Poster Abstract: Distributed Reasoning For Diagnosing Cascading Outages in Cyber Physical Energy Systems

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Introduction: The power grid incorporates a number of protection elements such as distance relays that detect faults and prevent the propagation of failure effects from influencing the rest of system. However, the decision of these protection elements is only influenced by local information in the form of bus voltage/current (V-I) samples. Due to lack of system wide perspective, erroneous settings, and latent failure modes, protection devices often mis-operate and cause cascading effects that ultimately lead to blackouts. Blackouts around the world have been triggered or worsened by circuit breakers tripping, including the blackout of 2003 in North America[1], where the secondary/ remote protection relays incorrectly opened the breaker. Tools that aid the operators in finding the root cause of the problem online are required. However, high system complexity and the interdependencies between the cyber and physical elements of the system and the mis-operation of protection devices make the failure diagnosis a challenging problem.

Our Approach: The uniqueness of our approach is that it does not involve complex real-time computations involving high-fidelity models, but performs reasoning using efficient graph algorithms based on the observation of various anomalies in the system. It is based on constructing a system level discrete event model that captures the causal and temporal relationships between failure modes (causes) and discrepancies (effects) in a system, thereby modeling the failure cascades while taking into account propagation constraints imposed by the circuit topology, operating modes, protection elements, and timing delays.

We classify the system into 4 layers: Plant, Controller, Observer and Diagnoser. *Plant* layer is composed of physical components such as generators, transmission lines, loads etc. followed by *Controller* layer that includes discrete devices like relays and breakers. The *Observer* layer acts as a supervisory layer for components in the Controller layer. This layer informs the diagnoser regarding the faults in plant and controller layer components by tracking the behavior of protection elements in controller layer.The *Diagnoser* layer consists of reasoning engine that depends upon the failure propagation graphs, system state (as estimated from observable events) and observer reports for generating hypotheses regarding the active faults in the system.

[1]North American Electric Reliability Corporation, 2012, State of Reliability Report

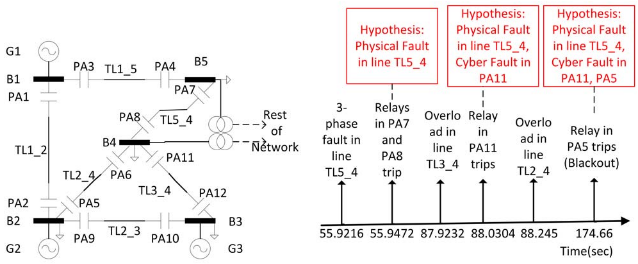

Figure 1: Diagnosis of blackout scenario in IEEE 14 Bus System

The diagnoser layer is composed of a distributed online diagnostic engine consisting of two reasoners. The first, called the Temporal Casual Diagram *TCD* reasoner is responsible for providing system level hypotheses associated to the failure modes attributed to devices in plant and controller layer. The second, called the *Cascade* reasoner lists the implications of the actions of protection devices in reaching an unstable system state. This is an extension of our previous work[2], which did not consider the cascade phenomena.

Example: The left side of figure 1 shows a standard 'IEEE 14 Bus' topology. Protection Assemblies, Buses, Transmission Lines and Generators are represented as PA_n, B_n, TL_n, G_n respectively. *PA* is a container for protection equipment namely distance relays (PA_n_DR) and breakers (PA_n_BR). The right side of figure 1 shows response of the reasoning prototype against a typical blackout scenario simulated in the Real Time Digital Simulator (RTDS). This example shows cascading blackout phenomenon where initially a 3-phase fault in induced in line *TL5_4*. The isolation of this fault by the protection equipments ensues an overloading of line *TL3_4* followed by mis-operation of relay *PA_11_DR*. The incorrect tripping increases current in line *TL2_4* forcing *PA_5_DR* to miss-operate, resulting in a blackout.

[2]N. Mahadevan, A. Dubey, G. Karsai, A. Srivastava, and C.-C. Liu . Temporal causal diagrams for diagnosing failures in cyber-physical systems. PHM 2014

978-1-5090-1772-0/16/$31.00 ©2016 IEEE