# REDUCING FALSE ALARMS AND IDENTIFYING FAULT TYPE & LOCATION WITH ADVANCED ANALYTICS ON PMU DATA

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# RTDMS EVENT CONFIGURATION

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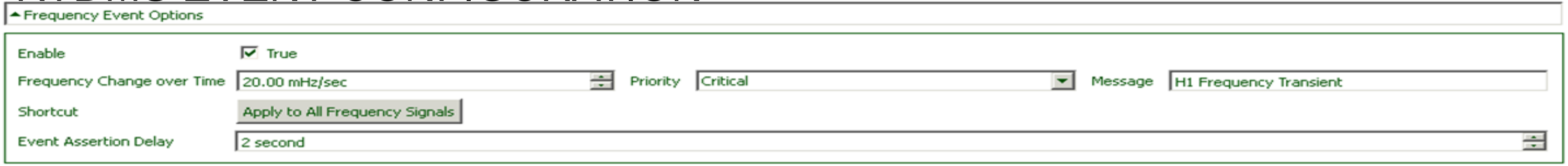


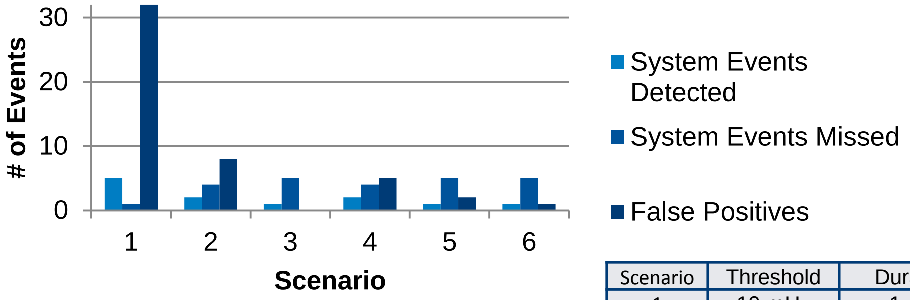

- Settings:
  - Threshold = Max-Min across 1 second
  - Assertion Delay = # of seconds threshold needs to be met

## SAMPLE OF SYSTEM EVENTS FOR ANALYSIS

| EVENT TIME | LINE | KV | PRELIMINARY CAUSE |
|---|---|---|---|
| '08/19/2015 14:36:18 | SEATTLE | 500 | Confirmed lightning event; -184kA |
| '08/19/2015 16:55:56 | SPOKANE | 100 | Confirmed lightning event; -93kA |
| '08/19/2015 17:01:42 | OTHELLO | 44 | Multiple lightning strikes on the line; unable to determine actual strike |
| '08/19/2015 19:02:13 | SPOKANE | 100 | Confirmed lightning event; -29kA |
| '08/19/2015 18:43:17 | PACIFIC | 44 | Confirmed lightning event; -43kA |
| '08/19/2015 19:42:04 | TACOMA | 100 | Confirmed lightning event, -49kA |

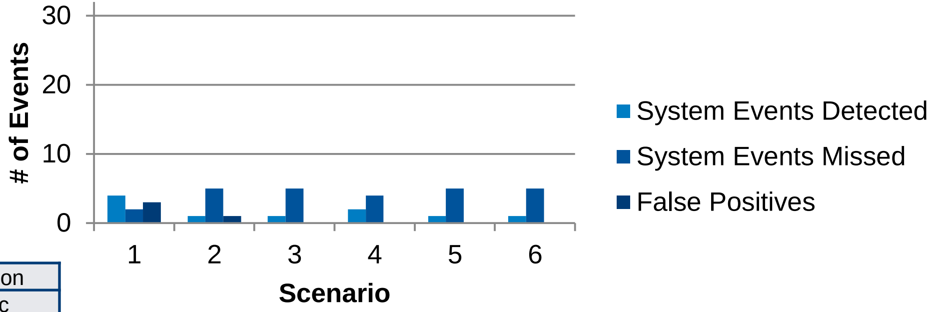
# RTDMS EVENT DETECTION ANALYSIS FREQUENCY

## RTDMS DATA w/ALL PMUs

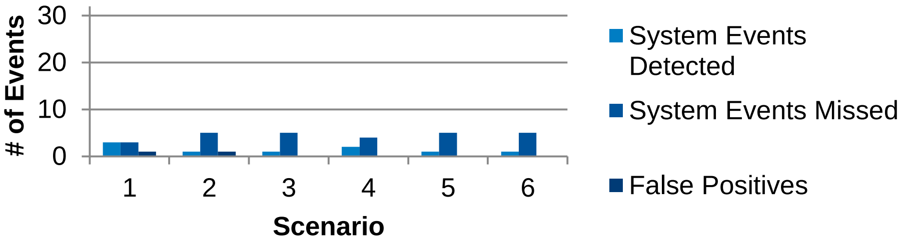



| Scenario | Threshold | Duration |
|---|---|---|
| 1 | 10 mHz | 1 sec |
| 2 | 10 mHz | 2 sec |
| 3 | 10 mHz | 3 sec |
| 4 | 20 mHz | 1 sec |
| 5 | 40 mHz | 1 sec |
| 6 | 60 mHz | 1 sec |

## RTDMS DATA w/ALL PMUs # of PMUs Exceeding Threshold = 4+

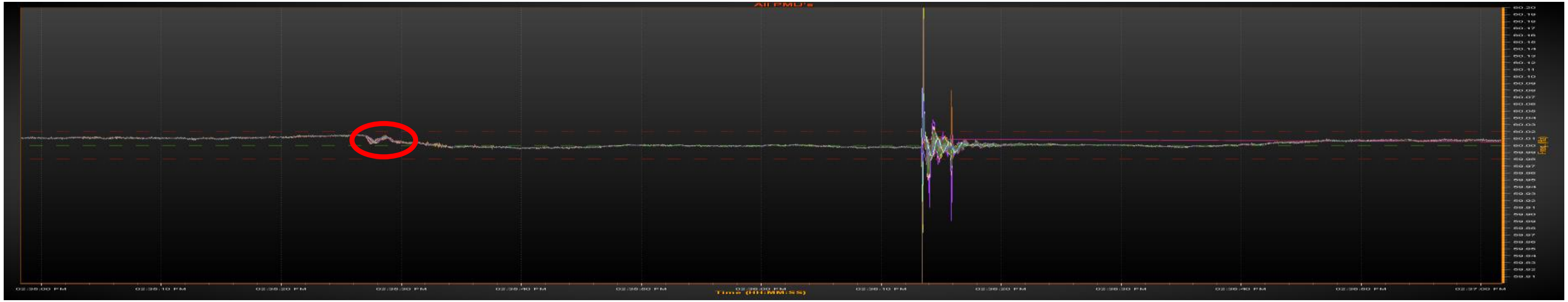



## SAS PROCESSED DATA w/LOCAL PMUs ONLY




- Analyzing only local PMUs creates less false positives
- Using a multiple PMU requirement for exceeding threshold creates less false positives
- Possibly differences in data quality filters

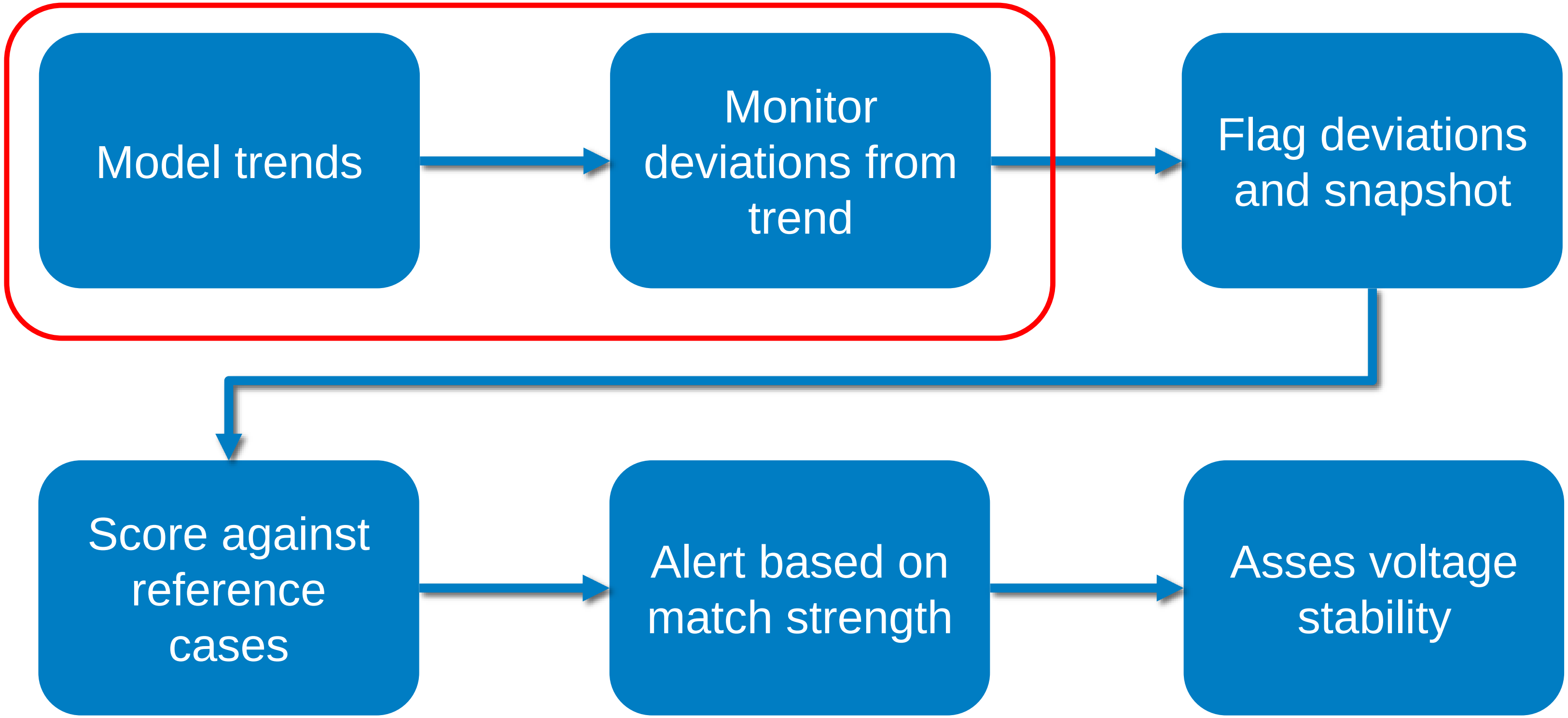
# FALSE POSITIVES




Event Not Captured in Trip Report


Data Quality or Equipment Issue?

# ALERT PROCESSING – A MULTISTEP APPROACH



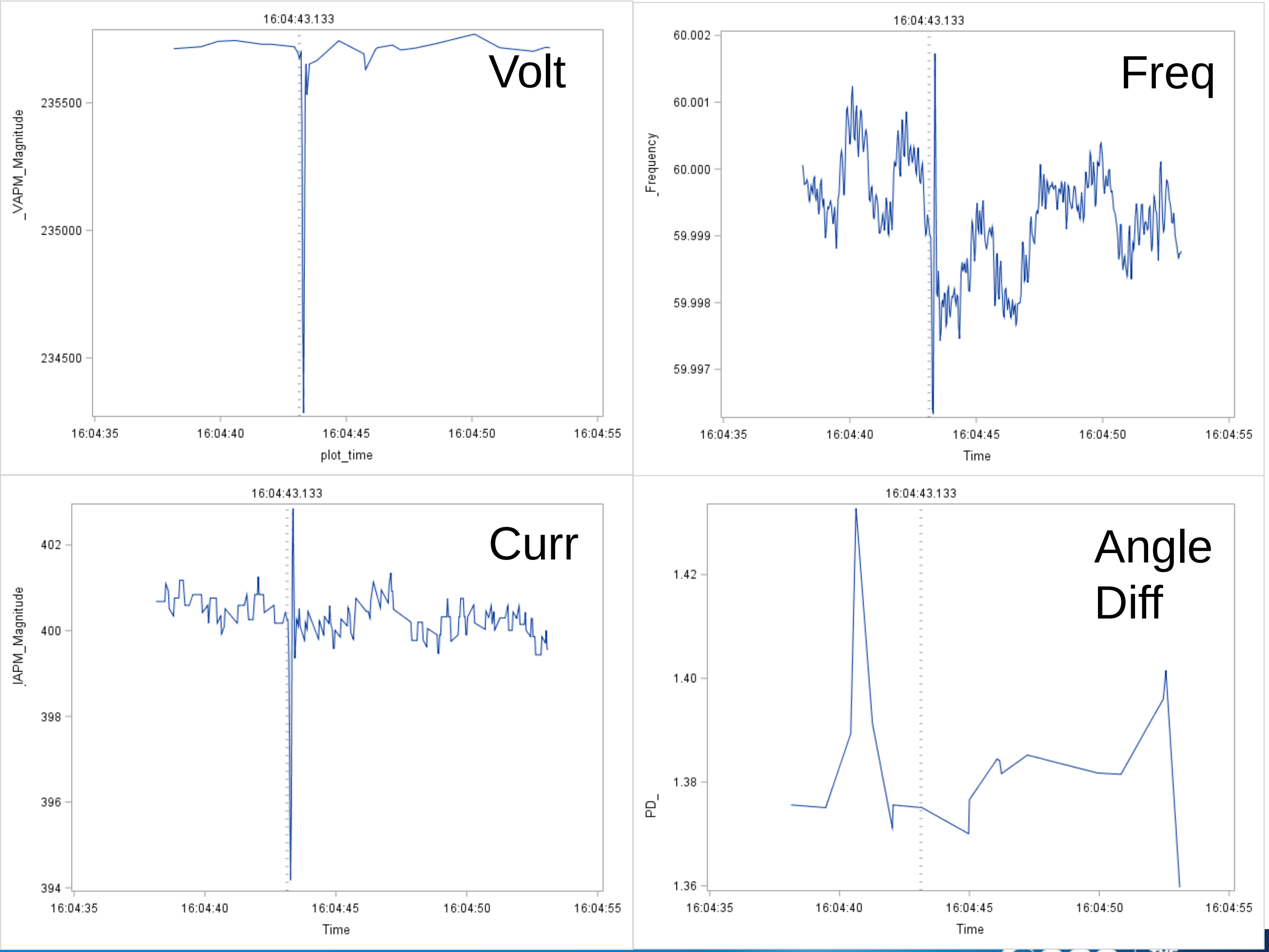
# INITIAL STEPS

- Model Trends
  - Use time series methods to model current trend in measurements
  - Estimate next expected values
- Monitor for deviation from trend
  - Improvement from range based alerts, or delta based alerts

- Fast method for initial data pass
- Reduce volume for subsequent steps

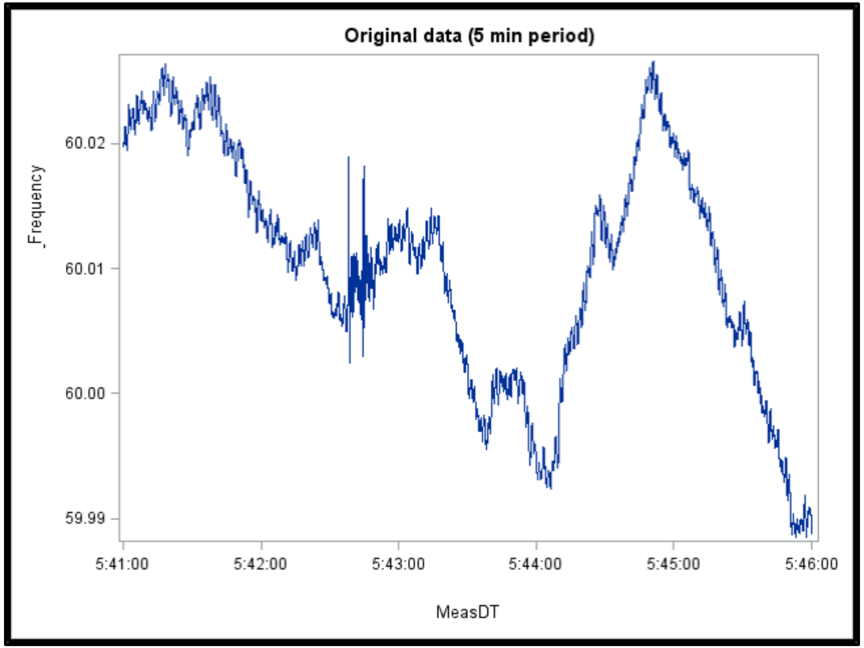
# EVENT # 5

- Lightning event signature
- Not logged in event log

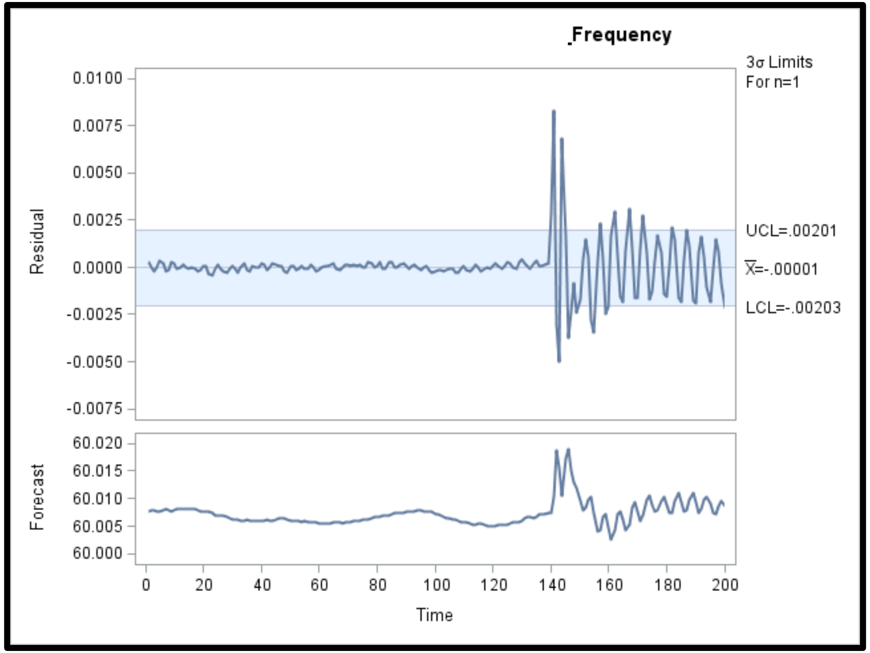


# TREND MODELING

## Before Trend Modeling



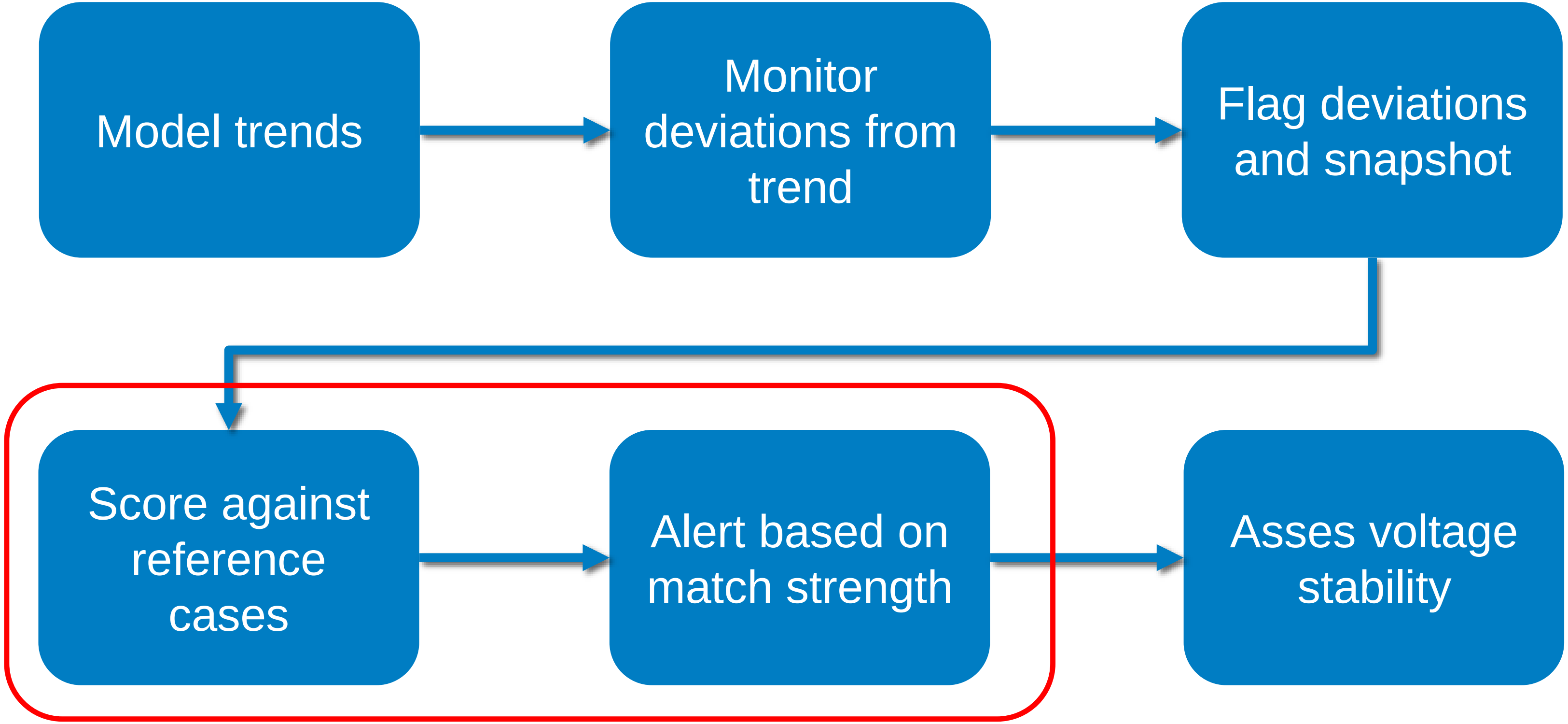

## After Trend Modeling



# ANALYSIS AFTER INITIAL STEPS

- Previous logged events were detected
- Additional true events detected
  - Confirmed in next steps
- Reduced false positives

# ALERT PROCESSING – A MULTISTEP APPROACH



# EVENT PATTERN MATCHING

1. Snapshot events detected in initial steps
2. Use pattern matching techniques to compare to known reference patterns
3. Score current snapshot to determine match strength
4. Validate event and determine cause based on match score strength

# EVENT #5

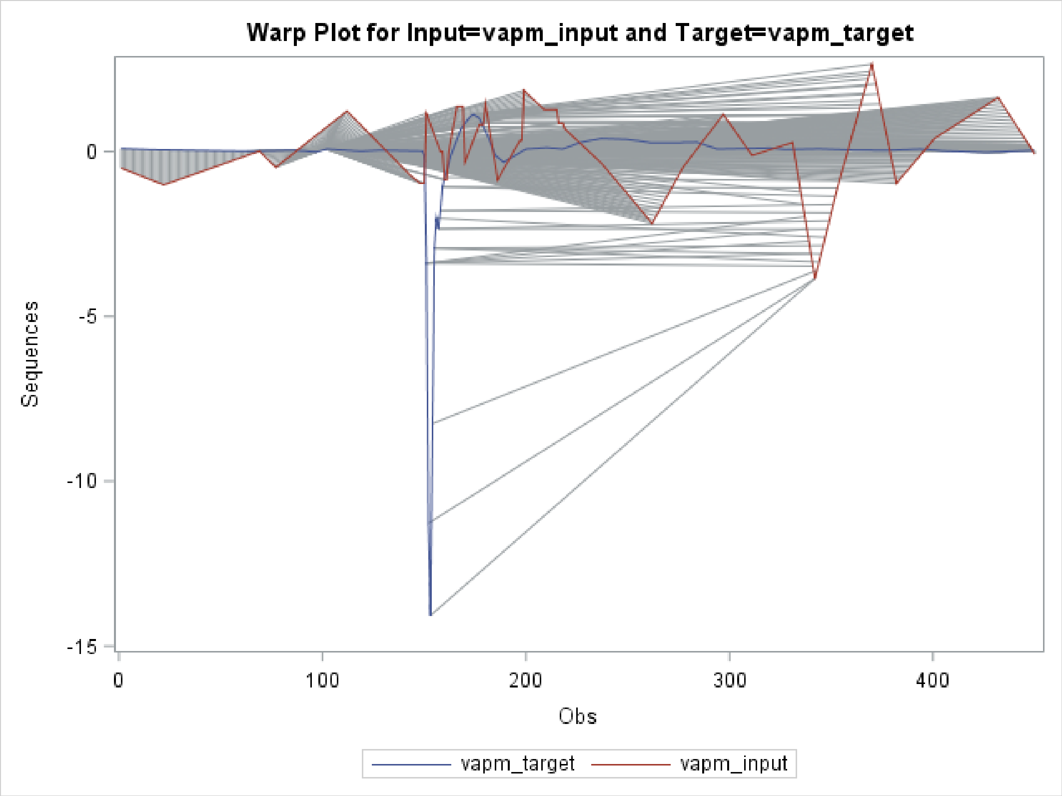
# SIMILARITY ANALYSIS AND SCORE

- Similarity Score = 45.05

# EVENT #7

# SIMILARITY ANALYSIS AND SCORE

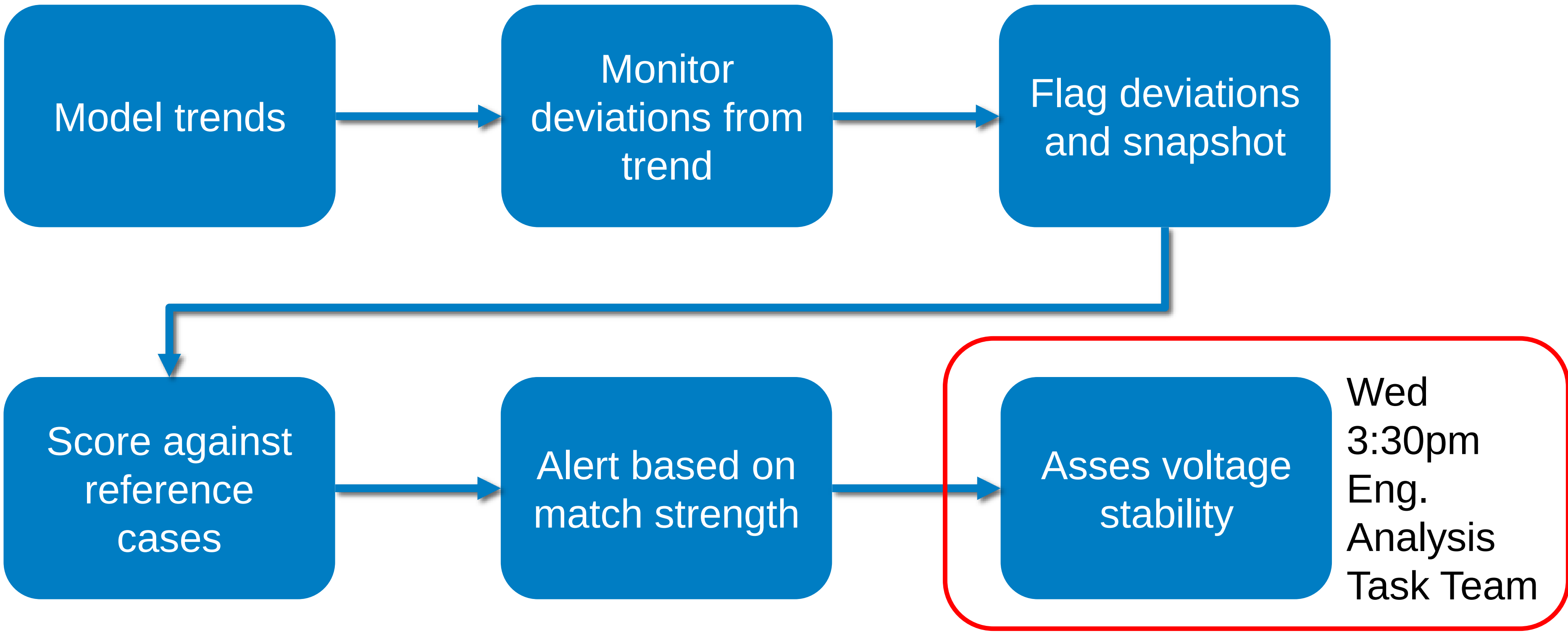
- Similarity Score = 291.01



# ANALYSIS AFTER PATTERN MATCHING

- Confirmation of previous events and additional events
- Provides identification of event type
- Confidence score
  - Allows for non-exact matches
  - Provides ranking for most severe events
  - Separates out non-matches as false positives
    - Can be included in post-event analysis for further research

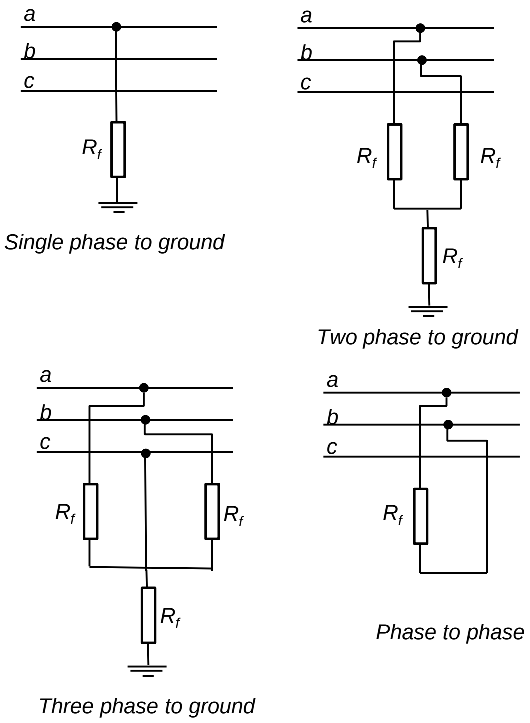
## ALERT PROCESSING – A MULTISTEP APPROACH



# STATISTICAL APPROACH TO FAULT LOCATION

## QUESTION CAN STATISTICS BE USED TO LOCATE FAULTS

- Hypothesis: PMU Data, Current/Voltage magnitudes and angles can be used to determine the fault location on the line.
- Running multiple simulations for short circuit analysis can produce results that can be modeled statistically.
  - Vary location, generation and impedance
  - Capture Current/Voltage magnitudes and angles
  - Use data mining techniques to develop models to estimate location.
  - Validate simulation results with actual PMU fault data

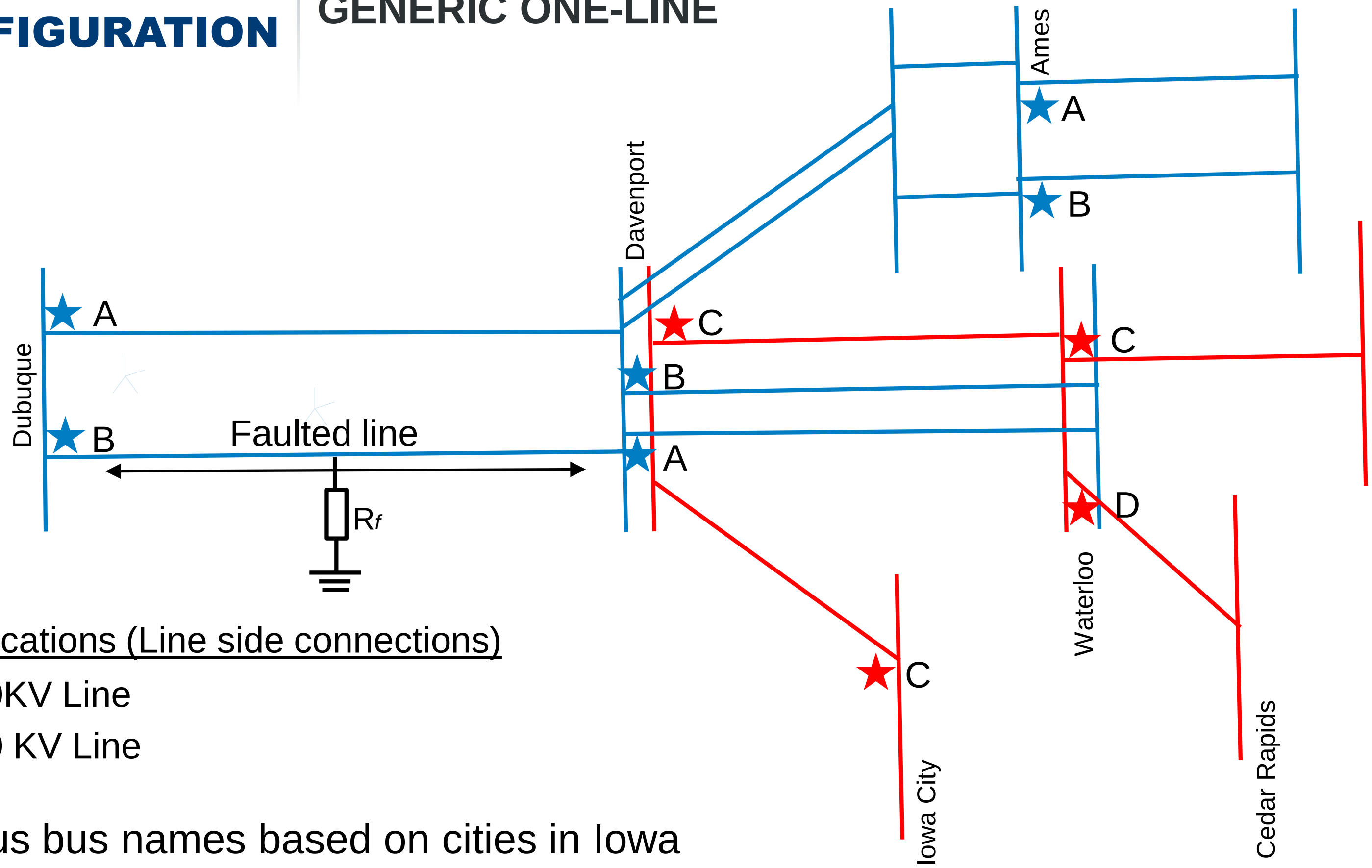


# EXPERIMENT | WHAT SIMULATIONS TO RUN FOR FAULT TYPE

- Fault type and variables
  - Control variables
    - Fault Impedance – 0, 1, 5 Ohms
    - Fault location – distances from bus:  1% to 99% in 1% increments.
    - Fault Type:  B phase to ground (most actual faults in the field for this line are B phase)
    - Neighboring bus generation on and off
  - Observed variables from simulation
    - Voltage Magnitude and Angle
    - Current Magnitude and Angle
    - Two steps away from faulted line
    - Used only data matching PMU output

## NETWORK CONFIGURATION

## GENERIC ONE-LINE




PMU Locations (Line side connections)

- ★ - 500KV Line
- ★ - 230 KV Line

Fictitious bus names based on cities in Iowa

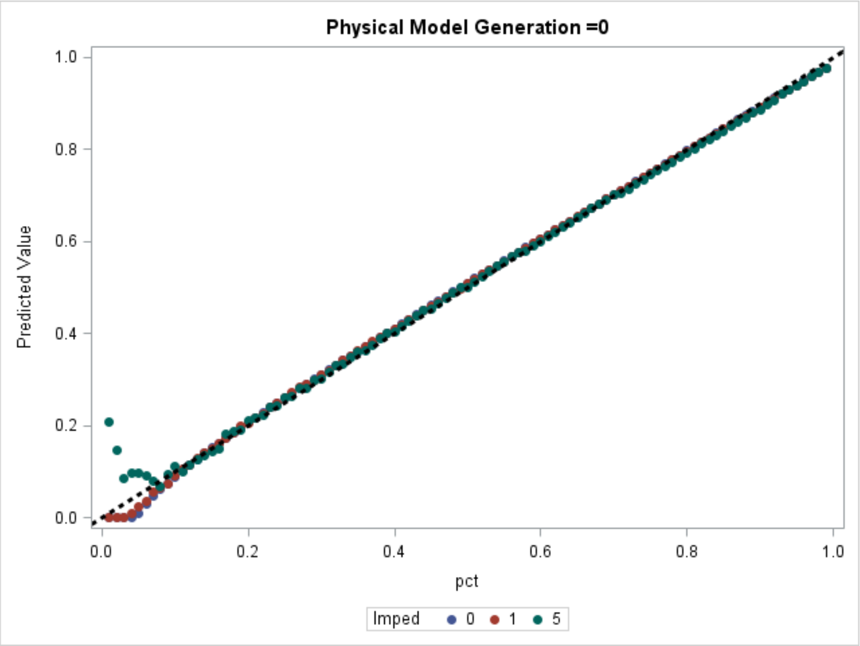
# THE CHOSEN MODEL

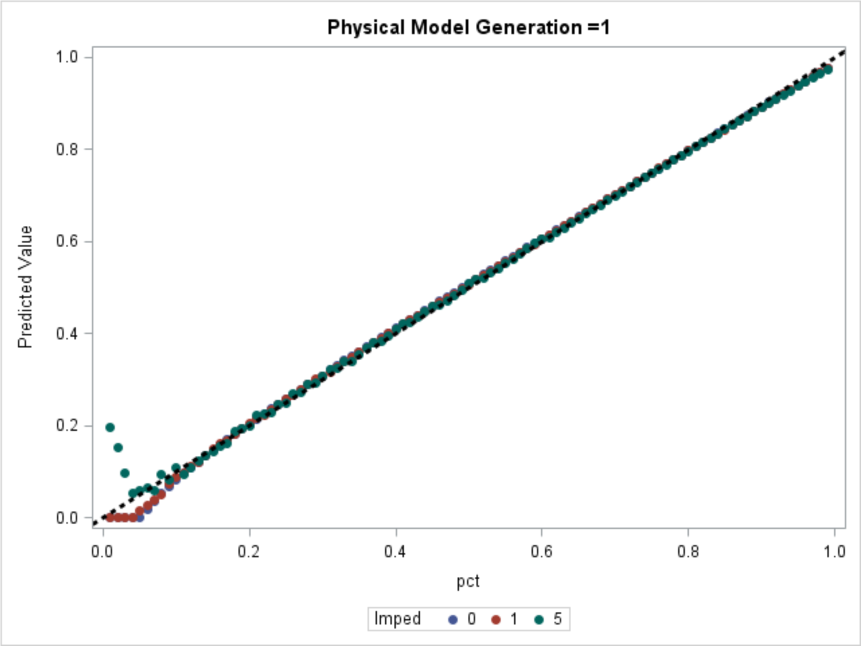
- Random Forest
  - Number of observations (594) were small for the number of variables (160)
  - Random Forest performs well under these conditions
  - It averages a large number of predictions that are developed from many random regression trees.
  - It uses an algorithm that finds important variables which can split the response into similar groups. Single regression tree’s performance may be variable, thus averaging a large number of regression trees often give more consistent prediction results.

# CROSS-VALIDATION DEVELOPING MODEL FROM SIMULATED DATA

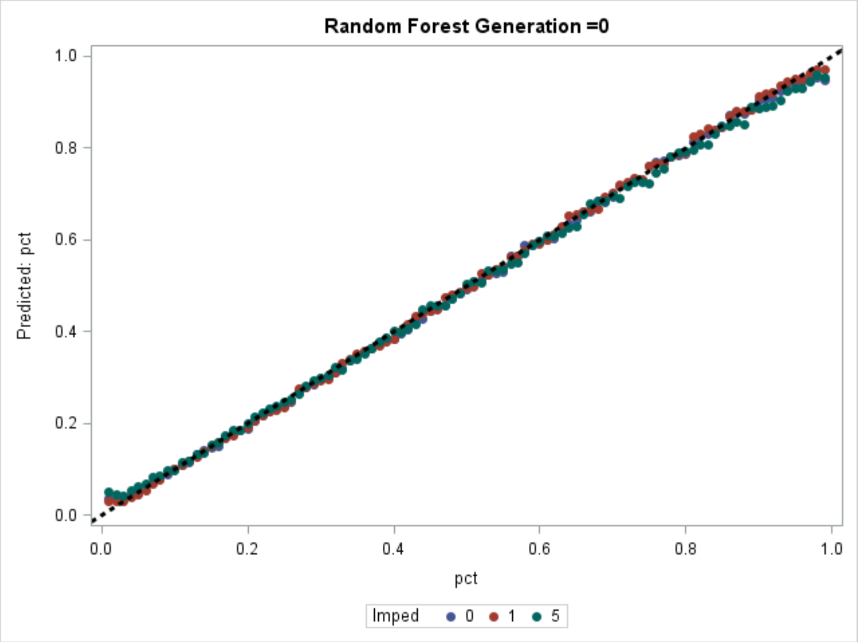
- Experimental setup
  - randomly assign the simulated data into 10 parts.
  - Use 9 parts to train the model and predict on the 1 part hold out.
  - Repeat this process 10 times with different part as hold out each time.
- Three approaches
  - Physical Model [1]
  - Statistical Model
  - Combined Physical and Statistical
- Impedance was not used in model training since we will not obtain that information in the actual scenario.

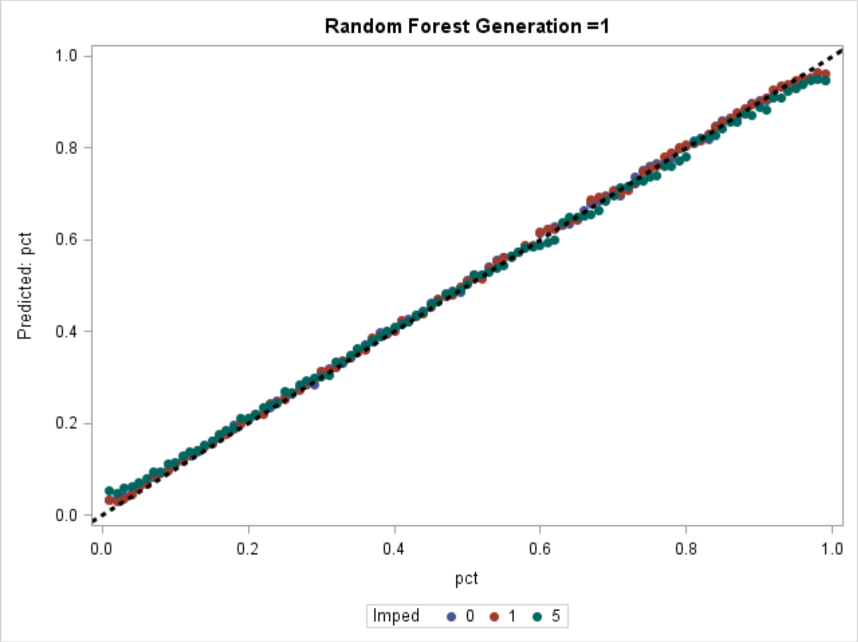
# PHYSICAL MODEL



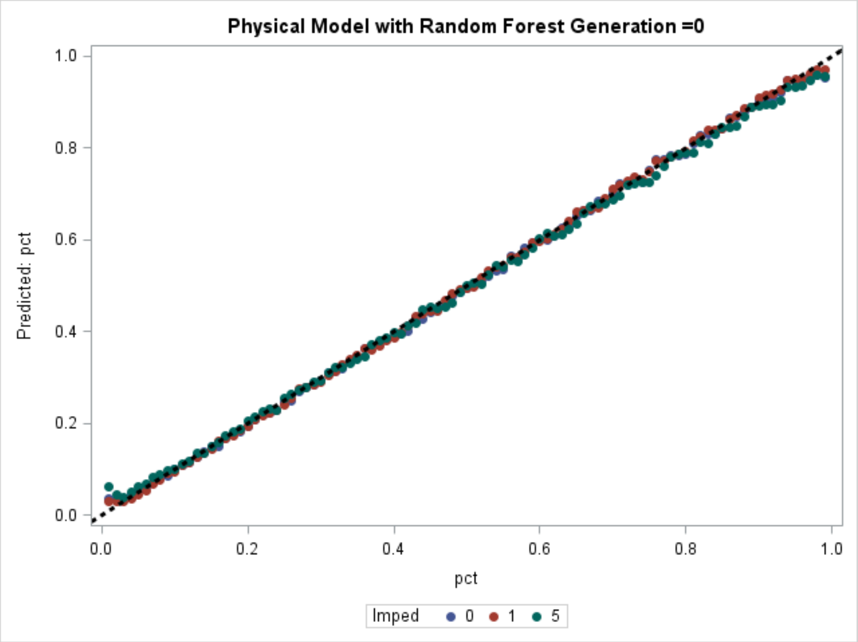



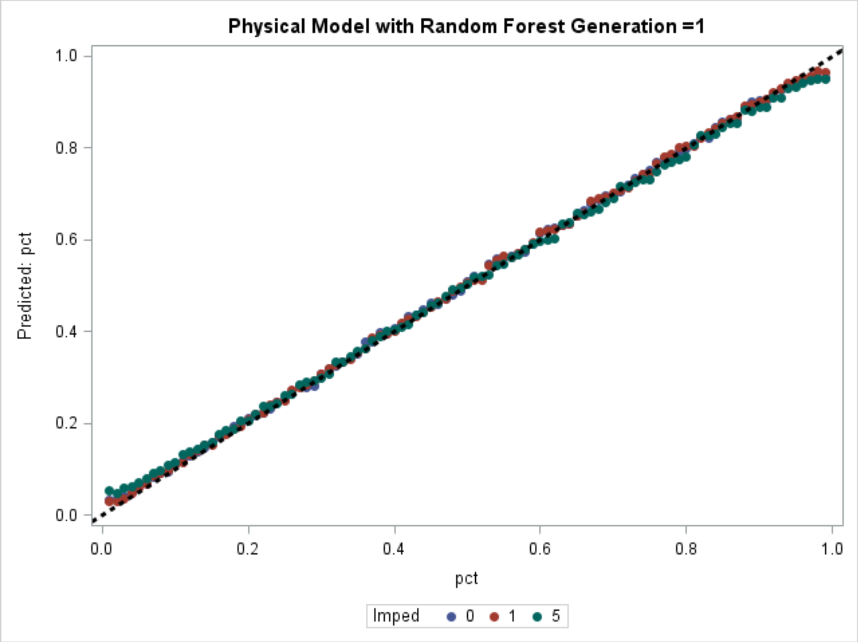
# STATISTICAL MODEL



# COMBINED PHYSICAL AND STATISTICAL MODEL



# MODELING RESULTS

| Method | RMSE |
| --- | --- |
| Physical Model | 0.017511 |
| Random Forest | 0.011078 |
| Random Forest + Physical Model | 0.010306 |

# ACTUAL FAULTS

- Predictive models were used to score actual faults on the B phase of the Dubuque line.
- PMU's on the faulted line are connected to the line-side and they stop recording a couple of cycles after the fault.
- The last reading of the PMU contains transient signals that are distorting the current and voltage measurements. Only after these two transients have died down do we see just the steady-state short-circuit current. [2]
- Scoring the predictive models against the distorted measures did not result in useful information.
- New Question: How to use PMU's to observe the steady state short-circuit current and voltage values?

# CITATIONS

[1] Impedance-Based Fault Location in Transmission Networks: Theory and Application. Swagata Das, Surya Santoso, Anish Gaikwad, Mahendra Patel
[2] A Report on using PMU data under fault conditions. Krish Narendra, Harold Kirkham

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# THANK YOU