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Trajectory of Apparent Impedance in Transient Stability Prediction

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Transient stability prediction development

- 1. Traditional methods are unreliable for real-time stability prediction problems[1-2]
- 2. Real-time prediction methods such as rotor oscillation prediction based on time series require about 300 milliseconds (18 cycles) after the start of the transients [3].

Motivation 1: Can we have faster and more accurate real-time prediction technique?

- 3. PMU are being installed in many places for transient stability assessment and enhancement

Motivation 2: Can we optimize PMU placement for transient stability prediction?

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Proposal – Apparent Impedance trajectory

- **A. Instability Prediction –**

  More complete : combine voltage and current simultaneously

  Fast:**12 cycle (200 millisecond)**

  More Accurate: **>90%** of prediction success

- **B. Optimize PMU placement**

  Few PMU placement: **<10%** of the buses installed with PMU

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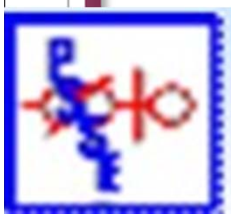
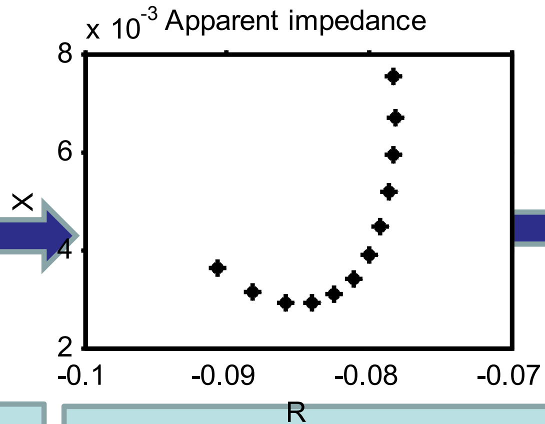
Optimize PMU placement pre-calcuated

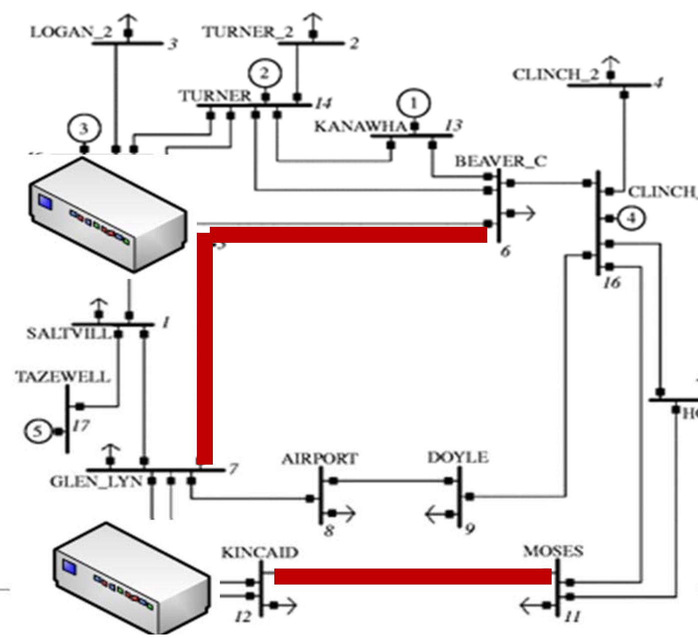




- Apparent Impedance: Z=V/I= R+jX
- Record **12 cycles** trajectory after fault clearing
- The apparent impedance trajectory are 2 x 12 = **24 dimensions.**

Create fault cases

Record the apparent impedance trajectory in 12 cycles



Critical branches

Decide PMU placement

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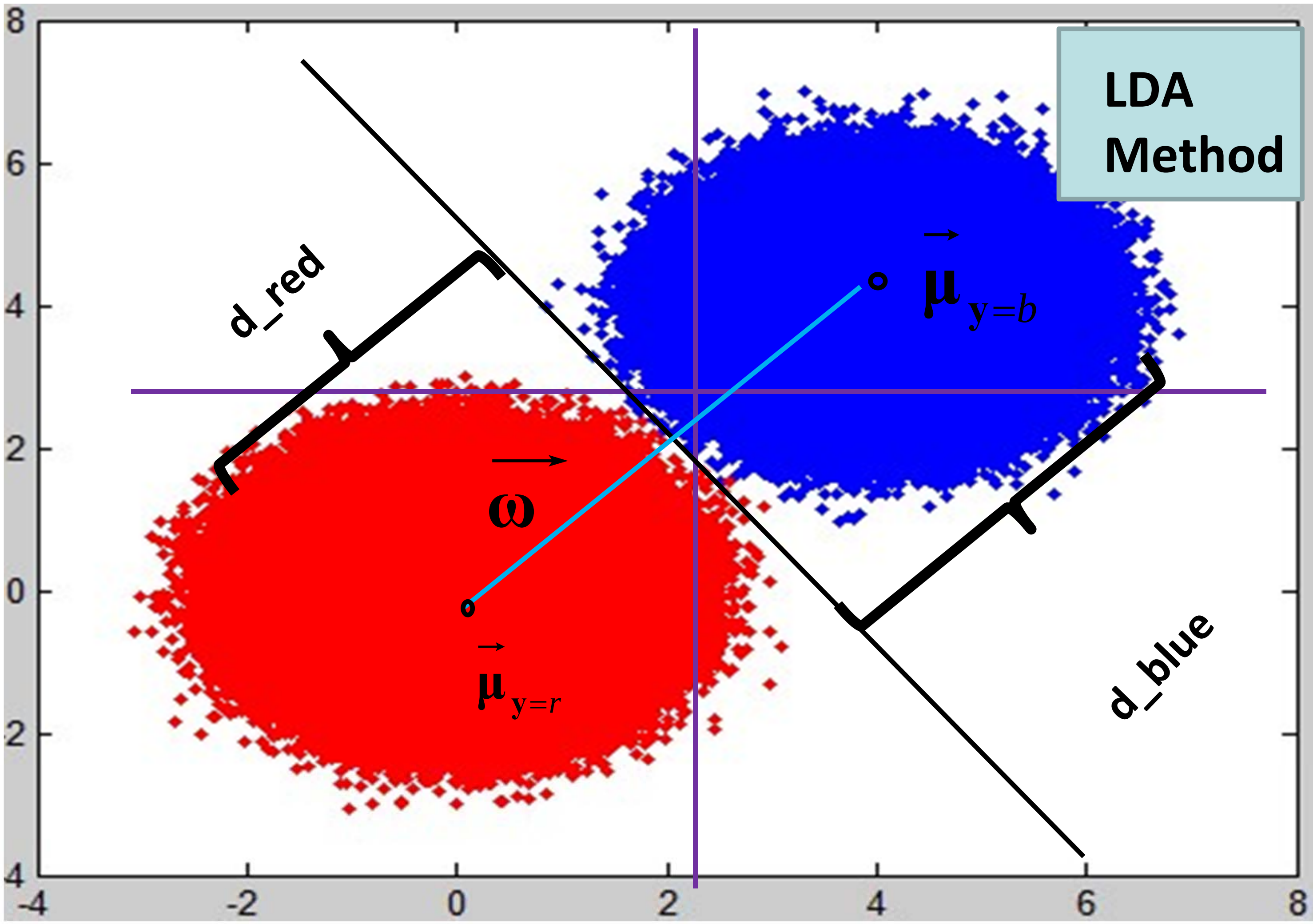
Perpendicular plane Method[4]

Concept



Use distance to represent the characteristic of two groups data in 1 dimension

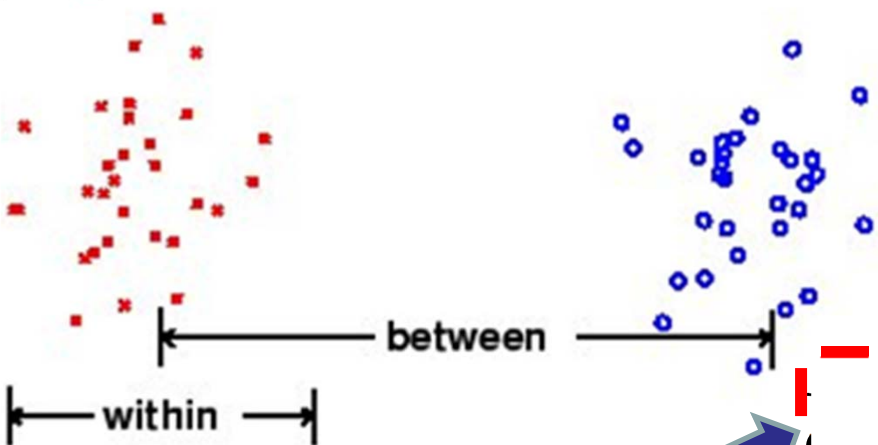
Extend the method to high dimensions

Algorithm –

Step 1: Change shape by LDA

- Suppose two classes of observations have means $\mu_{y=r}$, $\mu_{y=b}$ and covariance $\Sigma_{y=r}$, $\Sigma_{y=b}$. The separation between these two distributions[4-6]:

$$S = \frac{\sigma^2_{between}}{\sigma^2_{within}} = \frac{(\vec{\boldsymbol{\omega}} \cdot \vec{\boldsymbol{\mu}}_{y=b} - \vec{\boldsymbol{\omega}} \cdot \vec{\boldsymbol{\mu}}_{y=r})^2}{\vec{\boldsymbol{\omega}}^T \cdot \sum_{y=b} \cdot \vec{\boldsymbol{\omega}} + \vec{\boldsymbol{\omega}}^T \cdot \sum_{y=r} \cdot \vec{\boldsymbol{\omega}}}$$



$$\vec{\boldsymbol{\omega}} = \vec{\boldsymbol{\mu}}_{\mathbf{y=b}} - \vec{\boldsymbol{\mu}}_{\mathbf{y=r}}$$

The larger S, the better partition

$$\frac{\partial S}{\partial \omega} = 0$$

$$\vec{\boldsymbol{\omega}} = (\vec{\boldsymbol{\mu}}_{\mathbf{y=b}\_new} - \vec{\boldsymbol{\mu}}_{\mathbf{y=r}\_new})$$

$\vec{\boldsymbol{\omega}}$: normal to the discriminant hyper-plane

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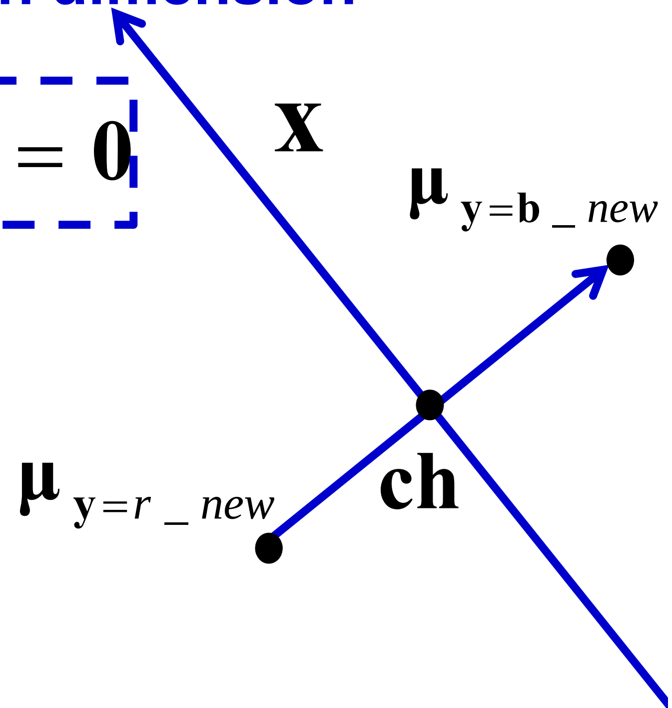
Extend the method to high dimensions

Step 2: find perpendicular plane in high dimension

$$(\vec{\boldsymbol{\mu}}_{\mathbf{y=b}\_new} - \vec{\boldsymbol{\mu}}_{\mathbf{y=r}\_new})^{\mathbf{T}} \cdot (\mathbf{x} - \mathbf{ch}) = \mathbf{0}$$



$\vec{\boldsymbol{\mu}}_{\mathbf{y=b}\_new}, \vec{\boldsymbol{\mu}}_{\mathbf{y=r}\_new} = vector\ (24,1)$

– centroid of two new groups

ch – center of two centroid

Plane perpendicular to that vector given by

$$\hat{x}_1 + a_1 \hat{x}_2 + a_2 \hat{x}_3 + \ldots\ldots + a_{23} \hat{x}_{24} = a_{24}$$

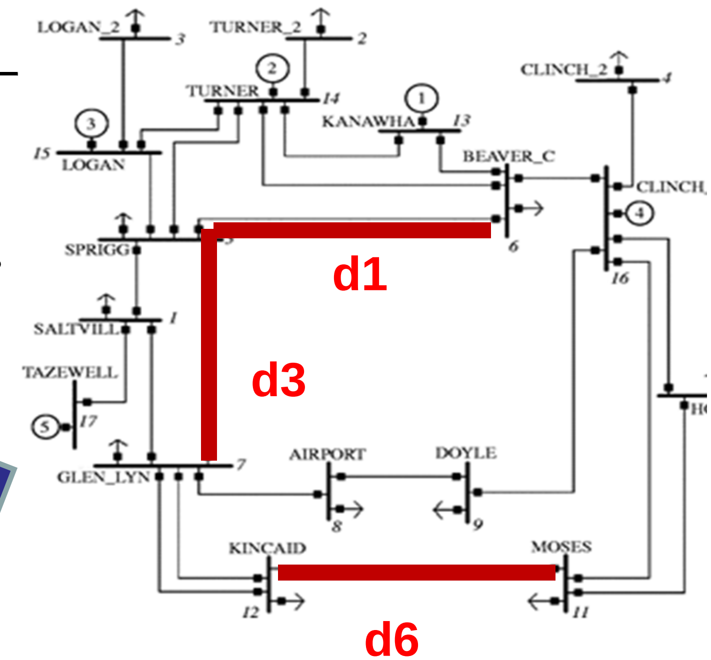
Extend the method to high dimensions

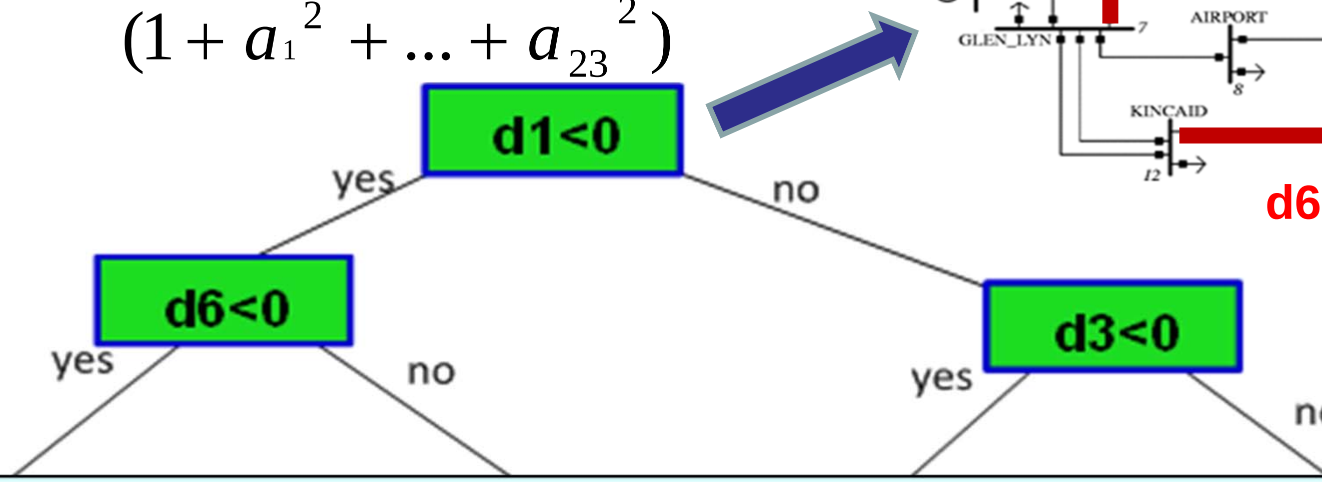
Step 3: calculate distance

minimizing $$d = \frac{1}{2}[(\hat{x}_1 - x_1)^2 + (\hat{x}_2 -$$

Subjects to $$\hat{x}_1 + a_1\hat{x}_2 + a_2\hat{x}_3 + \ldots\ldots$$

$$d = \frac{a_{24} - x_1 - a_1 x_2 - \ldots - a_{23} x_{24}}{(1 + a_1^{\ 2} + \ldots + a_{23}^{\ 2})}$$

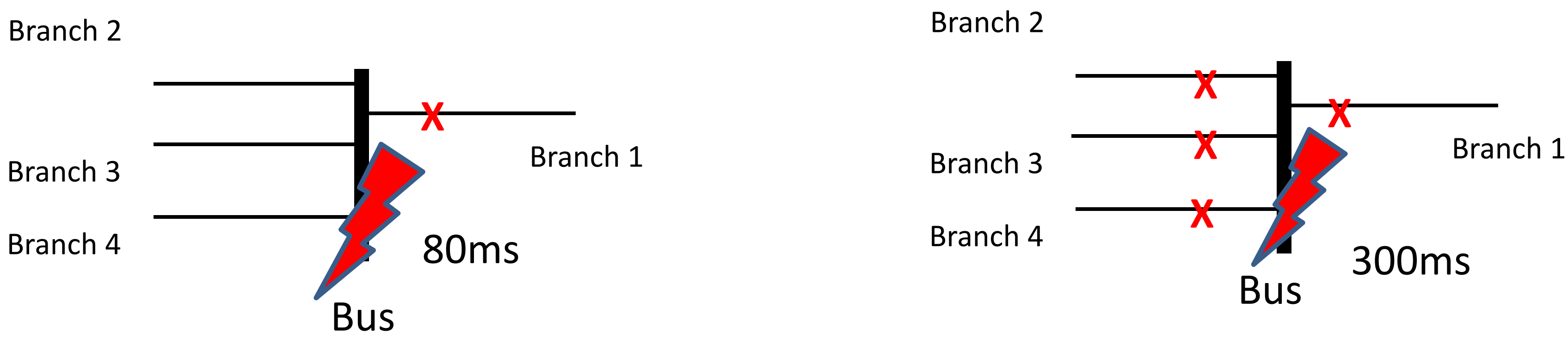




Integrate the 24 dimensional data into one important index value—— Distance

Case Study

Create fault Cases in Simulation:



Slight fault **Severe fault**

+

Different topology changes

(trip different branch before simulation).

Two test systems:

1. IOWA : 17 generators 162 buses (285 branches).
2. WSCC: 127 buses system (abbreviated)

Prediction success rate

Test with the IOWA system

Comparison with different nodes	89 nodes of the decision tree	8 nodes of the decision tree
ROC train	97.25%	90.34%
ROC test	95.14%	90.41%

Test with WSCC 127 buses system

Comparison with different nodes	17 nodes of the decision tree	5 nodes of the decision tree
ROC train	98.32%	97.18%
ROC test	98.22%	96.39%

Comparison of cycle numbers

WSCC 127 buses system

	10 Data point	12 Data point	18 Data point
Optimal node no.	56	36	26
ROC Train	0.9931	0.9945	0.9867
ROC Test	0.9842	0.9861	0.9858
ROC Test at 5 Nodes	0.892	0.9459	0.9489

12 Data point is accurate enough for the prediction

Summary

1. The high dimensional data has been integrated into one important index value.

2. The apparent impedance trajectory method takes about 200 milliseconds for prediction.

3. With the nodes of the decision tree, the critical location for PMU placement is determined.

Reference

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[4] Anamitra Pal, J. S. Thorp, Taufiquar Khan, and S. S. Young, "Classification Trees for Complex Synchrophasor Data," submitted to IEEE Transactions on Smart Grid.

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