Line Outage Identification in Power Systems

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1. Introduction

- **Motivation:** prevent minor faults from developing into large-scale blackout
- Real-time fault detection and diagnosis
- Explore line outage identification with machine learning methods

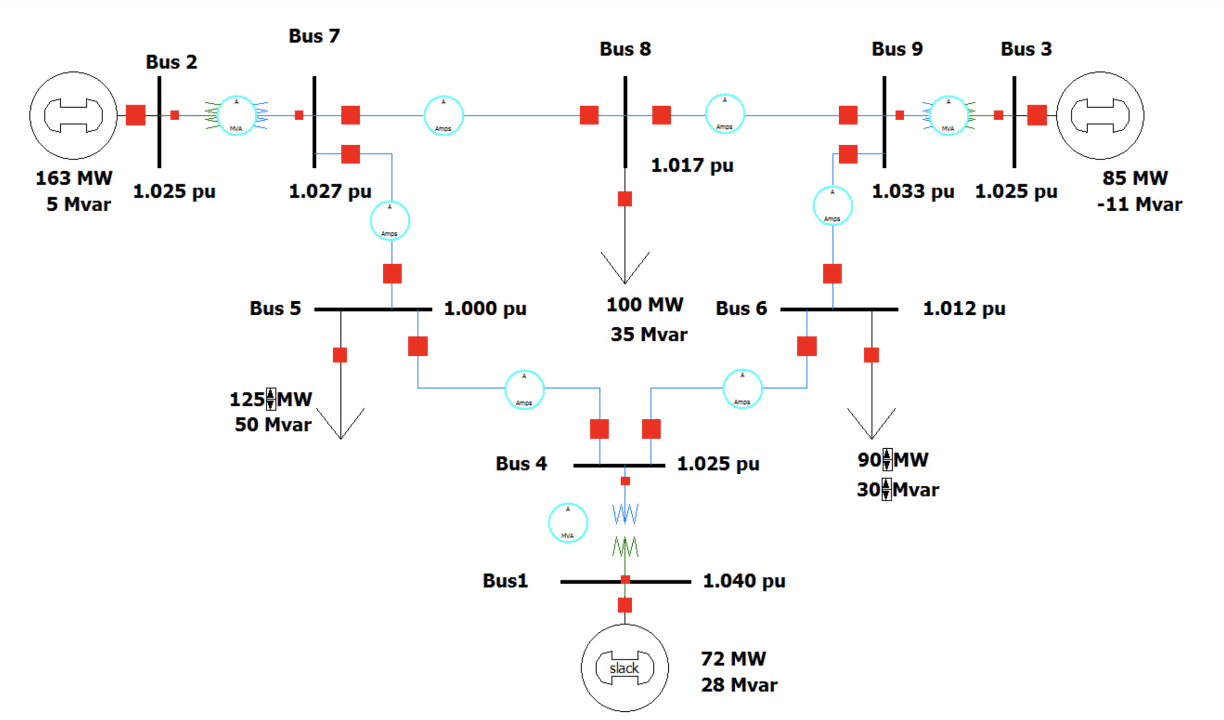

Figure 1: *9 Bus Power Grid*

2. Preliminaries

- Power transfer between bus i and j

$$P_{ij} = |V_i||V_j|(G_{ij}\cos(\theta_i-\theta_j)+B_{ij}\sin(\theta_i-\theta_j)) \quad (1)$$

- Since $G_{ij}\to 0$, and $\theta_i-\theta_j$ is very small, eq. (1) simplifies to

$$P_{ij} = |V_i||V_j|(B_{ij}(\theta_i-\theta_j)) \quad (2)$$

- Abrupt changes in power transfer are observable from abrupt changes in $\theta_i-\theta_j$.

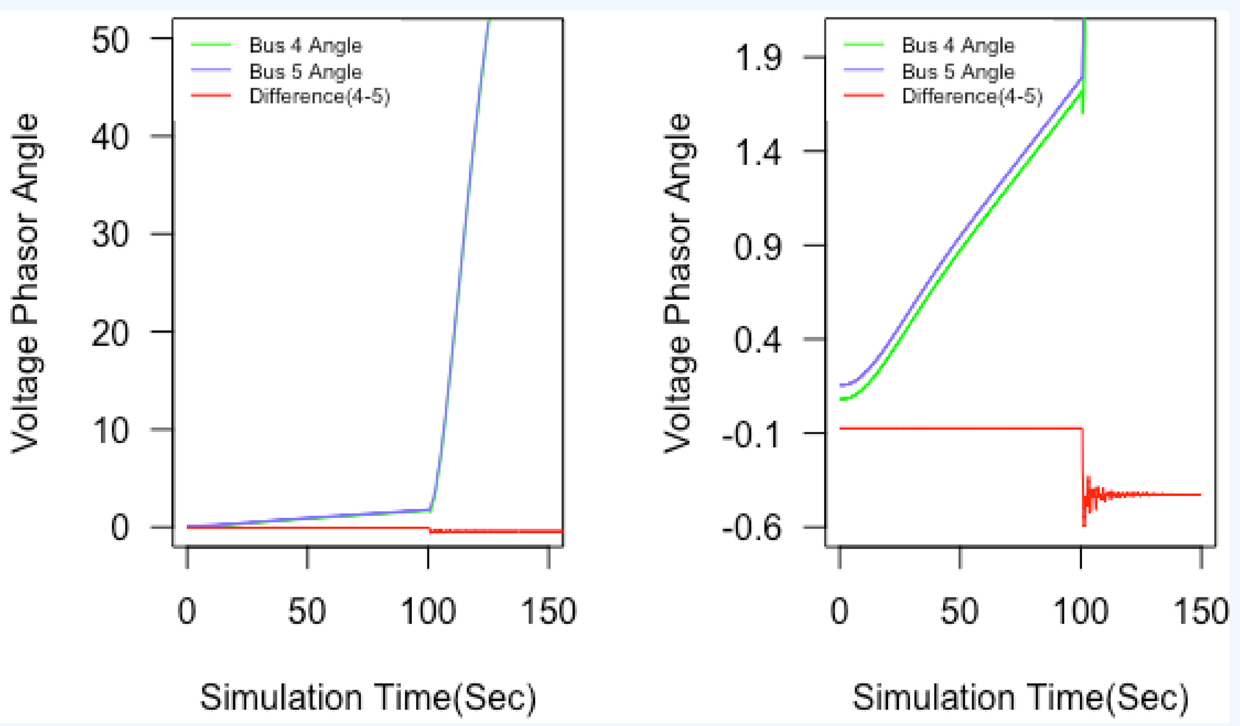

Figure 2: *Voltage phasor angle regarding bus 4 and bus 5 versus time*

3. Dataset

- Dynamic analysis of IEEE standard test systems
- Fixed generation
- Random loads
- Line outage simulation
- Dataset creation from measurement data

4. Methodology

1. **Feature Extraction**
   - Input: angle differences x_j
   - Fourier transform: $X_k = \sum_{j=0}^{t-1} x_j e^{-2i\pi kj/n}, k = 1,\ldots,t$
   - Predictors: amplitudes of top frequency components $|X_k|$

2. **Classification Algorithms**

- **Logistic Regression**
  - Estimation: Maximum Likelihood Estimation

$$\max_{\beta} \prod_{i:y_i=1} p(x_i) \prod_{i:y_i=0} (1-p(x_i)),$$

where $p(x_i) = \frac{e^{\beta x_i}}{1+e^{\beta x_i}}$

  - Prediction:

$$p(Y=1|X) = \frac{e^{\beta X}}{1+e^{\beta X}}$$

- **Random Forest**
  - Number of decision trees: B
  - Each tree is a weak classifier with prediction result $\hat{f}^b(x)$
  - Averaging the predictions from all trees for final output:

$$\hat{f}(x) = \frac{1}{B}\sum_{b=1}^{B} \hat{f}^b(x)$$

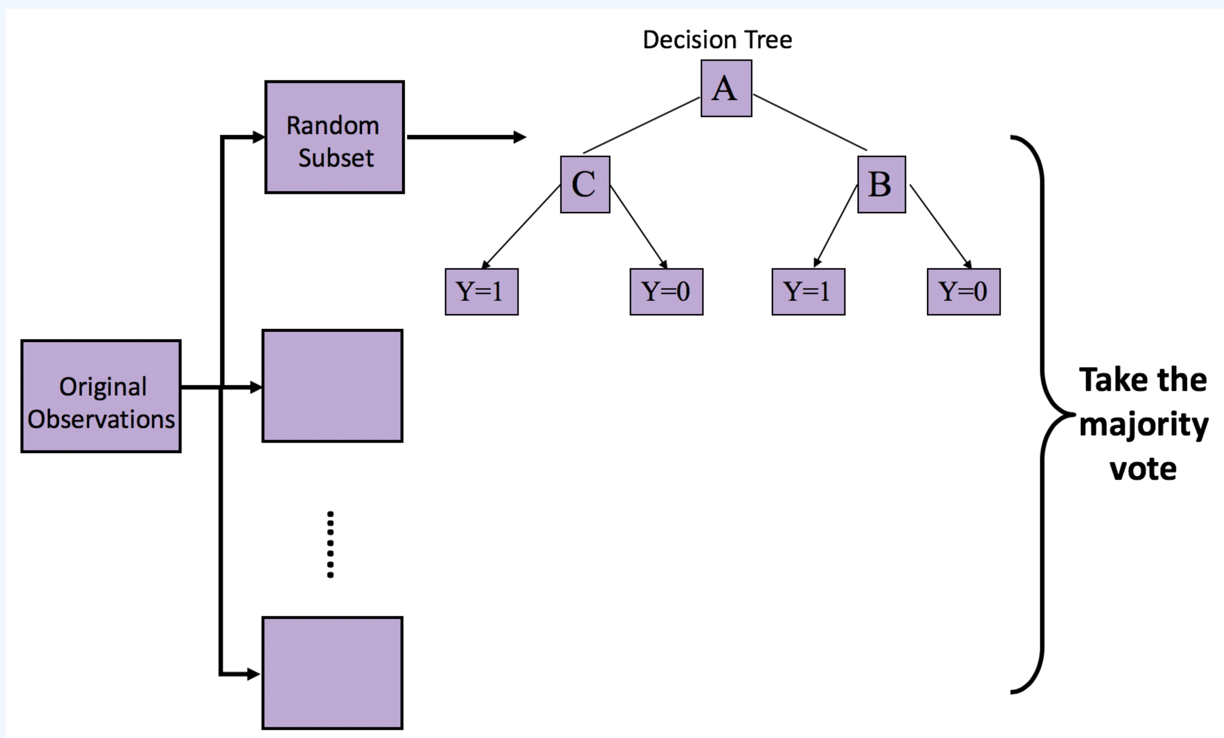

Figure 3: *Random Forest Flowchart*

5. Results

Table 1: *Line Outage Detection for IEEE 39-bus System*

Methods	Precision		Recall	
	Single	Double	Single	Double
Logistic Regression	0.972	0.935	0.839	0.794
Random Forest	0.989	0.9996	1	0.983

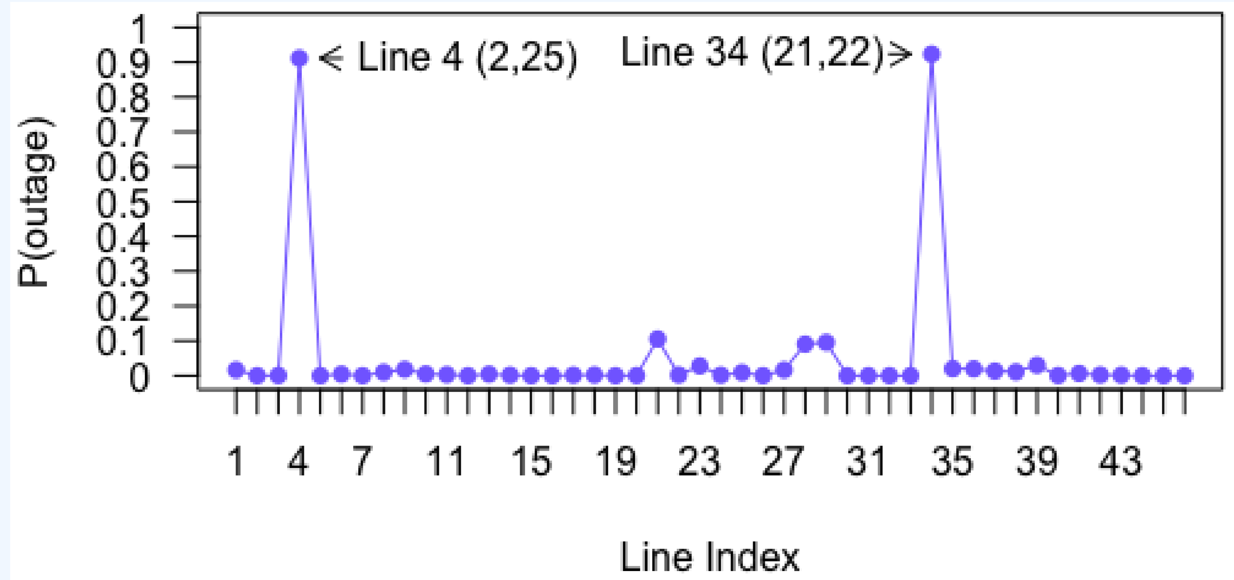

Figure 4: *Predicted Outage Probabilities using Random Forest*

6. Ongoing Neural Network Development

- **Layers:** Linear, Convolution, Pooling
- **Activations:** Sigmoid, Tanh, Relu, SoftMax
- **Loss Functions:** Mean Square Error, Cross Entropy

7. Conclusions

- Pure data-driven without knowing system matrix
- High recall and precision
- Random forest model has an edge over logistic regression

8. Acknowledgements

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