

Hierarchically Coordinated Protection: An Integrated Concept of Corrective, Predictive, and Inherently Adaptive Protection

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- ✓ **Problem**
- ✓ **Protection Paradigm**
- ✓ **Methodology**
- ✓ **Results**
- ✓ **Conclusion**

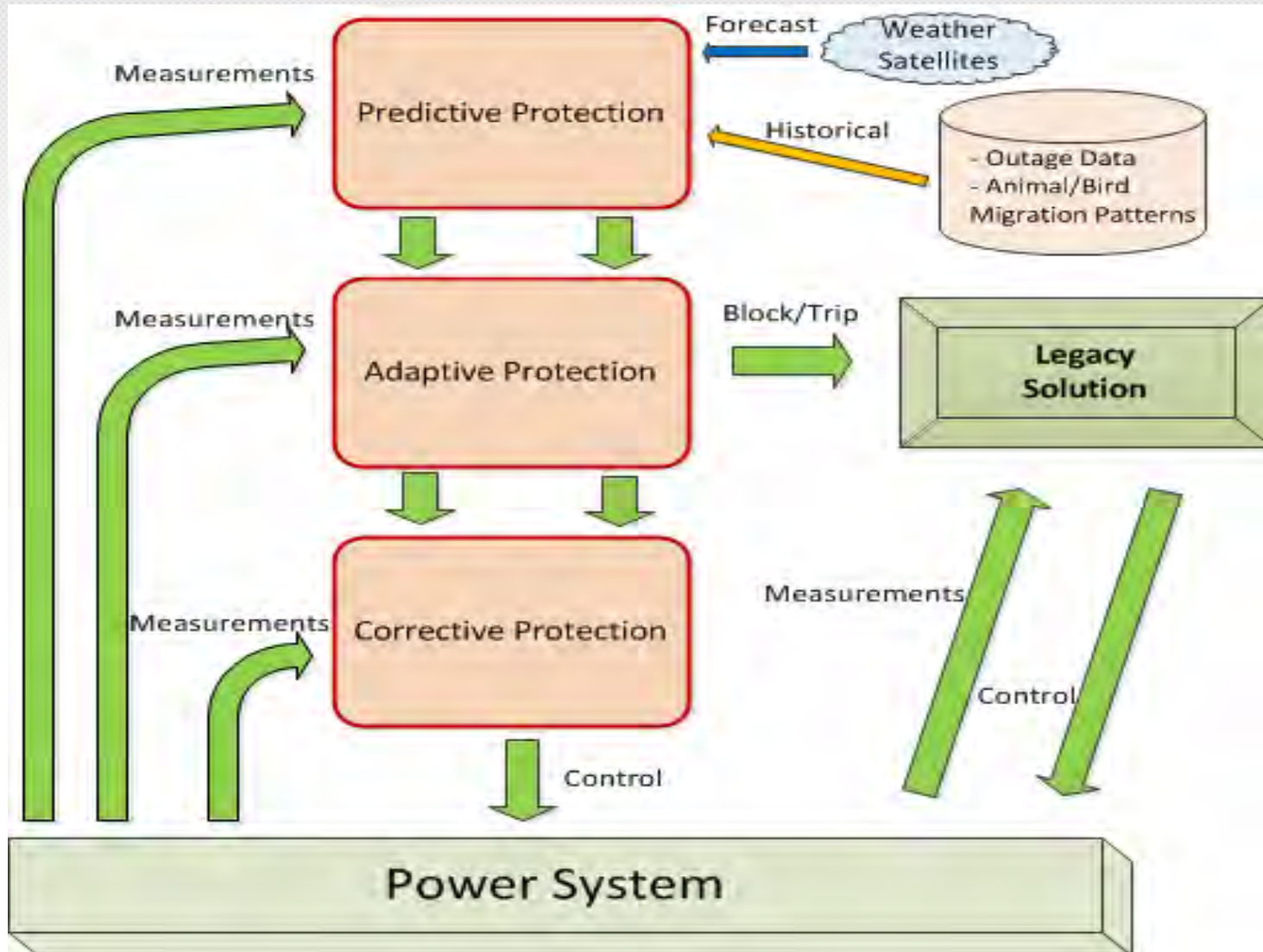


- Dependability:
 - The relay should trip if there is a fault
- Security:
 - The relay should not trip if there is no fault
- There are different approaches to assure that the relays trip correctly:
 - if an incorrect trip, correct with better decision
 - if an incorrect trip is possible, issue blocking
 - if a fault is likely, prepare for a relay trip

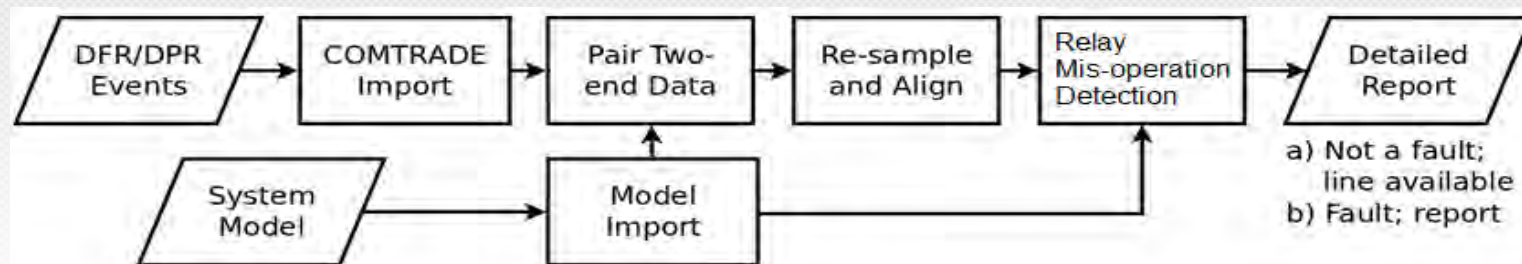
Proposed Approach



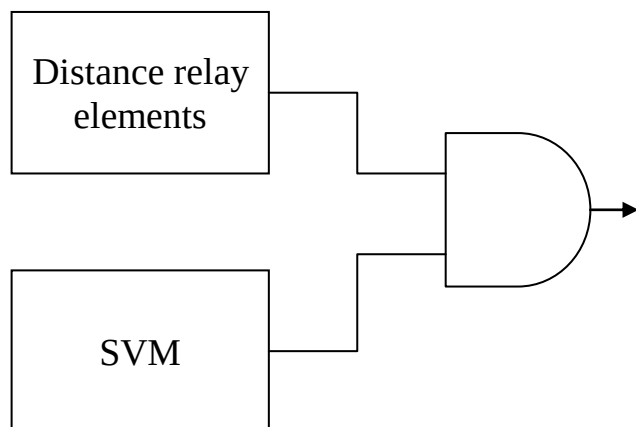
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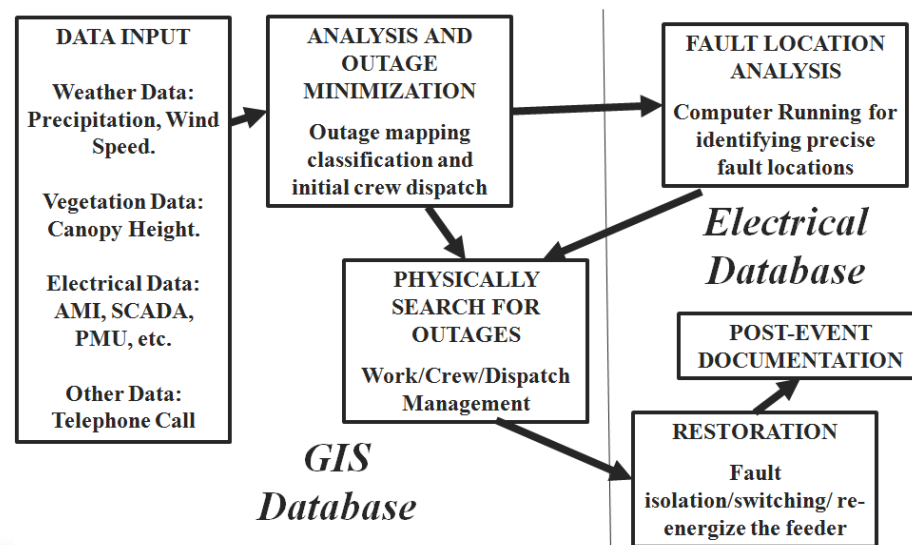
Corrective: Automated analysis of time-synchronized event data

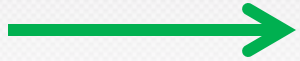


Adaptive: Fortifying the distance protection with supervised learning method



Predictive: Outage management using weather data





Corrective

Adaptive

Predictive



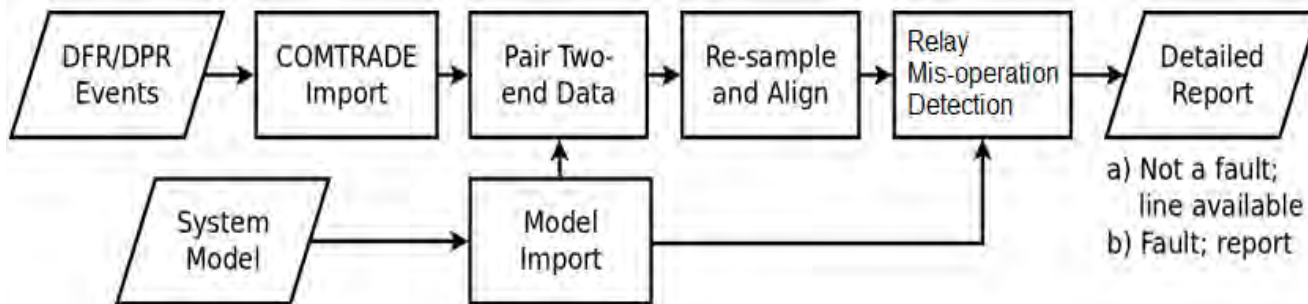
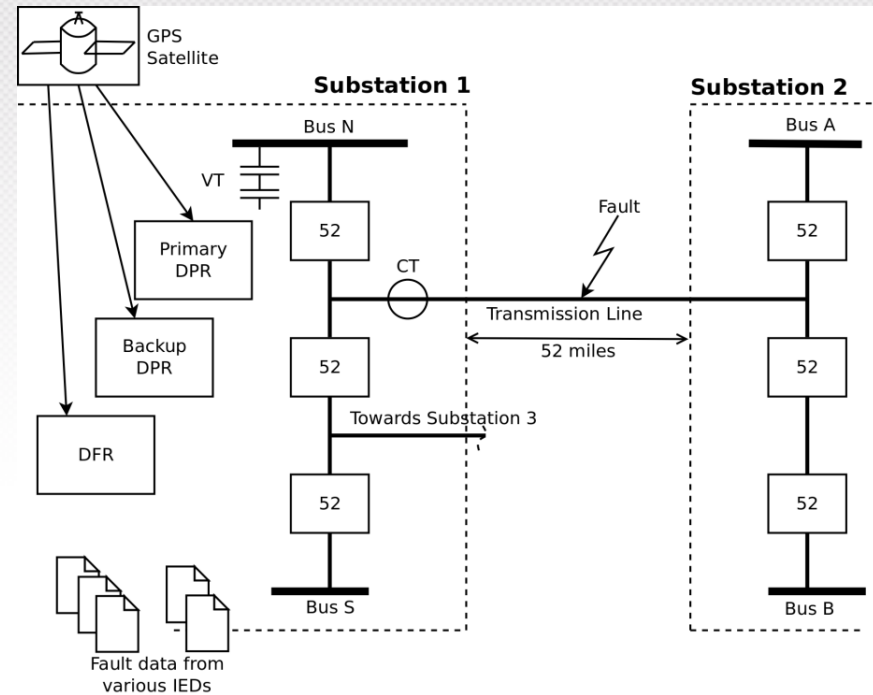
Motivation (Corrective)



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Relay Mis-operation Detection tool

- DFR/DPR Events Import
- System Model Import
- Pairing the Two-end Data
- Re-sample and Align
- Relay mis-operation detection

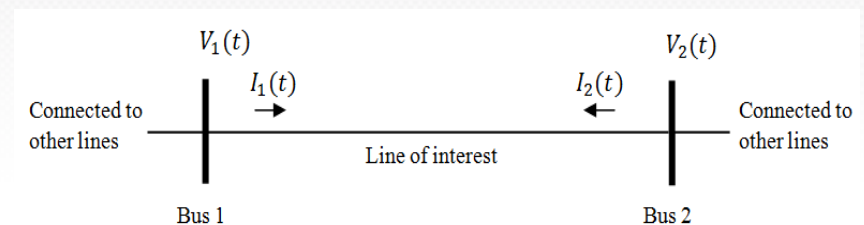


Relay Mis-operation detection formulation

- Calculation of instantaneous power at two ends:

$$P_1(t) = V_1(t) \times I_1(t)$$

$$P_2(t) = V_2(t) \times I_2(t)$$



- Calculation of decision making function using signum function:

$$\text{sgn}(x) = \begin{cases} -1, & x < 0 \\ 0, & x = 0 \\ 1, & x > 0 \end{cases}$$

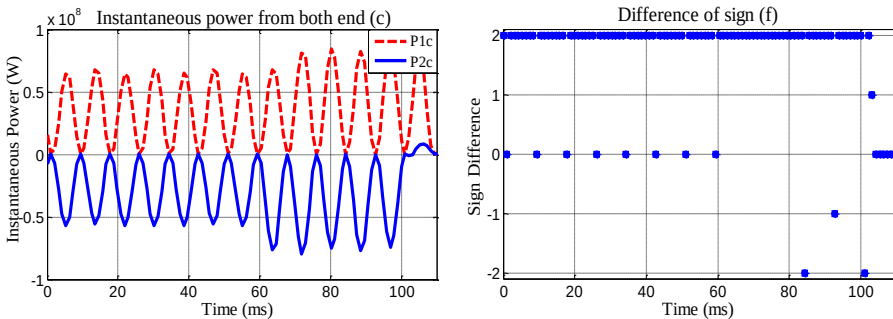
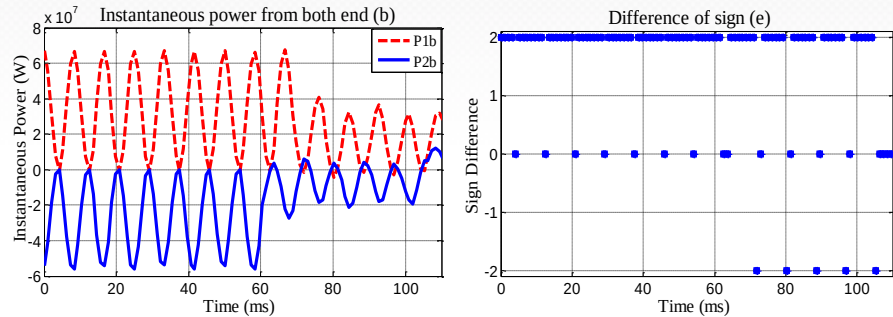
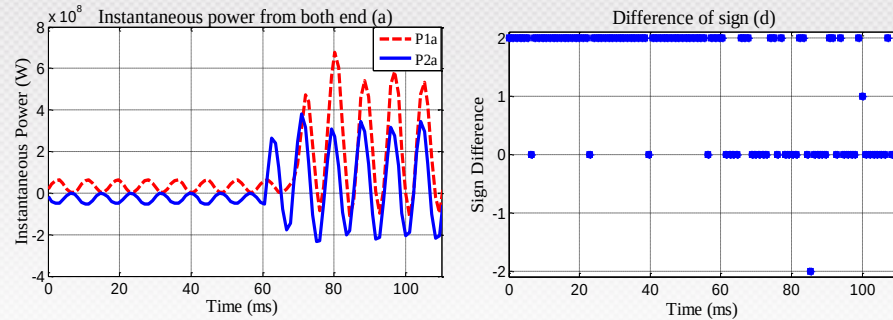


$$P \text{sgn}(t) = \text{sgn}(P_1(t)) - \text{sgn}(P_2(t))$$

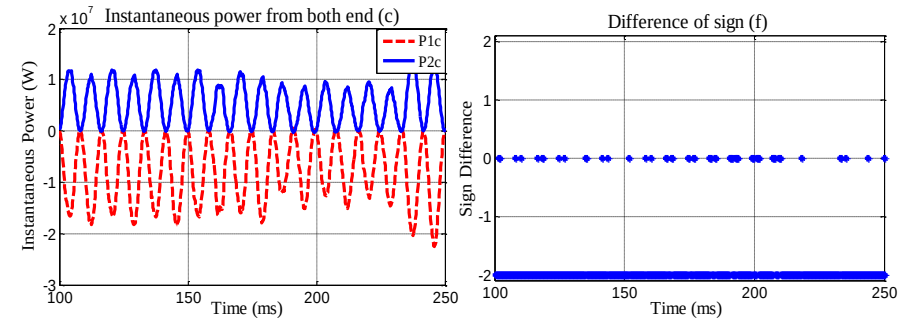
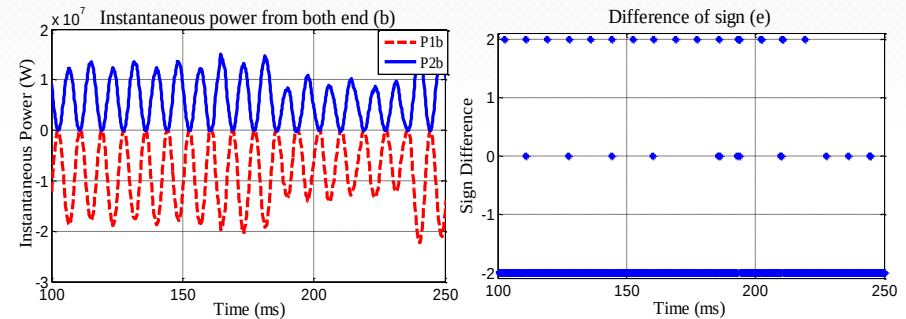
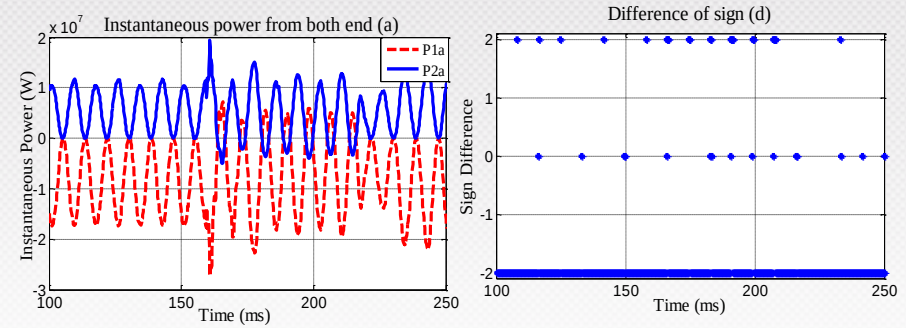
Simulation Results (Corrective)



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Example of single phase to ground fault detection and classification



Example of Relay Mis-operation Detection

Corrective

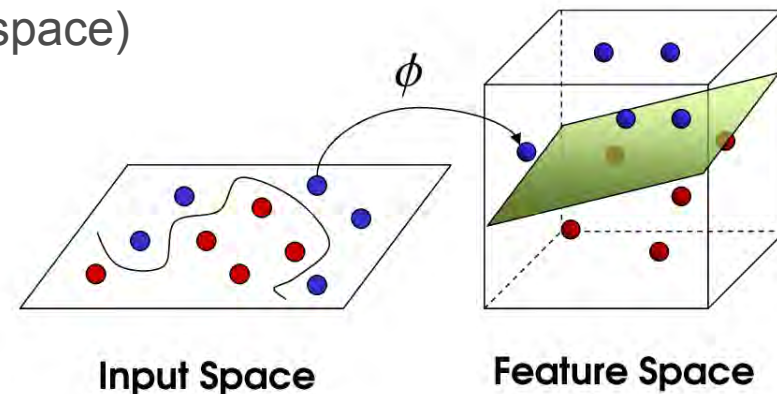


Adaptive

Predictive

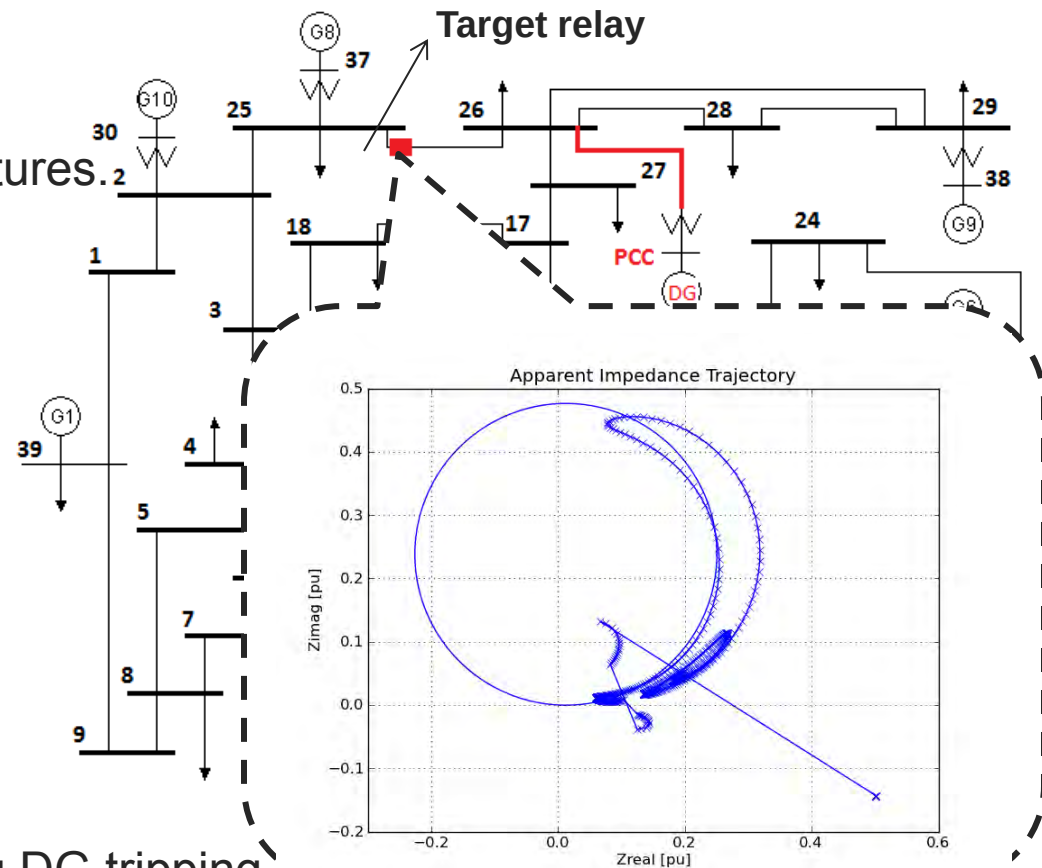


- **Unintended bulk DG tripping** might trigger mal-operation of distance relays and cascading failures consequently.
- Among supervised learning techniques, SVM is shown to be an accurate and easy to train method.
- SVM is a learning method based on the statistical learning theory.
- SVM could be trained to detect and recognize the DG tripping scenarios from faults and fortify the distance decision making.
- In SVM method, original input space is mapped into a high-dimensional dot product space(feature space) by a Kernel function (Φ) and a hyper-plane is determined to maximize the generalization ability of the classifier.
- Proper feature vectors are obtained by PMU measurements of voltages and currents at relay location.



SVM Based Protection Scheme

- Instances preparation
 - Each instance contains one “target value” (0=DG tripping 1=else) and voltage/current features.
- Feature extraction
- Training set data preparation
Scenarios consisting:
 - Various DG tripped capacities (50, 100, 150) MW
 - Various instants of DG tripping following the fault [0.2-2] s
 - Various fault locations triggering DG tripping

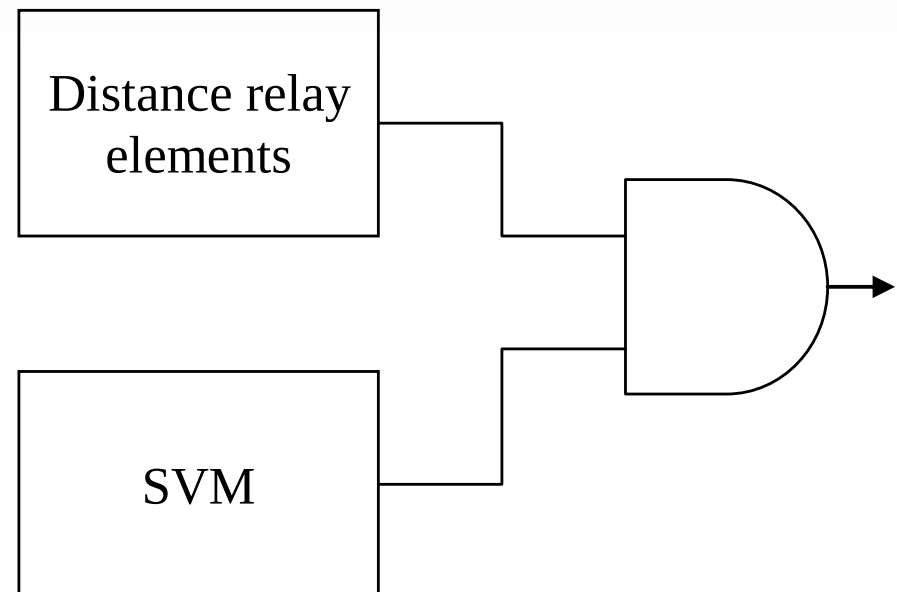


Simulation Results (Adaptive)



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- SVM is trained for unintended DG tripping scenarios, figure below, in New England 39 bus system.
- 25000 instances (15000 training/10000 testing) of DG tripping cases and faults are provided.
- Radial basis function (RBF) kernel is deployed.
- Cross-validation results in:
 $C=32768$ and $\gamma=32$.
- SVM accuracy: 93.7%



Corrective

Adaptive



Predictive

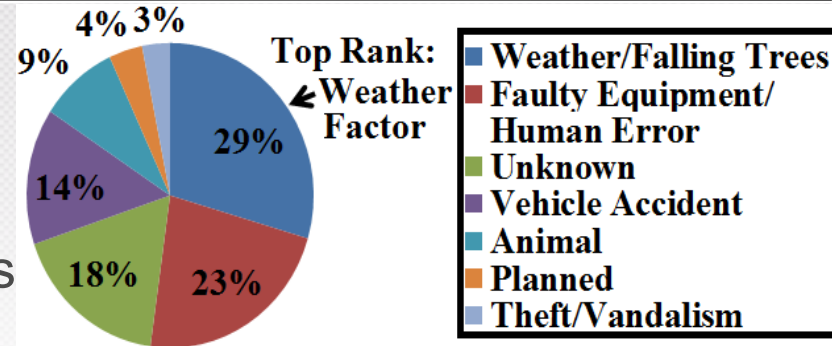


Motivation (Predictive)

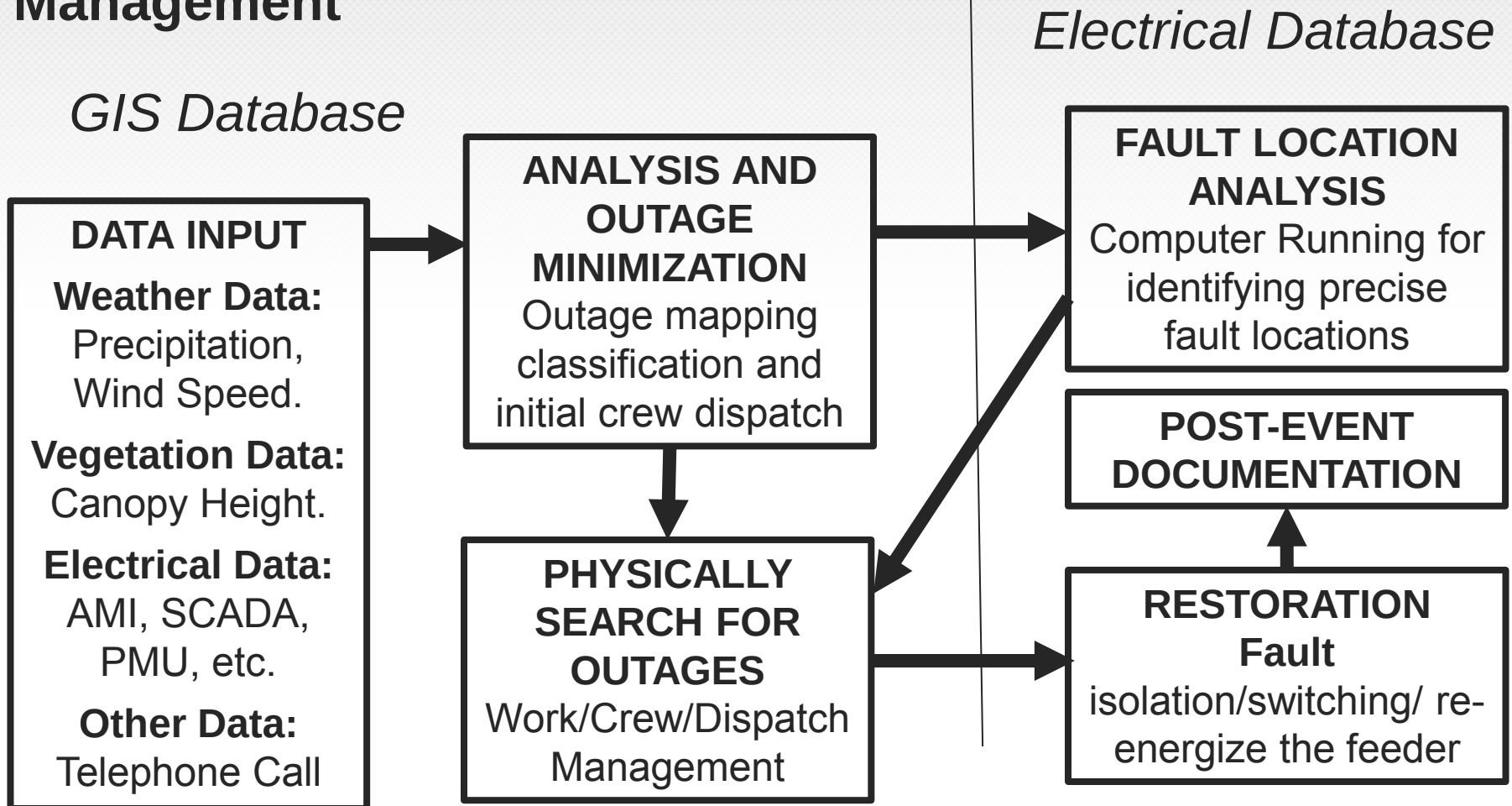


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- Predictive approach for outage management:
 - Weather is the main reason for outages
 - GIS platforms and databases:
 - Visualizations and spatial analysis;
 - Interpretation for enabling better decision making;
 - Hazard zone classifications: which area has higher potential to have outages.
 - Crew management :
 - Dispatch and field management in a proactive manner;
 - More efficient workflows: outage work orders and communication flows.



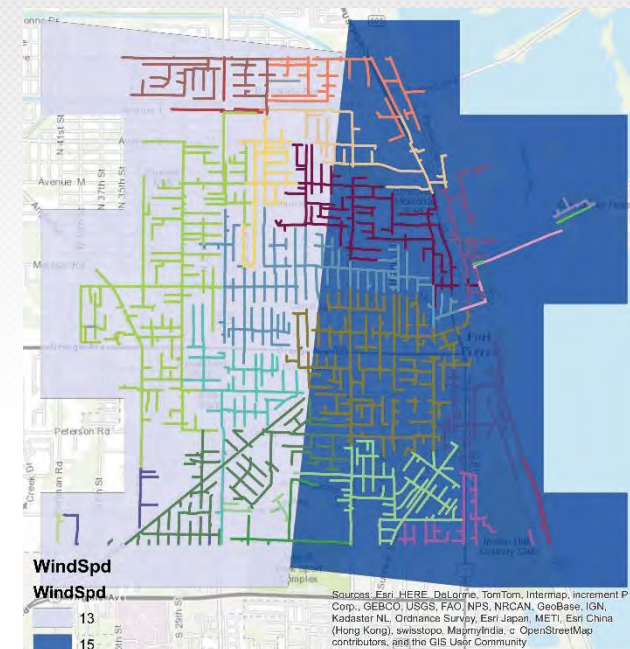
Weather Impacts on Outage Management



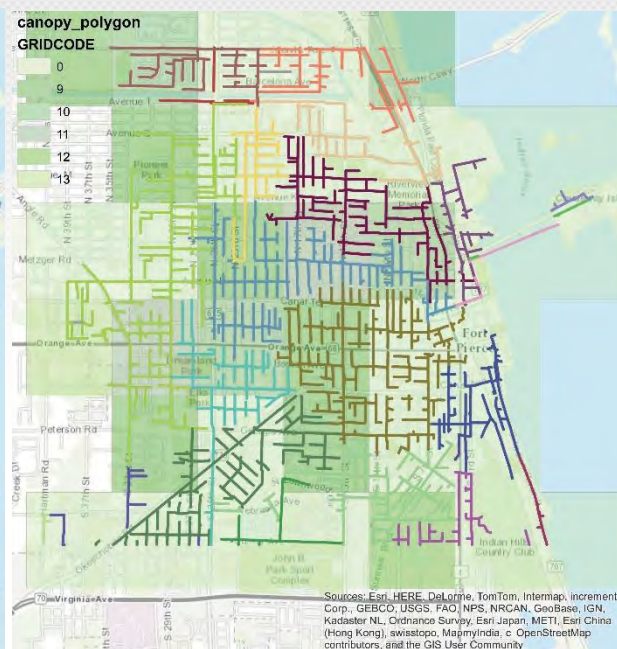
Simulation Results (Predictive)



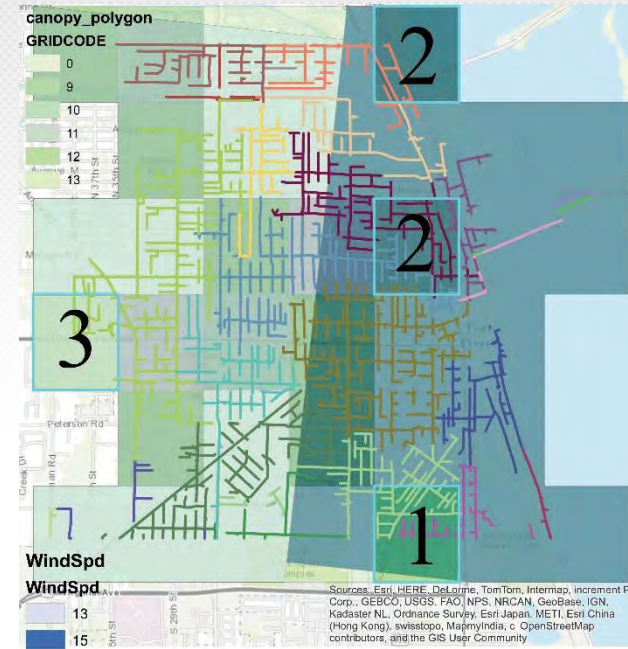
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Power system and wind data
(higher wind speed at right
hand side)



Power system and canopy
height data (darker green for
larger canopy height)



Identify the zones having
higher wind speed and larger
canopy height data

Corrective, adaptive and predictive relay features are feasible.

Such protection paradigm has distinct benefits but requires additional data or equipment.

Test results illustrate the robustness of the solutions.

Future steps are needed to identify other applications that may benefit from such a paradigm.



The practical use of such a protection paradigm is yet to be fully explored.

Thanks

