An Application of Wide Area Synchrophasor based Transient Stability Status Prediction

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Outline

- Introduction
- Concept of the Proposed Method
- Laboratory-Scale Test Setup
- Simulation Results
- Conclusion
Transient stability is a fast phenomenon and a generator or group of generators can potentially lose the synchronism within a few seconds after a severe disturbance.

Fast recognition of such instabilities provides opportunity to initiate appropriate emergency control actions.

In literature, there are a few basic approaches to predict the transient stability status of a power system:

- Time-domain simulations
- Transient-energy-function (TEF) methods
- Curve-fitting techniques
- Machine-learning based classification techniques

However, all of them have inherent limitations and drawbacks.
Objectives

- To develop a method to predict impending transient (rotor angle) instability conditions following a fault.

- The proposed new method involves monitoring the loci of generator operating points on ROCOV-$\Delta V$ plane with the post-fault voltage measurements obtained from PMUs, and declaring an instability condition if the operating point of any generator crosses a predefined boundary.

- The proposed method is transparent and simple to implement.

- It is capable of predicting first-swing transient instabilities as well as multi-swing transient instabilities.

- The method can recognize the unstable generator(s) enabling the initiation of specific emergency control actions.
One machine to infinite bus (OMIB) system with the initial steady-state power flow solution
Concept of the Proposed Method

Variations of rotor angle and voltage magnitude following a fault
Concept of the Proposed Method

Introduction

Concept of the Proposed Method

Laboratory-Scale Test Setup

Plot of ROCOV vs. ΔV

Stability boundary

Unstable region

Stable region

450 ms
490 ms
500 ms

Voltage deviation, ΔV (pu)

ROCOV (pu/s)
Laboratory-Scale Test Setup

- GPS Antenna
- GPS Clock
- IRIG-B
- Power System Model (IEEE 39-Bus Test System)
  - GTSYNC Card
  - GTNET Card (s)
  - PMU 1
  - PMU 2
  - PMU N
  - V & I
  - V & I
  - V & I

- Synchrophasor Communication Network
- TCP/IP
- Real Time Digital Simulator (RTDS™)
- Transient Stability Prediction Algorithm
- Stability Status
- Unstable Generator
- Data Storage
- PDC

RTDS™ and laboratory scale synchrophasor network
Simulation Results: IEEE 39-Bus Test System
Simulation Results: Fault Detection

Variations of voltage magnitude and ROCOV of 6 cycles fault
Simulation Results: Stable Case (F₁)

Variations of rotor angle and voltage magnitude

Fault on line 16-17 (25% of the length) cleared by removing the line after 6 cycles
Simulation Results: Stable Case (F₁)

Variations of ROCOV vs. voltage deviation

Fault on line 16-17 (25% of the length) cleared by removing the line after 6 cycles
Variations of rotor angle and voltage magnitude

Fault on line 2-25 (50% of the length) cleared by removing the line after 6 cycles
Variations of ROCOV vs. voltage deviation

Fault on line 2-25 (50% of the length) cleared by removing the line after 6 cycles
Variations of rotor angle and voltage magnitude

Fault on line 16-17 (95% of the length) cleared by removing the line after 6 cycles
Simulation Results: Unstable Case II ($F_3$)

Variations of ROCOV vs. voltage deviation

Fault on line 16-17 (95% of the length) cleared by removing the line after 6 cycles
## Simulation Results: Fault Types

<table>
<thead>
<tr>
<th>Fault type</th>
<th>Condition</th>
<th>Predicted as stable</th>
<th>Predicted as unstable</th>
<th>Early prediction advantage* (ms)</th>
<th>Overall accuracy (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single-phase to ground</td>
<td>Stable case</td>
<td>219/219</td>
<td>0/219</td>
<td>--</td>
<td>100.0</td>
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<tr>
<td></td>
<td>Unstable case</td>
<td>0/6</td>
<td>6/6</td>
<td>619</td>
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<td>Phase-to-phase</td>
<td>Stable case</td>
<td>200/200</td>
<td>0/200</td>
<td>--</td>
<td>100.0</td>
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<tr>
<td></td>
<td>Unstable case</td>
<td>0/25</td>
<td>25/25</td>
<td>601</td>
<td></td>
</tr>
<tr>
<td>Phase-to-phase to ground</td>
<td>Stable case</td>
<td>176/177</td>
<td>1/177</td>
<td>--</td>
<td>99.6</td>
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<tr>
<td></td>
<td>Unstable case</td>
<td>0/48</td>
<td>48/48</td>
<td>705</td>
<td></td>
</tr>
<tr>
<td>Three-phase to ground</td>
<td>Stable case</td>
<td>106/108</td>
<td>2/108</td>
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<td>99.1</td>
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<tr>
<td></td>
<td>Unstable case</td>
<td>0/117</td>
<td>117/117</td>
<td>653</td>
<td></td>
</tr>
</tbody>
</table>

* Mean values of early prediction time advantage, which is defined as the difference between the time when the proposed algorithm predicts an unstable condition and the time when the instability is declared when applied the criterion given in the transient stability assessment tool (TSAT)
## Simulation Results : Topology Changes

<table>
<thead>
<tr>
<th>Topology change</th>
<th>Condition</th>
<th>Predicted as stable</th>
<th>Predicted as unstable</th>
<th>Early prediction advantage* (ms)</th>
<th>Overall accuracy (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Line 5-8 out of service</td>
<td>Stable case</td>
<td>230/231</td>
<td>1/231</td>
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<td>99.7</td>
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<tr>
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<td>Unstable case</td>
<td>0/69</td>
<td>69/69</td>
<td>717</td>
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<tr>
<td>Line 22-23 out of service</td>
<td>Stable case</td>
<td>256/258</td>
<td>2/258</td>
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<td>99.3</td>
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<td></td>
<td>Unstable case</td>
<td>0/42</td>
<td>42/42</td>
<td>630</td>
<td></td>
</tr>
<tr>
<td>Line 25-26 out of service</td>
<td>Stable case</td>
<td>215/215</td>
<td>0/215</td>
<td>--</td>
<td>100.0</td>
</tr>
<tr>
<td></td>
<td>Unstable case</td>
<td>0/85</td>
<td>85/85</td>
<td>603</td>
<td></td>
</tr>
</tbody>
</table>

* Mean values of early prediction time advantage, which is defined as the difference between the time when the proposed algorithm predicts an unstable condition and the time when the instability is declared when applied the criterion given in the transient stability assessment tool (TSAT)
A novel transient stability prediction approach based on the ROCOV-ΔV characteristics of the post-fault voltage magnitudes obtained from PMUs located at the generator terminal buses was proposed.

RTDS simulation studies carried out for the IEEE 39-bus test system showed over 99% overall prediction accuracy under all types of faults.

The average early prediction time advantage compared to the rotor angle separation methods was more than 600 ms, which allows more time to take an appropriate corrective action.

Furthermore, the proposed method was shown to be robust for random changes in pre-fault generations and loads as well as network topology changes.
Thank you

Q & A