SVM based Smart Protection Relays: Local Protection and System-wide Control

Yi Zhang, Marija Ilic, and Ozan Tonguz

Electric Energy System Group, CMU

3/11/2009

Motivation

- **Malfunction of protection relays is one of the major reason to accelerate the spreading of blackouts.**
- **Protection relays should be more than just a huge "FUSE"**
- **Protection relays can be used as**
  - Protection components for local equipments
  - Fast controllers for system-side effects

Role of Relays: Preventing Equipment Safety vs. System-wide Effects

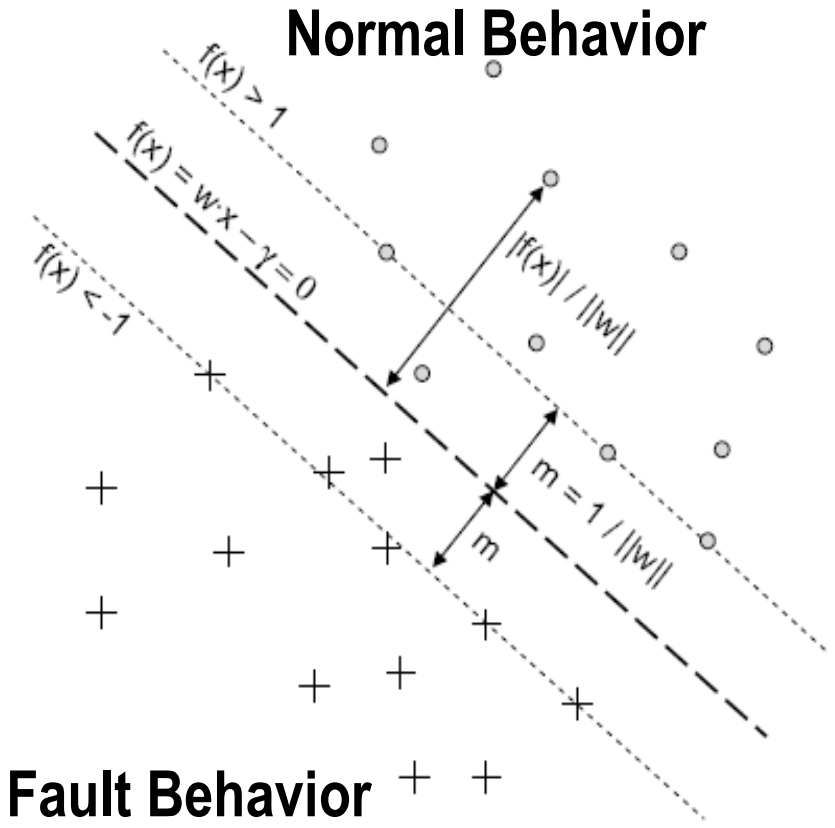
- **Safeguarding the Equipment**
  - A relay is a safeguard of each major piece of equipment
- **System-wide Effects**
  - Relays sometimes malfunction by responding to overloads although there were not faults on the protected lines.
  - This is a common mode of failure which accelerates the geographic spread of the cascading faults
  - Relay malfunctioning is one of the major contributing factors to 70% of the major electric power outages and blackouts.

Basic working principles for SVM based relays

- Using Support Vector Machine (SVM) Classification to make decisions
- Using multiple features, which include magnitude of current and voltage, phase of current and voltage, real and reactive power
- Using Principle Component Analysis for feature selection
- Adaptive settings

SVM-based Decision Making Mechanism

- The goal of SVM method is to produce a model which predicts target value of data instances in the testing set which are given only the attributes



SVM Classification-Based Smarter Relays: Application of SVM Method to an Improved Protection Relay Logic

- **Six candidate features:**
  - *magnitude of current*,
  - *phase of current*
  - *magnitude of voltage*
  - *phase of voltage*,
  - *real power*
  - *reactive power*
- **Three Classes:**
  - Relaxed condition: Normal condition and far away faults
  - Stand-by condition: Zone 2 and Zone 3 faults
  - Emergency condition: Zone 1 faults

Principal Components Analysis of Features

- **Principal components analysis (PCA) is applied to pick up the best features with highest energy**
- **For SVM classification:**

  Reactive Power > Real Power > Phase of Voltage

  > Magnitude of Voltage > Phase of Current > Magnitude of Current

- **Combination of Features:**
  - **Reactive Power + Real Power: 75%**
  - **Reactive Power + Real Power + Phase of Current: 85%**

Simulation Results of Simple Faulty Conditions

2 Features: Real Power and Reactive Power					
Train in Noise Free Test in Noise Free		Train in Noise Free Test in Noise		Train in Noise Test in Noise	
Train Accu.	Test Accu.	Train Accu.	Test Accu.	Train Accu.	Test Accu.
95.1071%	95.1044%	95.1071%	95.0254%	95.1336%	95.0913%

TABLE II

ACCURACY IN SVMCB SMARTER RELAYS WITH TWO FEATURES

3 Features: Real Power, Reactive Power and phase of Voltage					
Train in Noise Free Test in Noise Free		Train in Noise Free Test in Noise		Train in Noise Test in Noise	
Train Accu.	Test Accu.	Train Accu.	Test Accu.	Train Accu.	Test Accu.
96.4824%	96.3497%	96.3149%	96.3366%	96.2048%	96.1386%

TABLE III

ACCURACY IN SVMCB SMARTER RELAYS WITH THREE FEATURES

6 Features					
Train in Noise Free Test in Noise Free		Train in Noise Free Test in Noise		Train in Noise Test in Noise	
Train Accu.	Test Accu.	Train Accu.	Test Accu.	Train Accu.	Test Accu.
96.8351%	96.5342%	96.8351%	96.4354%	96.7204%	96.6265%

TABLE IV

ACCURACY IN SVMCB SMARTER RELAYS WITH SIX FEATURES

Simulation Results of N-1 Conditions

- **N-1 condition is defined as the system condition in which one piece of equipment has failed.**

2 Features		3 Features		6 Features	
Train Accu.	Test Accu.	Train Accu.	Test Accu.	Train Accu.	Test Accu.
84.2147%	83.0089%	85.9543%	84.8674%	86.9554%	86.6649%

TABLE V

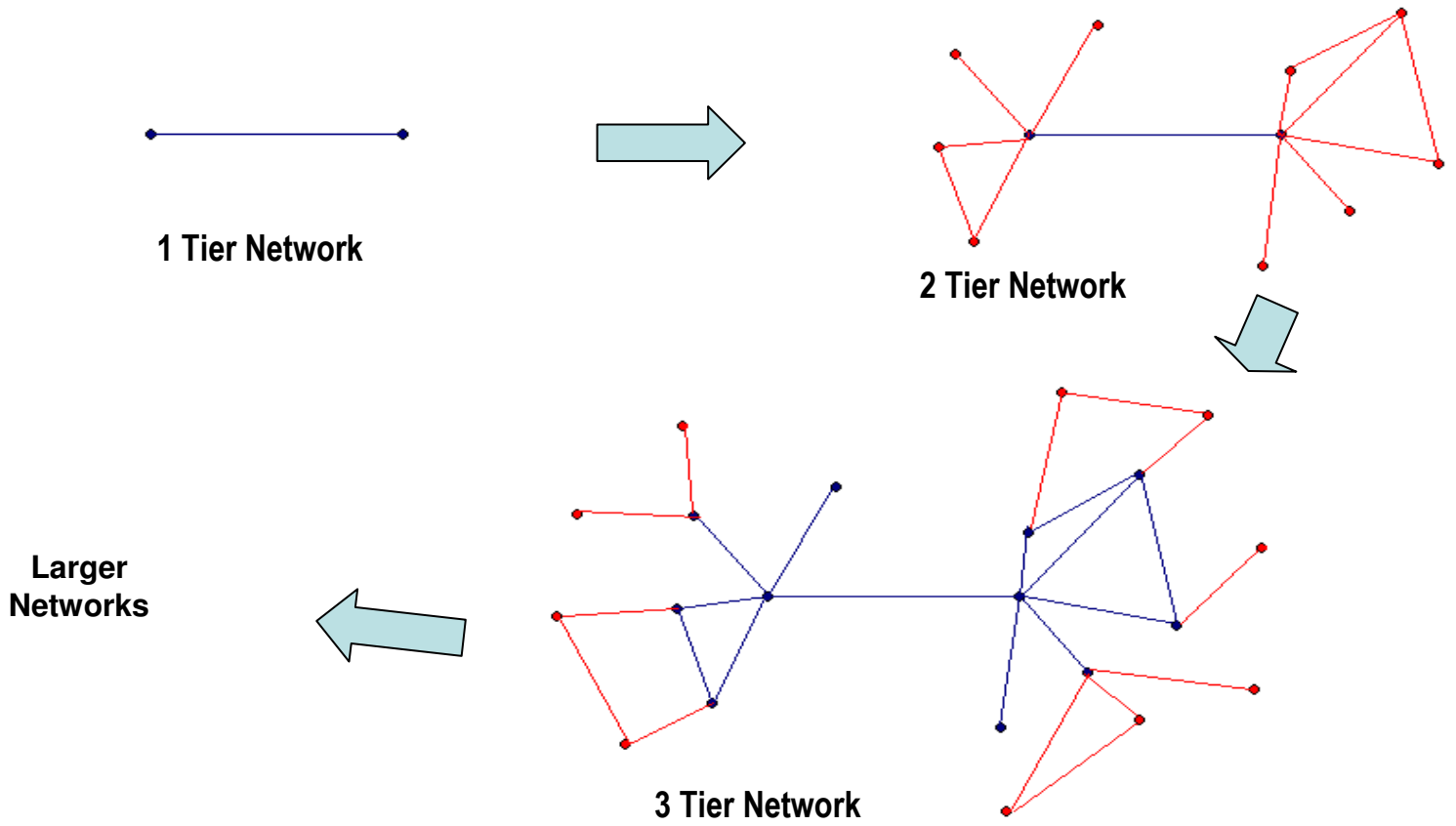
ACCURACY IN SVMCB SMARTER RELAYS IN N-1 CONDITIONS

- **The SVM-based smart relays can make reliably a correct decision when dealing with simple discrimination between normal and faulty conditions , which is larger than 95% even with two features.**
- **The SVM-based smart relays can also make a correct decision with more than 85% probability accuracy when making discrimination between faulty and N-1 conditions.**

Scalability of SVM Based Smart Relays

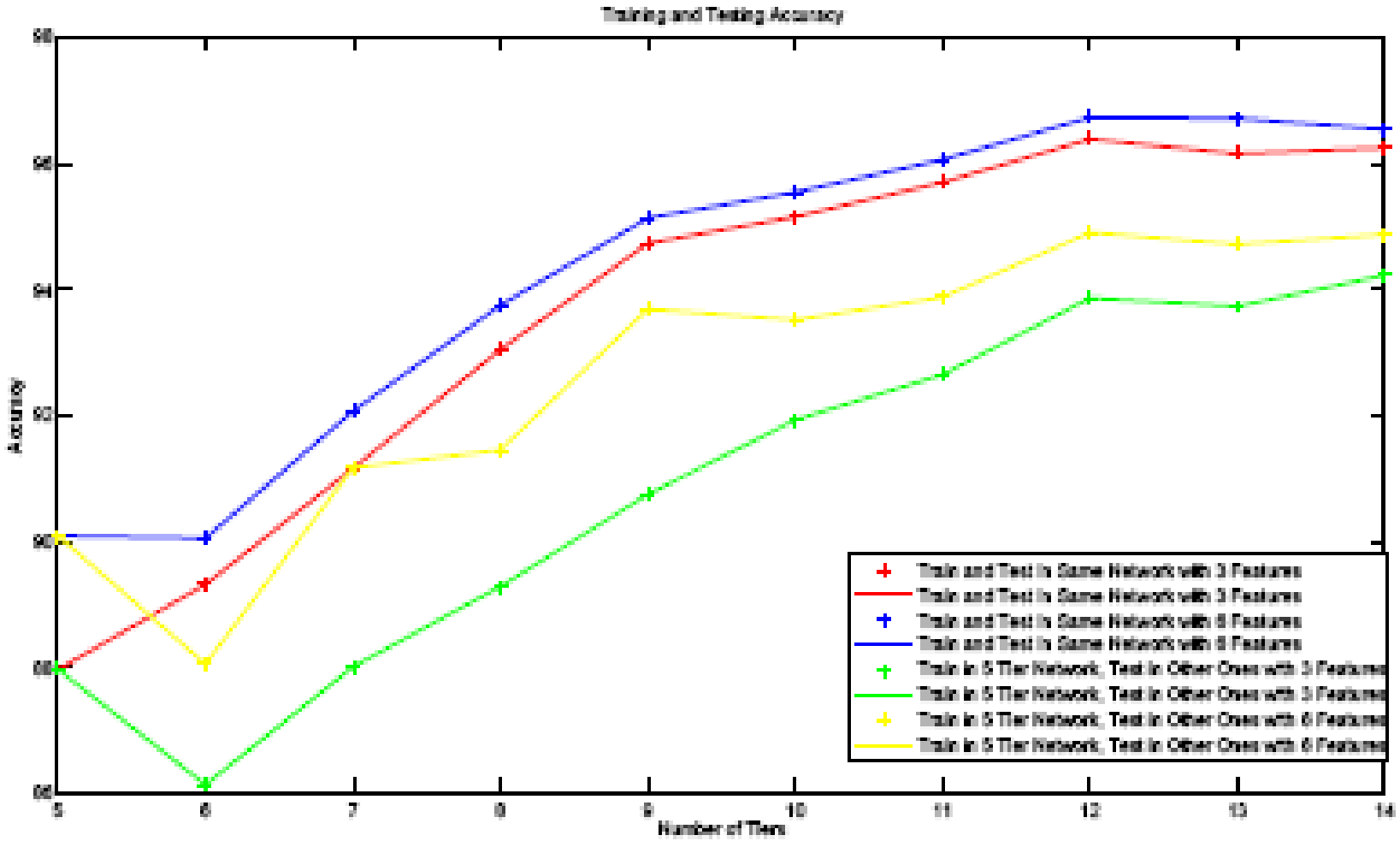
- **Definition: the ability and flexibility of an application to meet growth requirements of the system.**
- **Goal: Using the classifier which is trained in a smaller network on a larger one, to gain a near-to-best testing accuracy.**
- **Scalability is very important for off-line simulations, especially the ones dependent on statistical probability.**
  - Shorter simulation and training time
  - Less data is needed to be kept in relay for training and updating;
  - Quicker dynamic updating
  - lower communication traffic load

Concentric Relaxation Based Approach to Scalable SVM Based Smart Relays



Enlarge testing area tier by tier from a single transmission Line

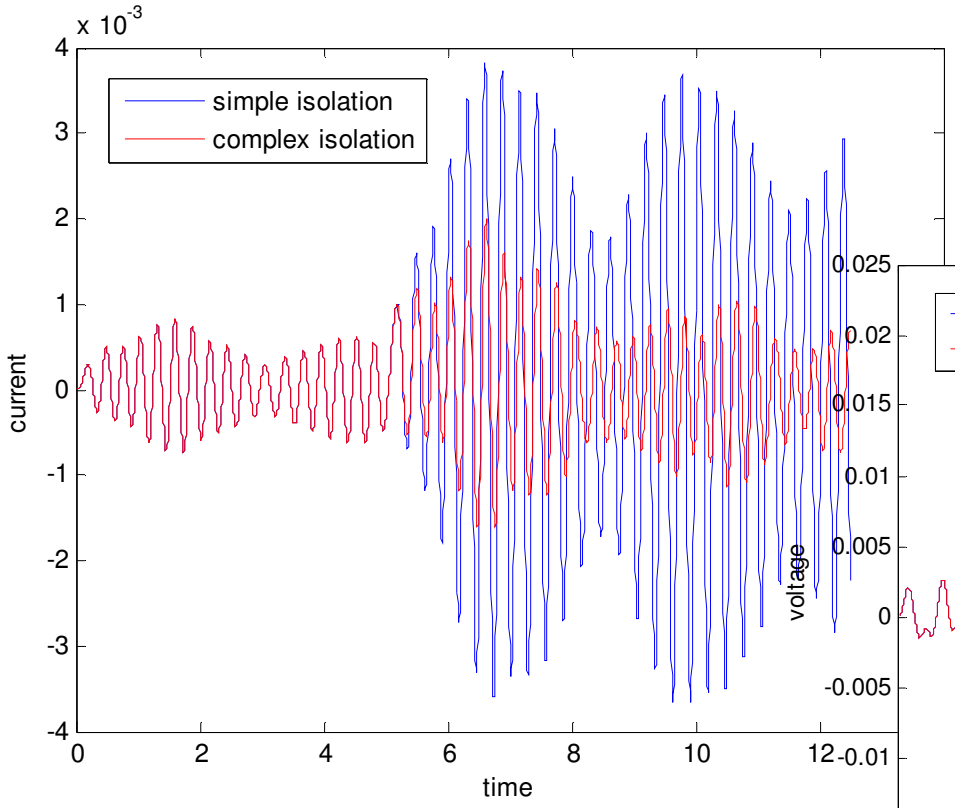
Simulation Results on 118 Bus Systems



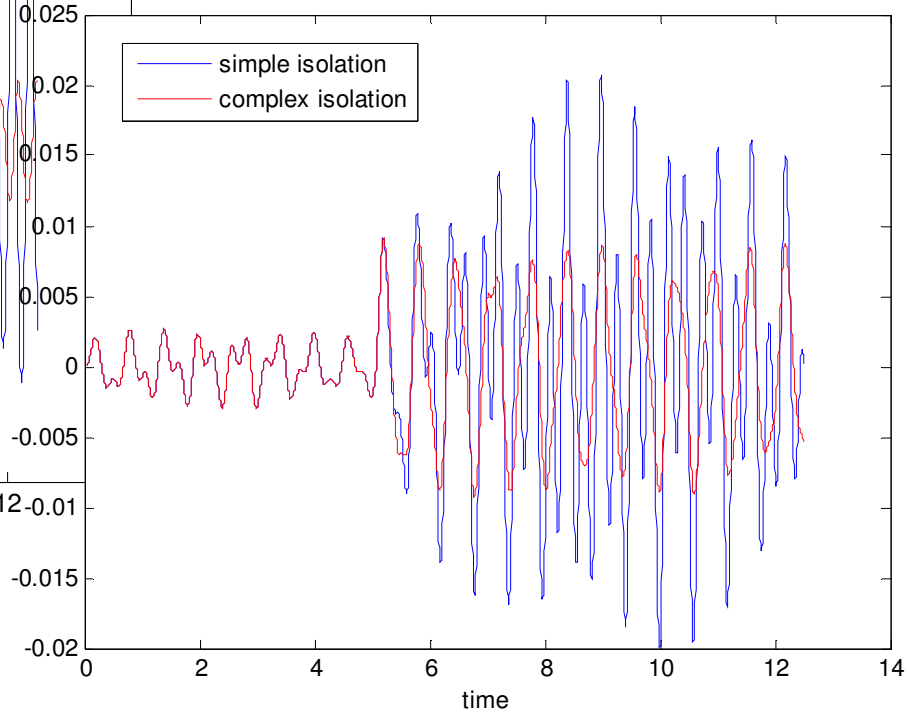
System-wide Effects

- Voltage instability
- Frequency oscillation
- Current oscillation
- ……
- Therefore, there may be a better solution than to isolate the faulty equipment only, on the sense of the system-wide stability

IEEE 14 Bus System Simulation

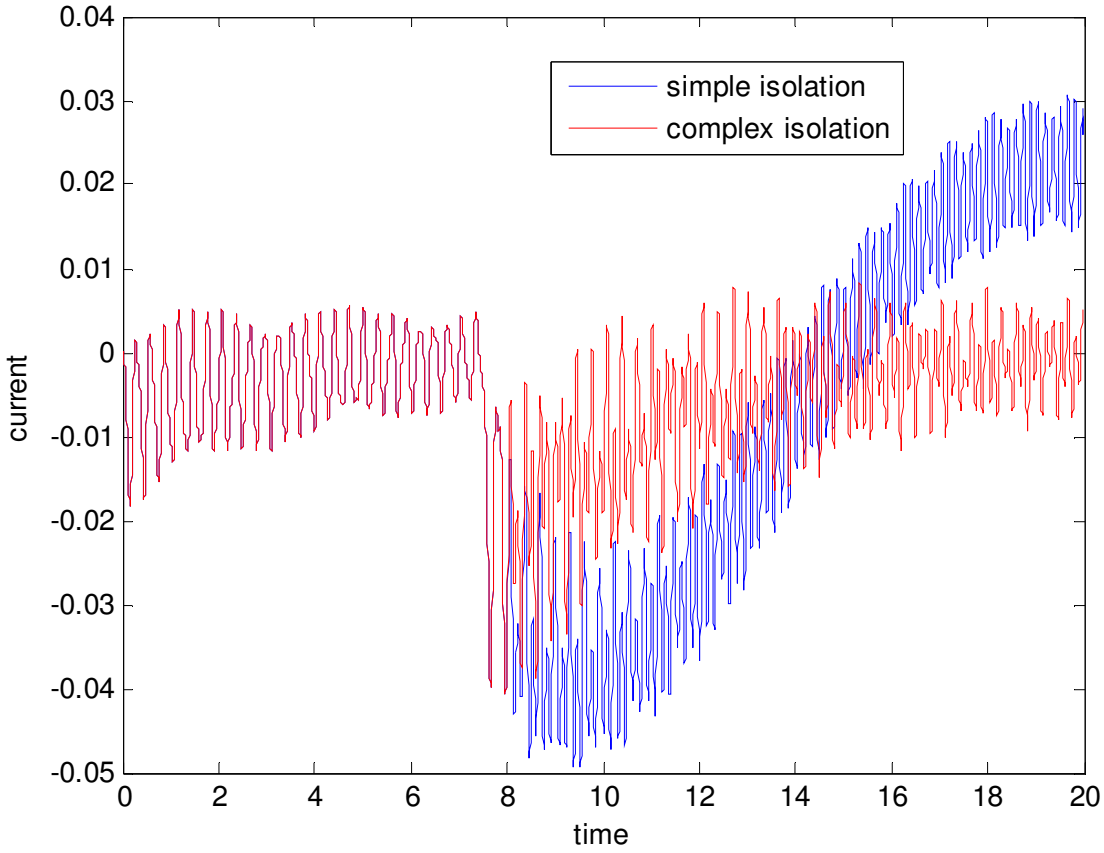


Current for line 10-11



Voltage for load 7

Current for line 4-5


simple isolation
complex isolation
current
time
0.04
0.03
0.02
0.01
0
-0.01
-0.02
-0.03
-0.04
-0.05
0
2
4
6
8
10
12
14
16
18
20

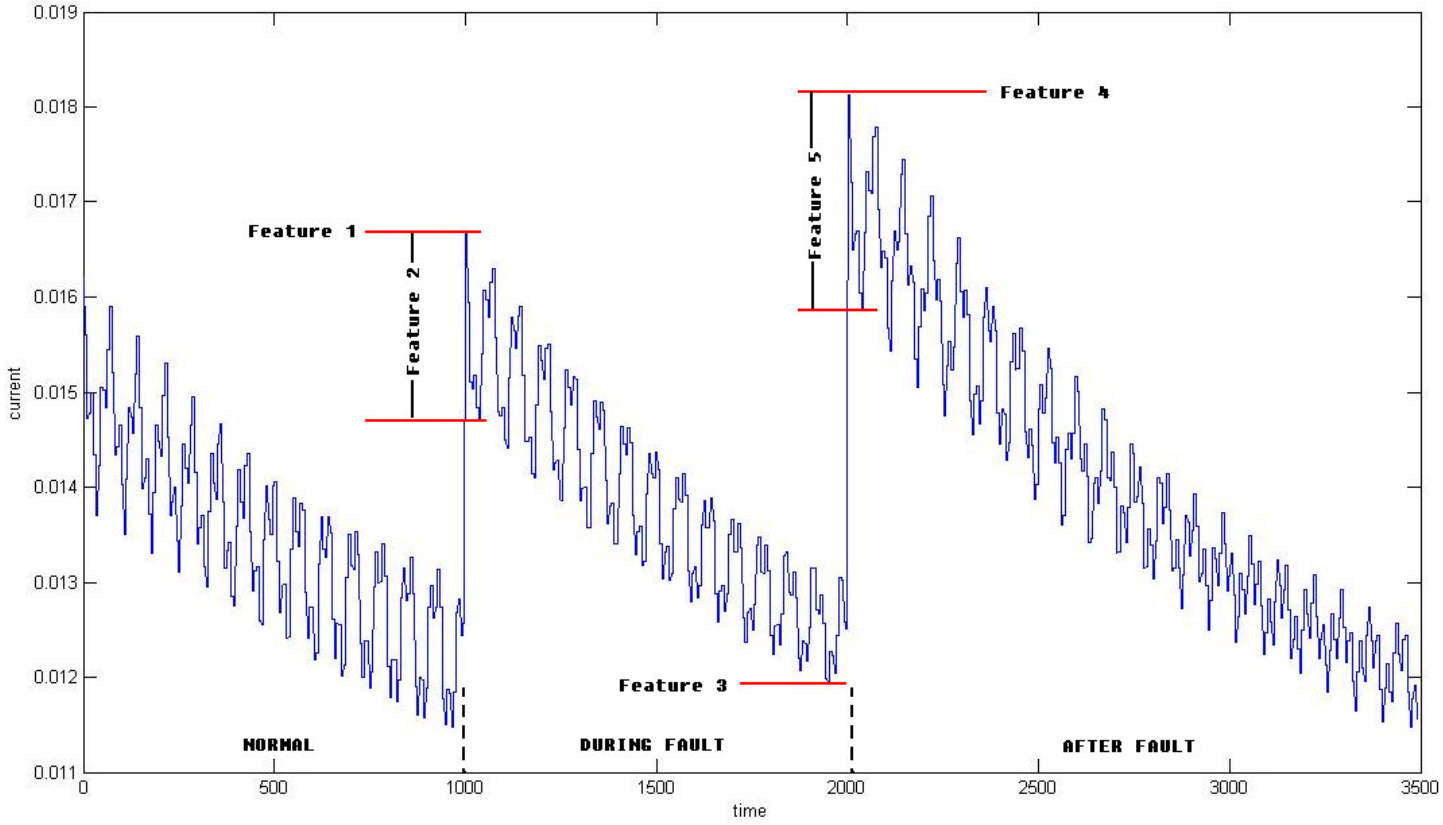
Transient SVM-based Smart Protection Relays

- **Motivation**
  - Instead of only working as a protect equipment, it may stabilize the system more quickly to trip extra relay(s) than just isolating the.
  - Protection relays can be used as binary fast controllers

- **Methodology**
  - Extract features from transient measurements
  - Use continuous time series to do SVM

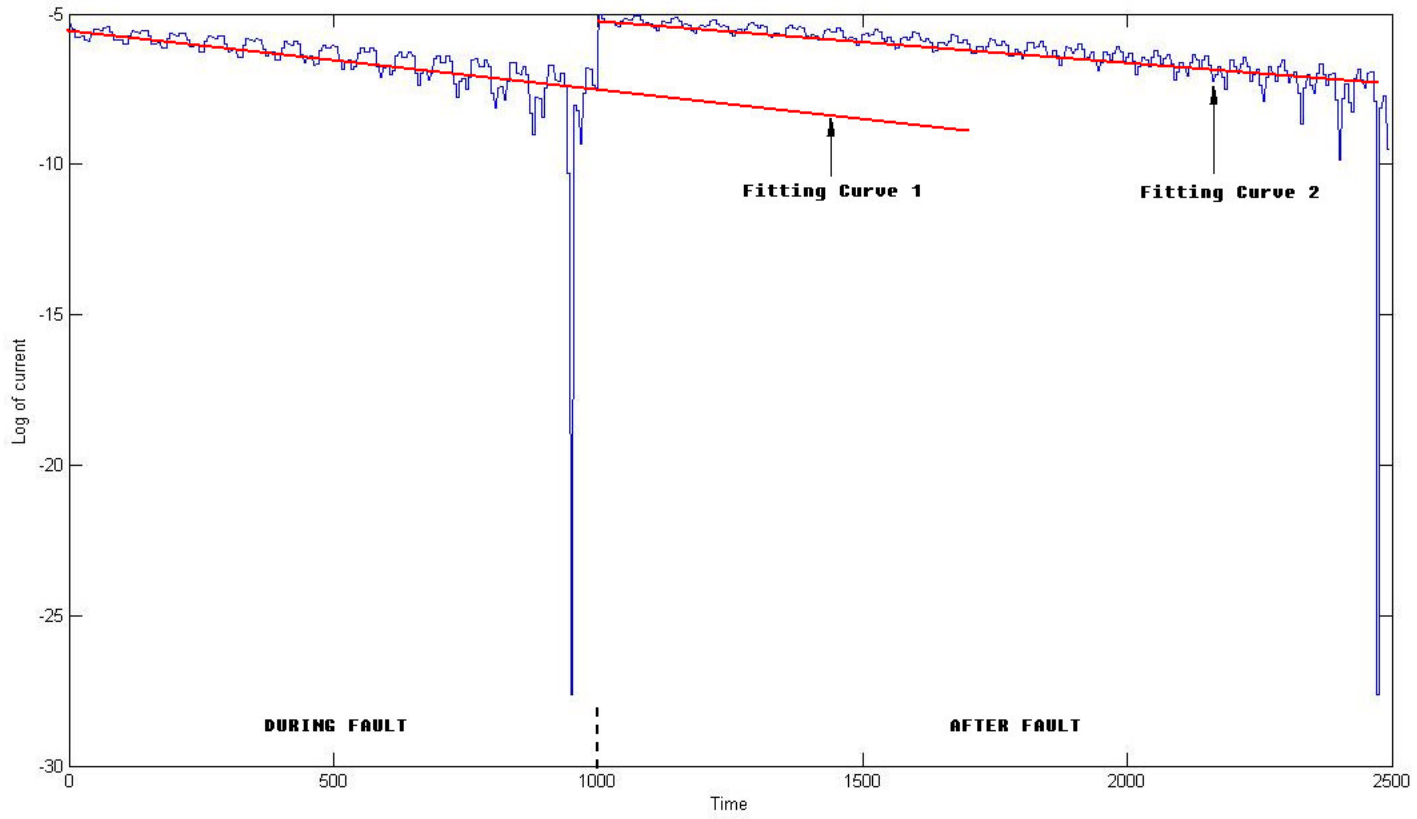
Features for Transient SVM Relay

- **Features:**
  - Max during fault; width during fault; min during fault; max after fault; width after fault



Features for transient SVM relay

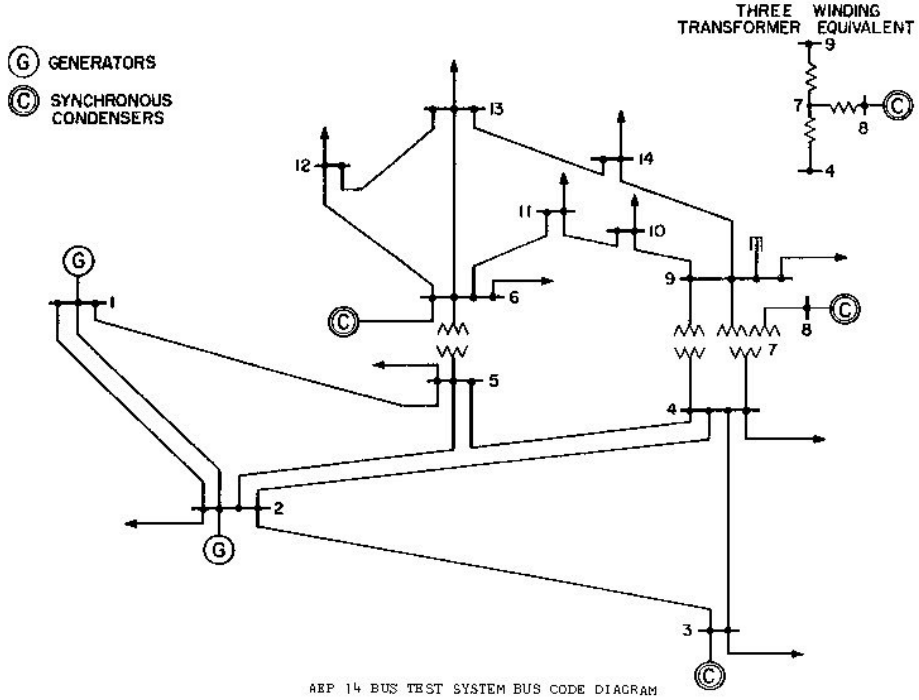
- **Features**
  - Do log and curve fitting on function: 2 parameters for curve 1 and 2 parameters for curve 2



Classes and Accuracy of SVM relay

- **Classes:**
  - Serious effect: destroy equipment; make system unstable
  - Moderate effect: may overloading equipment; potential harm
  - Minor or none effect

- **Simulation on 14bus system**
  - Class 1: generator faults;
    major line faults
  - Class 2: moderate line faults
  - Class 3: weak line faults
  - Accuracy: 97.2%



Conclusions

- **Support vector machine classifier is a viable method to help the relays to be more intelligent and adaptive.**
  - Increase the dependability and security simultaneously
  - May overcome the shortcomings brought by the invalid assumptions of conventional relays
- **SVM based smarter relays is scalable.**
- **Transient SVM-based protection relays, which use the features extracted from continuous time series, can achieve a high accuracy after training**
- **Transient SVM-based protection relays can be used as fast controller to stabilize the system**