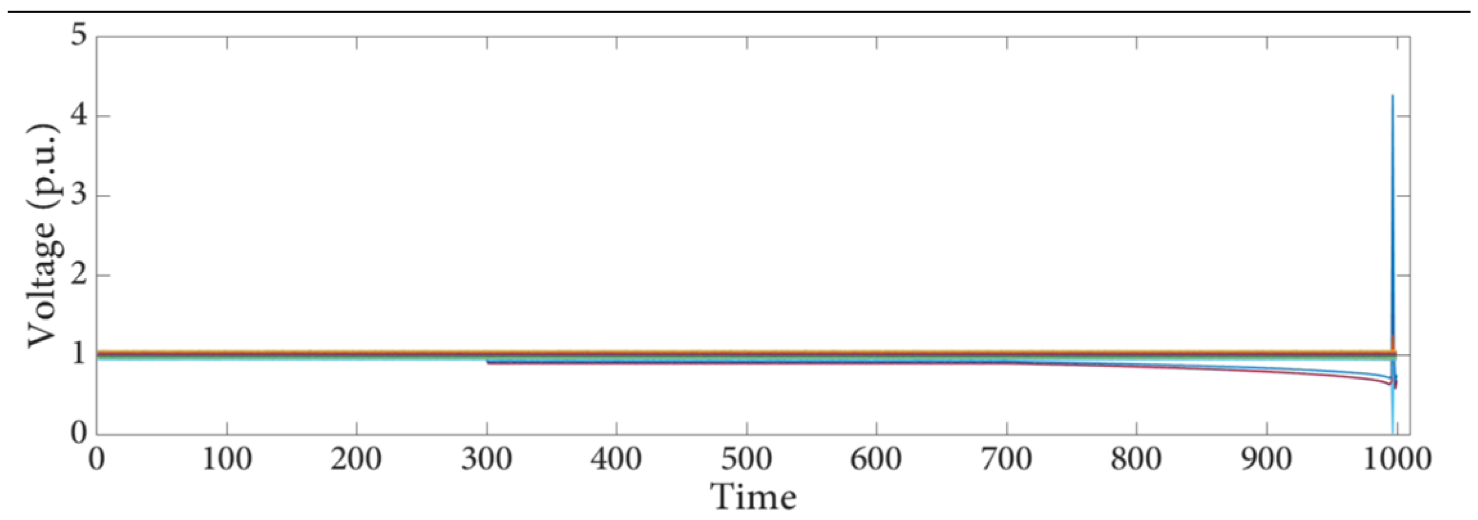


Figure 2 Voltage magnitude curves

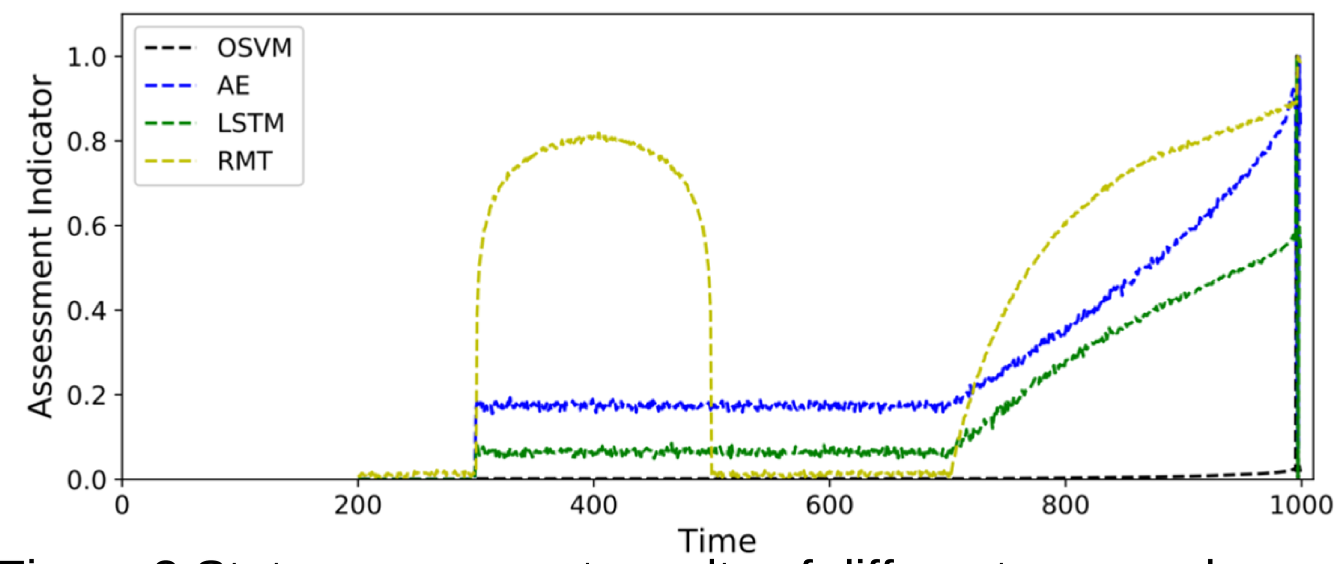


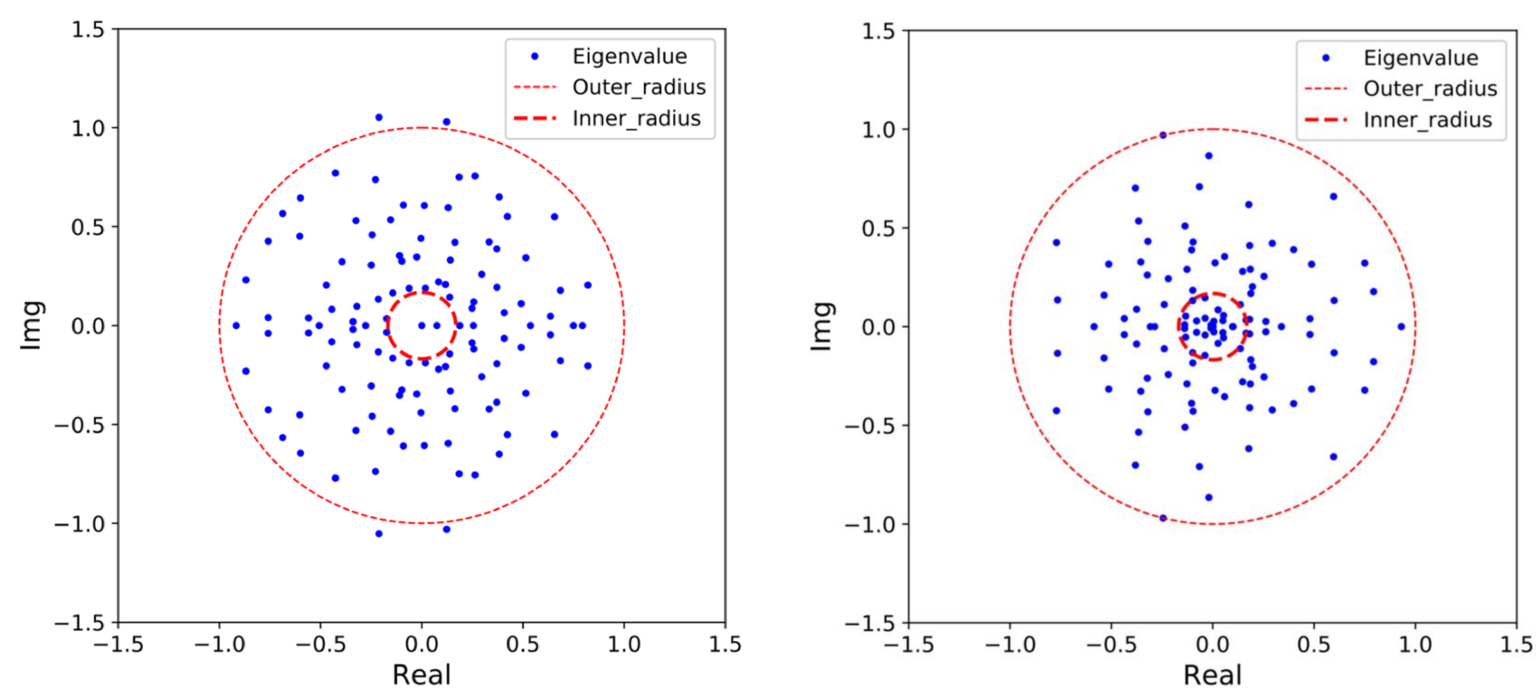
Figure 3 State assessment results of different approaches

The state assessment results and comparison of different approaches is shown in Figure 3. From the index curves, It can be obtained:

1) From t=200 to t=300, the indicator stays almost unchanged and the system operates in normal state. The ESDs converges almost surely to the theoretical Ring law, as shown in Figure 3(a);

2) From t=301, the indicator changes greatly and the system operates in abnormal state. The ESDs do not converge to the theoretical limits, as shown in Figure 3(b). The index curve is almost U-shaped and the width is equal to that of the moving data window.

3) From t=701, the indicator decreases gradually and it begins to change greatly. From t=996, the system begins to operate in abnormal state until it collapses.



3(a) normal state 3(b) abnormal state

Conclusions

The data-driven approach is capable of identifying system potential hazards at an early stage. The mean spectral radius gives insight into the grid operating state from a macroscopic perspective, which can be used to indicate the data behavior. The approach is purely data driven, sensitive to abnormal system behavior and robust against random fluctuations. Case study on IEEE 141-bus system validate that it can be served as a practical tool for real-time operating state assessment.