Cyber Physical Systems Requirements to Mitigate Stress Points by Introduction of Distributed Energy Resources into Scalable Grid Environments

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Abstract- ***The purpose of this paper is to describe the new approaches necessary to protect the new power grid This paper advocates the approach of protecting critical subnetworks as a reconfiguration strategy and assess the secure control system requirements to protect those critical subnetworks. As architectures, strategies, policies and technology black boxes are proposed; a methodology is required to evaluate the comparative increases in reliability and security obtained.***

To understand the scope, magnitude, and priority of risks associated with distributed potential intrusions in a large scale system composed of many critical subnetworks, this position paper will describe a framework for organizing, aggregating, and prioritizing risks to maintaining grid critical functionality.

I . INTRODUCTION

The US and world demand for electric services continues to grow in both quantity and complexity. National security and consumer demand continue to push public policy towards greater energy efficiency and have created a new focus on energy efficient services and clean, high quality generation sources. However, the security issues associated with this new complexity creates new vulnerabilities as well as opportunities to use the new interconnectivity to mitigate individual loss of individual components [Ref. 1-2]

New distribution end-use technologies, such as advanced automation and communications and plug-in hybrid electric vehicles (PHEVs), will dramatically change how utilities deliver electricity and how customers use it, allowing new efficiencies and greater customization of electric service.

Many Smart Grid technologies hold the promise of mitigating the effects of critical stress points on the grid. However, simplifying assumptions in the modeling of these technologies and an inability to dynamically characterize the grid where they are used have thus far prevented the wide-spread deployment of smart grid devices. If the security aspects of operating interdependent networks within a grid (critical sub networks) are not addressed, these deployments will be restricted even more. In essence, how do these new technologies allow us to operate trusted networks composed of untrusted components.

II. CHARACTERIZATION OF THE GRID INFRASTRUCTURE

Before proceeding with improvements to the grid, the grid's performance must be analyzed dynamically under a wide variety of load distributions. In this way the current analog-controlled electricity distribution infrastructure can be overlaid with a digitally monitoring and control smart grid.

In order to effectively model each grid configuration, it must be characterized dynamically under a variety of load conditions.

Advanced Metering Infrastructure (AMI) will become an enabling technology for understanding current and future demand response and developing grid performance metrics. As a result, modeling and simulation of infrastructure characterization will include these devices.

III. NODE PRIORITIZATION ANALYSIS

Node prioritization analysis is critical to determining and mitigating the effects of stress points on the grid. This analysis must be performed dynamically under a variety of grid configurations and load conditions. The state of millions of independent devices must be analyzed simultaneously and dynamically. The initial characterizations of the grid infrastructure will represent the baseline analysis and characterization of the current grid stress points [Ref 5-8].

Various combinations of Distributed Energy Resources (DERs), storage devices and other smart devices will be incrementally introduced into the model to identify their effect on grid stress points. Devices will be added to the model and the analysis will be performed iteratively under the same load conditions.

Metrics that characterize both overall grid and individual node performance in terms of state and timing will be identified and implemented into the model. Simulations will be used to perform node prioritization analysis for each node under each load variation and for each grid configuration. Node data will be analyzed collectively in order to determine node prioritization.

Metrics will include real time angle and volt stability and collapse detection and prevention via intelligent data, reactive power control based on intelligent coordination controls, fault analysis and reconfiguration schemes based on intelligent switching operations.

IV. PREDICTIVE IMPACT MODELS

Prediction and anticipation are essential stabilizing forces in any complex system. Predictive impact models enable the planning and implementation of a wide range of DERs, at all transmission and distribution levels. Complex, two-way interactions will be modeled and simulated. Node prioritization results will be used to predict system performance. In addition, predictive impact models will account for weather-driven non-scheduled renewable energy sources require new operational procedures. [Ref. 2]

By assessing health in real time, AMIs will enable the implementation of Demand Response (DR) programs for large industrial customers to individual consumers and their appliances. Distribution loadings will be monitored using data from downstream AMI. By monitoring equipment operating conditions against loading data, ambient conditions and designed limits, asset utilization and efficiencies can be optimized and equipment life can be extended.

Adaptive Dynamic Programming (ADP) will perform complex power systems prediction under uncertainty and enable decision making data on potential risks and weaknesses under wide ranging natural and man-made threat scenarios and stochastic demand levels.

Predictive impact models will help to reduce price volatility and create optimal responses from smart appliances. Smart meters, Intelligent Electronic Devices (IEDs) and diagnostic monitoring equipment will create cost saving opportunities and reduce the cost of operations, maintenance and system planning.

Some example systems include the ORNL STORAGE system. The Simulation Testbed for Outage, Restoration, and Analysis of Grid Evolution (STORAGE), is an agent-based simulation testbed integrated with grid-wide simulation models that resides within the Oak Ridge Mobile Agent Community. The STORAGE system has a baseline capability and is developing additional modular cabilities to forecast the national response to electric grid disruptions. STORAGE is a standing testbed capability consisting of the agent-based system interfaced to the service area/outage area estimator, and at the end of the second year a demonstration of the complete system ability to evaluate policy options.

This simulation system evaluates energy assurance and infrastructure vulnerability. The simulation system architecture is composed of “systems of systems” and their interfaces. This structure provides a standing testbed framework to model the evolution of the electric grid under future energy policy pathways such as water drivers (energy-water nexus) and mandated smart grid technologies.

The simulation system is actually composed of independent, interoperable modules of vastly different scales including a) a contingency toolkit, b) a transient system simulator, c) disruption restoration time estimator, d) a service area/outage area estimator, and e) a flexible interface that will permit policy option evaluation as different technologies are assumed to be deployed. The key system enabling this testbed is a simulation environment where 300 million agents model the population’s reaction to policy options.

V. OPTIMIZATION

The information from the grid characterization model, the node priority analysis and predictive impact model will be used to identify the anticipated power flow and the interplay between every part of the distribution system with every other part.

Model optimization will analyze the selection of energy sources and their full range of detailed electrical performance including the impact of future environmental and demographic scenarios

- Assess the available demand response capabilities
- Aggregate, schedule and issue demand response notifications
- Manage load groups
- Management and Trading of Renewable Energy Credits and Emission Allowances
- Improved Outage Management Functions
- Outage Restoration
- Equipment status
- Grid/Subgrid Configuration
- Switching Function Support

As with any power system performance is a compromise between efficiency and reliability with the goal of optimizing power flow along existing transmission. Energy operations such as distribution automation, load shedding programs and emergency operations can then be optimized.[Ref. 3-4]

Finally, visualization to quickly analyze network conditions and improve decision-making process will be performed. Systems such as the ORNL capability toolkit for wide area situational awareness will become much more important.

The capability toolkit, called VERDE – Visualizing Energy Resources Dynamically on Earth, takes advantage of the Google Earth® platform to display spatio-temporally informed power grid and related data. Custom libraries describe the electrical transmission network in the Eastern United States and the dynamic status of each transmission line. In addition to live status, VERDE provides a framework and mechanism to ingest predictive models, data from different sources, and predict outage and recovery scale and time estimates.

VI. IMPACT OF NEW TECHNOLOGY

Successful modeling and simulation of grid stress points and the mitigation of overstressed grid nodes using DERs will be transformational because it will enable future Smart Grid innovations. It will greatly improve our understanding of the smart grid and the DERs that help to mitigate the critical node stress under a dynamic range of conditions.

By increasing our understanding of DERs, this project promotes the reduction of GHG emissions. The increased use of DERs will reduce US dependence on foreign oil by creating energy closer to where it will be used.

The development of a standard modeling and simulation environment for the current and future grid, will strengthen America's role in the area of future smart grid development and the optimization of US grid efficiency.

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