Title: AI-Based Protective Relays for Electric Grid Resiliency

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The Challenge

The protection systems (circuit breakers, relays, reclosers, and fuses) of the electric grid are the primary component responding to resilience events, ranging from common storms to extreme events. The protective equipment must detect and operate very quickly, generally <0.25 seconds, to remove faults in the system before the system goes unstable or additional equipment is damaged. The burden on protection systems is increasing as the complexity of the grid increases; renewable energy resources, particularly inverter-based resources (IBR) and increasing electrification all contribute to a more complex grid landscape for protection devices. In addition, there are increasing threats from natural disasters, aging infrastructure, and manmade attacks that can cause faults and disturbances in the electric grid.

The challenge for the application of AI into power system protection is that events are rare and unpredictable. In order to improve the resiliency of the electric grid, AI has to be able to learn from very little data. During an extreme disaster, it may not be important that the perfect, most optimal action is taken, but AI must be guaranteed to always respond by moving the grid toward a more stable state during unseen events.

The Opportunity

There are two critical needs related to protection for which AI is well-suited to provide solutions. First, there is a need for distributed, intelligent control, i.e. smart relays, or other devices. Traditional methods of protection are no longer able to cope with the complexities of a modern power grid. Second, there is a need for grid operators to have visibility into their system, particularly during extreme events, and AI methods can provide the decision advantage that can make the difference between riding through an event and catastrophic failure.

Thrust 1: Develop methods to synthetically generate training data (GANs)

In electric grid applications (and in many other DOE missions) there are very few, or no, examples of the resilience events of interest. Even for more common resilience events from fallen trees or other storm damage, there are not enough events for standard AI techniques, and there is even less data from extreme events. This requires that AI methods for synthetically generating realistic event data be developed. This may include using generative adversarial networks (GANs) to generate realistic data. It may also include few-shot learning, which is intelligently leveraging the few samples which do exist within an AI framework. This capability will be key for robust AI for resilient grid applications.

Thrust 2: Develop physics-informed methods to increase robustness to unseen events

Physics-informed techniques have already been demonstrated to reduce data requirements for neural network architectures and to improve the ability to extrapolate to unseen data. This will be a key AI methodology for electric grid applications because the interactions on the grid, although complex are well understood via traditional modeling methods, and there is a wealth of domain knowledge that could be leveraged in physics-informed ML architectures. This can provide an interpretable, non-black-box decision advantage for grid operators in control centers or locally on devices.

Thrust 3: Develop in-situ (edge computing) machine learning methods for distributed control

Reliable, resilient, and distributed control will be critical for the protection system of the future. The ability of devices to maintain control and operation despite communication failure or unseen extreme events is key for resilient operation. Developing AI methods that can be placed locally, in-situ on protection devices can provide that capability. There are many challenges related to distributed AI, including the evolving nature of the electric grid, limited computation locally on devices, and the complex interactions between devices.

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Timeliness of the Effort

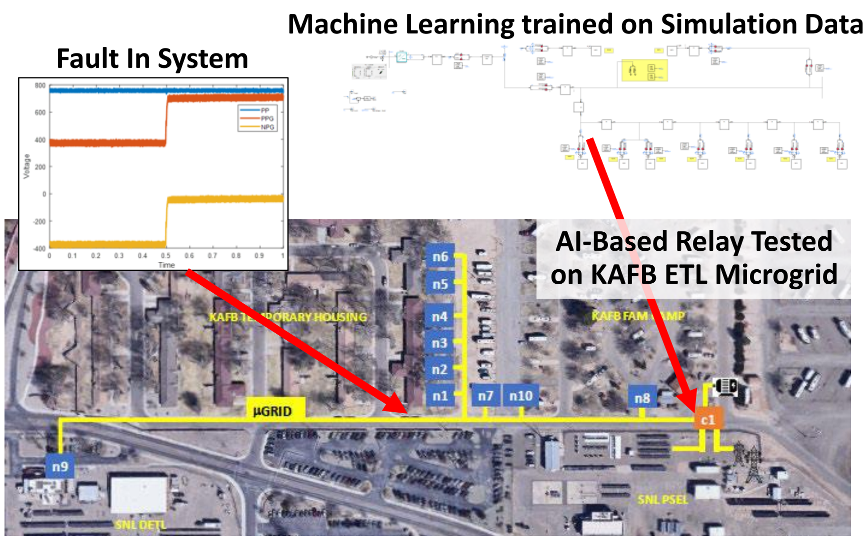
There are many recent examples of electric grid failures in the face of extreme events such as hurricanes or extreme winter storms; there are also many examples of more common outages that perhaps could have been prevented with more intelligent control and protection systems. Grid operators require more real-time insight into the systems and more distributed control is required; AI methods are poised to do both.

Recent cheap powerful local computational provides new opportunities for AI in protection. All decision-making must be made in fractions of a second based on local or nearby measurements. Traditionally, all power system protection was done with electromechanical relays, fuses, and circuit breakers. Digital relays and microprocessors have allowed for more intelligence in detecting faults, higher frequency sampling rates, and faster reaction times, sometimes even within 0.001 seconds. There is a need to modify our current protection architecture from digital logic processing to smarter AI-based methods.

The Impact

The impact would be a more resilient electric power grid to natural and manmade disasters. Cascading blackouts are often caused by incorrect settings in the protective relays [1]. Resilience is defined as "the ability to prepare and plan for, absorb, recover from, or more successfully adapt to actual or potential adverse events" [2]. AI will help the electric grid to absorb shocks and keep operating, manage the disruption to contain it, and respond quickly to recover to get back to normal as quickly as possible.

Example



References

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3. C. B. Jones, A. Summers, M. J. Reno, "Machine Learning Embedded in Distribution Network Relays to Classify and Locate Faults," IEEE Innovative Smart Grid Technologies (ISGT), 2021.
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