Probabalistic Evaluation of a High-Altitude Electromagnetic Pulse on the Electric Power Grid

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Abstract— The possibility of a high altitude electromagnetic pulse (HEMP) event over the US is existent, although the pervasiveness of consequences to the power grid are unknown. This paper describes a Monte-Carlo [1] based methodology to probabilistically quantify the consequences of a HEMP event above the power grid. The approach uses three fundamental steps to characterize these consequences. First, evaluate the probability of failure and associated failure modes of select grid components, as a function of magnitude and direction of the EMP. Second, sample these distributions to determine a single possible HEMP scenario to grid components. Third, impose the failure conditions on a dynamic grid model, which includes system protection, and determine the short and long-term survivability of load. After load survivability has been determined, re-dispatch the grid and drop load, as required, to ensure system security is maintained, post EMP event. Results were created after one hundred scenarios were realized. Histograms were formed, and a PDF of short and long-term consequence was created.

Keywords-component; grid, power, power system, electromagnetic, pulse, EMP, HEMP, probability, Monte-Carlo

I. INTRODUCTION

A high altitude electromagnetic pulse event is an artifact of a nuclear explosion. Such explostions can be designed to minimize mechanical damage while maxizing electromagnetic pulses, which can wreak havoc in electrical and electronic gear. Many facilities have been designed to withstand EMP events, including many grid control centers, however, little is known about the systemic effects of an EMP event on the electric power grid and there has been insufficnent motivation to call drastic measure toward defenses. As an artifact of a nuclear explosion, much of the information about a HEMP event are withheld, although some fundamental information exists in open literature that may shed light on the potential consequences to the grid [2, 3].

Sandia National Laboratory has launched a three-part multi-year investigation into this topic area. The first part concerns achieving a better understanding of the consequences to grid components, such as transformers, relays, SCADA systems, and PTs and CTs due to HEMP exposure.

The second part, which is the focus of this paper, attempts to identify electric power grid systemic consequences from a HEMP exposure. And the third part focuses on the development of new material types to mitigate or prevent damage to the systemic effects of a HEMP event.

This paper contributes to early research concering the systemic consequences to the power grid from a HEMP event [4]. Given the nature and sensitivity of the topic area and the early stage of this research, the paper will demonstrate the methdolody using realistic, but simulated data. The induced EM effects on the power grid are calculated using generalized EM models applied to the IEEE RTS 96 system, which includes topology layouts.

An EMP event is defined by three phases [5]. Phase E1, peaking at about 50kV/m, peaks at about 2.56ns and has decayed to near zero before 0.1us. Phase E2, peaking at about 100V/m, occurs extends to several miliseconds, and Phase E3, less than 100mV/m, extends to 100's of seconds, appears very much like a geo-magnetic disturbance (GMD). Given the body of work accomplished on GMD events, and their analogy to an E3 event, focus was limited to E1 and E2 events.

II. PROBABILISTIC MODELS

Complex systems consist of many smaller subsystems, which may have independent (regional, local, etc) failure modes and failure rates specific to them. Traditionally, very high reliability is expected of each of these components to ensure reliable power delivery (i.e. adequate CAIDI and SAIDI operational indices) [13].

Reliability-focused engineering methods, such as Failure Mode and Effects Analysis (FMEA) [14], and reliability block-diagrams (RBD) [15] can help identify different reliability states and causal relationships, and have been used to identify and characterize the fault and failure events in complex systems such as power grids.

Induced system voltages due to a generalized EMP event are calculated for various initial conditions of the HEMP event with respect to the modeled transmission system. Probability distributions are created regarding the location, intensity, and duration of the induced voltages and currents induced onto the grid model, and FMEA analsyis is subsequently conducted, resulting in PDFs for grid component failures, given a HEMP event. These PDFs are sampled and used as part of a Monte Carlo analysis using a dynamic grid simulation to determine the probabalistic grid consequences of an HEMP event.