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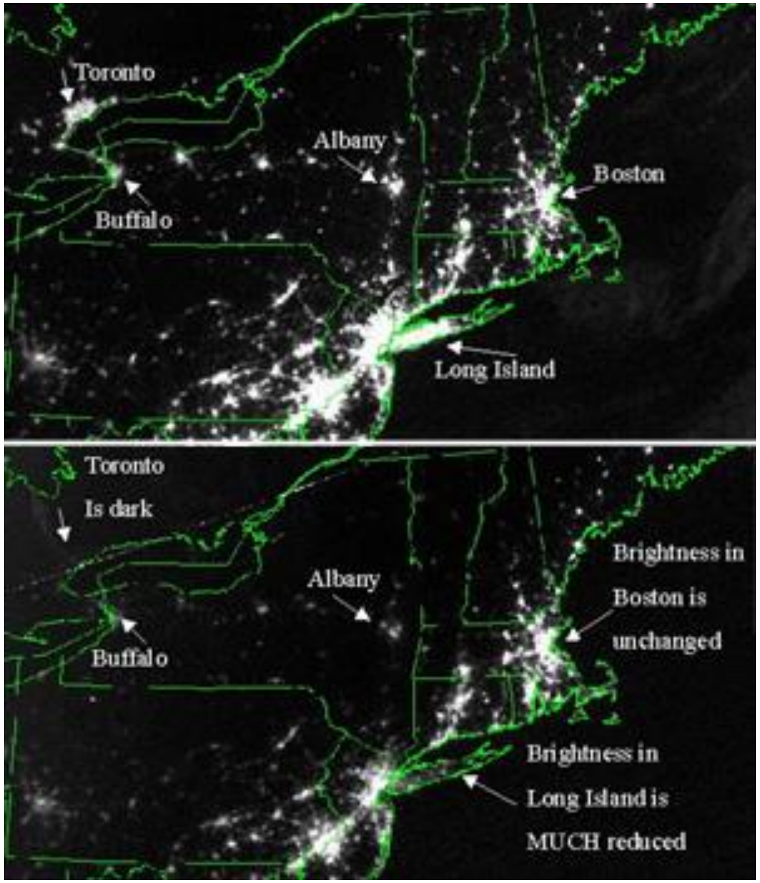
# An Overview of Restoration Issues and Black-Start Analysis

# Overview

- **Introduction and General Principles**
- **Restoration Plans and Procedures**
- **Blackstart Analysis**
  - Steady State Analysis
  - Dynamic Analysis
- **Black Start Units**
- **Concerns:**
  - Load-Frequency Control
  - Voltage Control
  - Load Rejection
  - Motor Starting
  - Self Excitation
  - Cold load Pickup
  - Switching Transient Overvoltages
- **Examples of Blackstart Analysis**




Source: Columbia University
Image Credit: NASA

## Introduction

- Extreme events can occur which may lead to a partial or total system blackout.

- Thus the ability to recover from such catastrophic events is necessary.

- Utilities have the responsibility to develop detailed restoration plans and procedures to restore the power system safely, efficiently, and as expeditiously as possible.

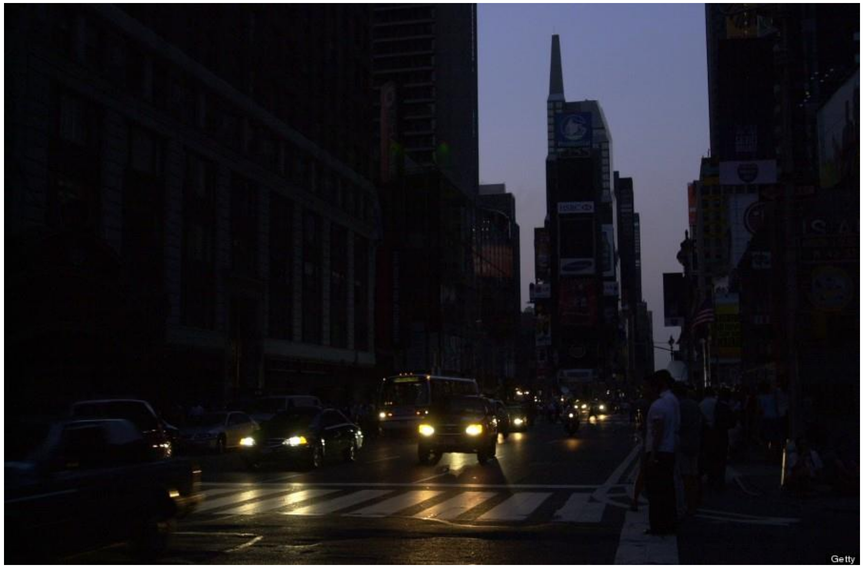


Image Credit: Getty

# Introduction

- Power system restoration issues can be broken up into:
  - Regulatory issues
  - Economic issues
  - Technical issues

- While the emphasis in the paper is mostly on the technical issues, the regulatory and economic issues are also very important.

# Regulatory Requirements

**Restoration plans and procedures must comply with national and regional requirements:**

- ISO System Restoration Requirements

- Regional Entities System Restoration Requirements (e.g., RFC, NPCC, MRO, WECC)

- NERC Emergency Preparedness and Operations (EOP) Standards
  - EOP-001-2.1b (Emergency Operations Planning)
  - EOP-005-2 (System Restoration from Blackstart Resources)
  - EOP-006-2 (System Restoration Coordination)
  - NUC-001-2.1 and 001-3 (Nuclear Plant Interface Coordination)

# Economic Issues

- Traditional vertically integrated utility structure
  - Utility was responsible for generation, transmission and distribution

- Market based structure
  - Different owners and operators for generation, transmission and distribution

- Common to both structures is the need to set clear requirements and compensation of the participants for fulfilling these requirements
  - Incentives for generation and transmission owners must be sufficient for them to not only offer these services but to diligently participate in the necessary testing and training required to implement them successfully when needed.

## General Principles

- Most outages are local events and restoration is handled by the local utility
- Outages involving larger geographic areas are less frequent, but require more complex restoration procedures
- Most outages involve only a portion of the power system
  - Restored with assistance from neighboring power grids
  - Complex process, but generally relatively straightforward
  - Tie lines from the outside power system are energized to establish one or multiple cranking paths as starting points used to energize the transmission system

## General Principles

- In the case of a wide spread blackout, there may not be help readily available from neighboring systems

- System restoration must begin from pre-selected generating units with the ability to start-up themselves, i.e., without requiring any external sources. These units are called blackstart units or blackstart resources

- Two major strategies
  - Top-down restoration
  - Bottom-up Restoration

# General Principles

- **Top-down Restoration**
  - Use blackstart units to energize the high voltage system
  - First establish a high voltage grid
  - Follow by the use of the sub-transmission network to reach selected power plants
  - Energizing lines in the bulk transmission system first is more difficult and will usually require larger generating units to be on-line
  - If successful, it will generally lead to a faster restoration of critical systems and loads

# General Principles

- **Bottom-up Restoration**
  - Use blackstart units to energize the subtransmission system
  - Energize paths to supply cranking power to larger generating units
  - Several simultaneous, independent “islands” are formed, which are eventually synchronized
  - EHV grid established when larger plants on-line
  - Can utilize smaller blackstart units
  - Generally more time consuming

# Blackstart Units

- **Hydroelectric units**
  - fast primary frequency response characteristics
  - steep ramping rate capability.

Source: Caterpillar

- **Diesel generator sets**
  - Usually require only battery power to start and can be started very quickly
  - Small in size

Source: Solar Turbines Incorporated

- **Aero-derivative gas turbine generator sets**
  - Requires only local battery power to start
  - Can pick up load quickly
- **Larger gas turbines operating in a simple cycle mode and steam turbine units**
  - Not in themselves blackstart capable
  - Coupled with on-site diesel generator sets to be a blackstart source
  - Time to restart and ramping capability a function of how long off-line.

# Fundamental Requirements for Restoration Plan

- Energization of initial cranking paths using overhead transmission lines to establish a stiff transmission backbone in the power system
- Cranking paths must include POIs to critical power plants and electrical ties to neighboring control areas
- Provide off-site power to Nuclear Plants
- Identify probable system areas for electrical islanding

# Restoration Plans

- **Detailed documentation of each cranking path**
- **Step-by-step description of the energization sequences**
  - Equipment to be switched at each step
  - Pre-switching requirements (e.g., generator voltage setting adjustments, checking of shunt reactor or capacitor bank status, etc.)
- **Staffing and communication requirements**
- **Training of control center staff and field staff**
- **Communication protocols**
- **Requirements of the BSR units**
- **Testing of the plans**

# Black Start Analysis - Typical Scope of Work

**Goal 1: Identify and verify cranking paths to provide off-site power to nuclear power plants and other priority generation and load**

**Goal 2: Identify and verify cranking paths using overhead transmission for all probable basic minimum power systems (BMPS)**

- Identify blackstart resources (BSR) locations that satisfy goals 1 and 2
- Creation of a Restoration Plan Data Base
- Determination of a viable restoration plan that complies with Regional Entities, FERC, NERC and NRC (U.S.)
- Training of utility personnel for updating and reassessment of Restoration Plan

# Key Facilities in Basic Minimum Power Systems

- ☑ Blackstart Resource(s)
- ☑ BSR critical components: stand-by generation, fuel supply, protection system, minimum load, communication system(s), DC resources
- ☑ Cranking path(s)
- ☑ Electrical island stabilizing load
- ☑ Reactive power resources (BSR Reactive Power Capability, shunt reactors)
- ☑ Black started generating resources
- ☑ Synchronization point(s) to other electrical islands: standing phase angle (SPA)

## Steady-state Analysis: Work to be Performed

- Building of electrical islands positive sequence network models
- Step-by-step build up of cranking path(s)
- Voltage profile:
  - BSR voltage schedule
  - Selection of OLTC/ULTC tap position
- Assessment of reactive power demand to BSR (leading and lagging)
- Assessment of the impact of the stabilizing load on electrical island voltage profile
- Ferranti effect – balanced switching
- Viability of cranking paths

## Dynamic Analysis: Work to be Performed

- Building of dynamic model set-up for the BSR
- Verifying tuning of BSR excitation system and governor/turbine system (OC voltage set-point step-test and load step test)
- Replacement of droop governor/prime mover system with a droop/isochronous governor/turbine
- BSR ability to control voltage in response to large induction motor start
- BSR ability to control frequency in response to large induction motor start or other load pickup
- Self-excitation assessment

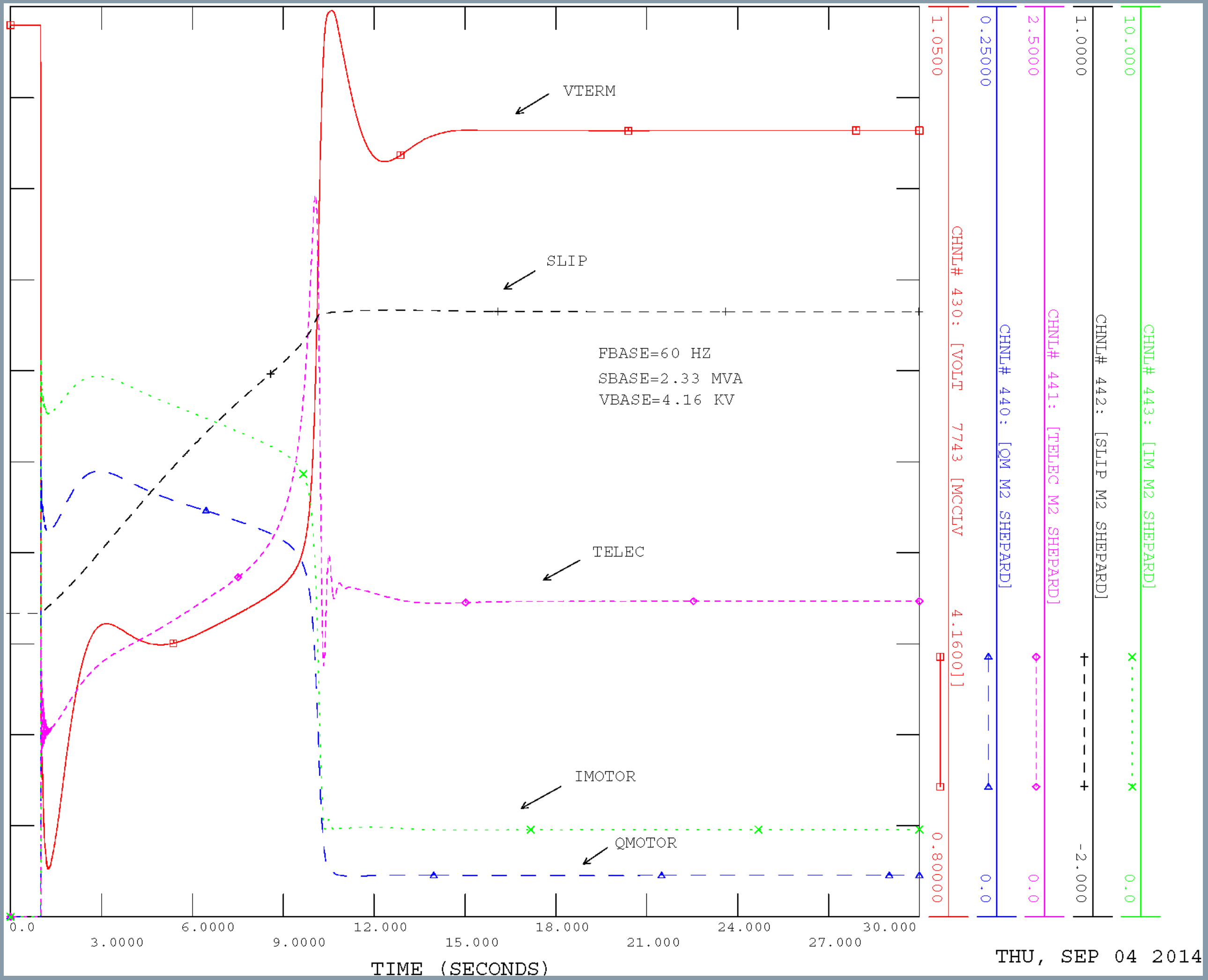
# Dynamic Analysis

- Frequency stability and BSR's governing response
- Dynamic voltage response to load pickup
- Load rejection
- Fundamental frequency over-voltage
- Self-excitation [ Bc > (1/Xq) pu on BSR MVA base]
- Synchronization of Electrical Islands

# Motor Starting

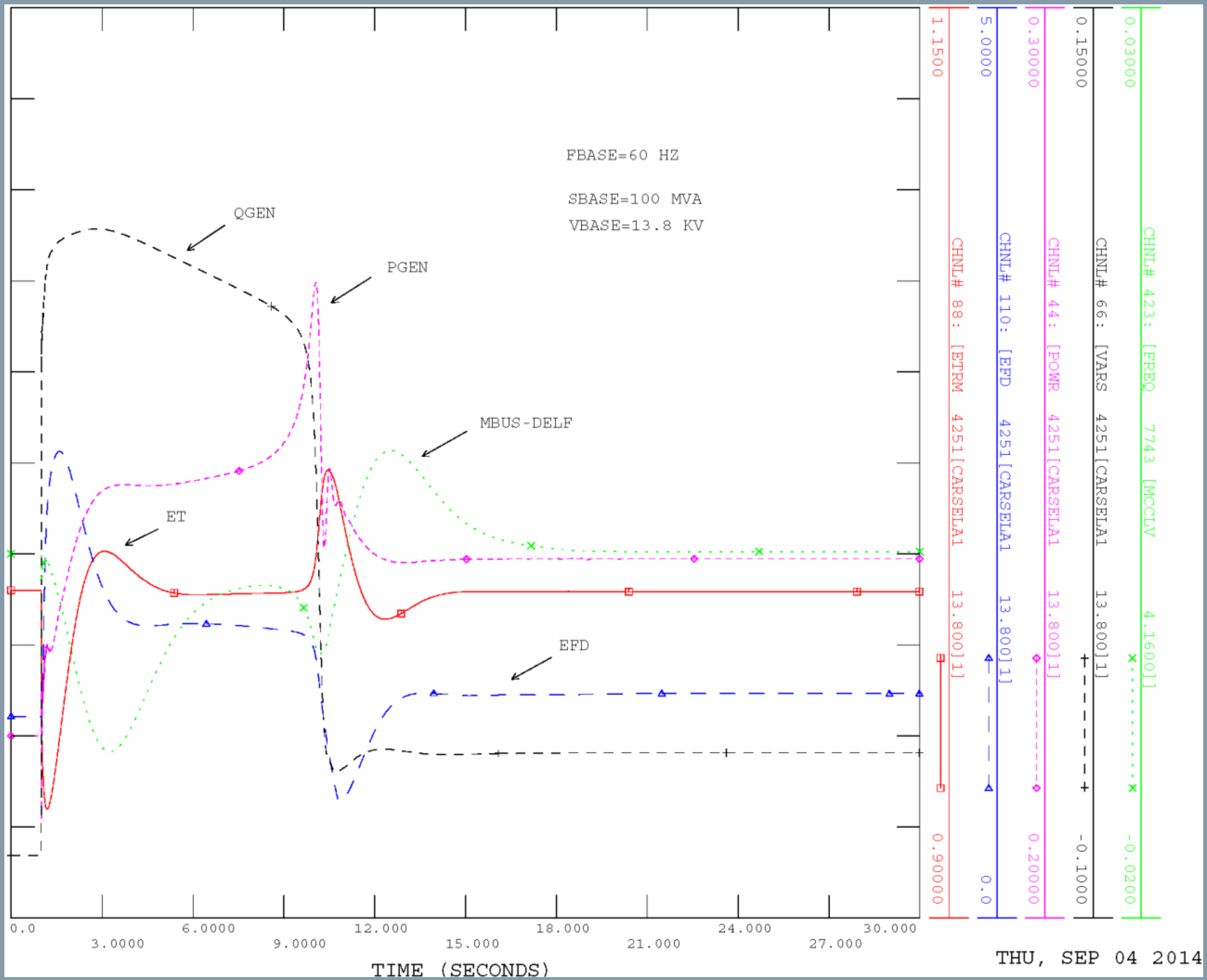
- Start-up of the auxiliary motors of a larger plant
- Range from several hundred to several thousand HP
- Starting method – often direct across the line
- Starting current typically 5 to 6 times motor load current
- Good motor data needed

# Example - Motor Starting Directly Across the Line



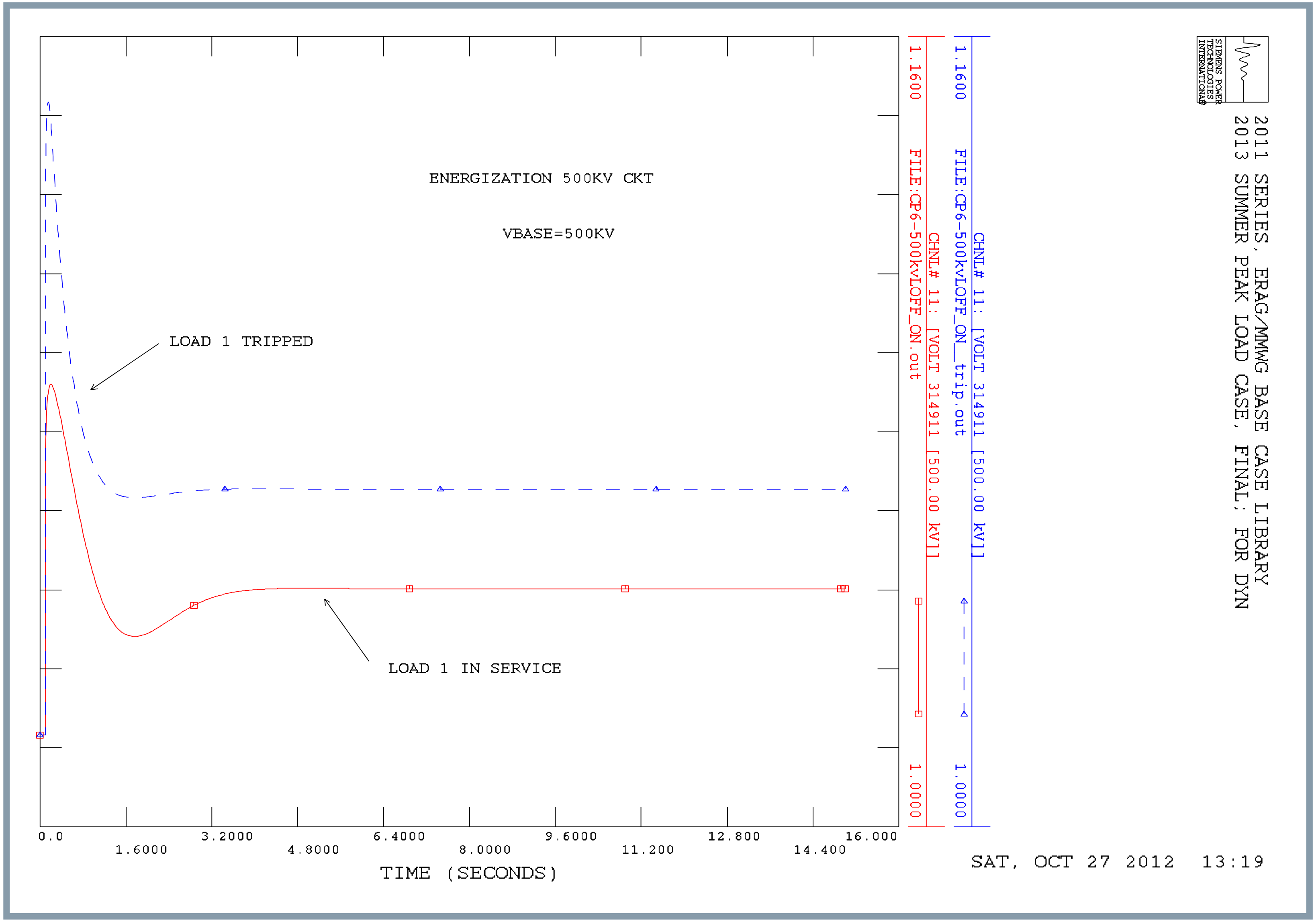

## Motor Response

# Example - Motor Starting Directly Across the Line



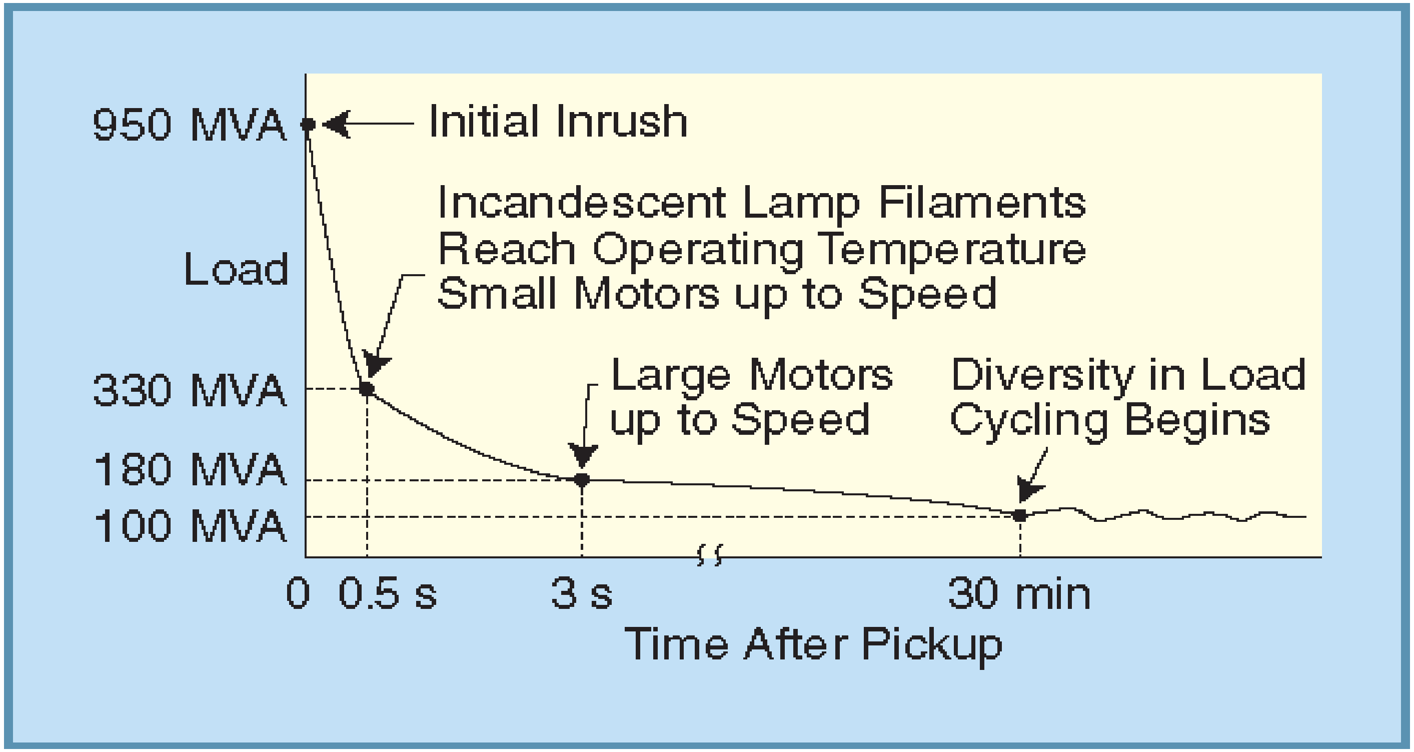

**Blackstart Unit Response**

# Example - Fundamental Frequency Over-voltage



# Cold Load Pickup

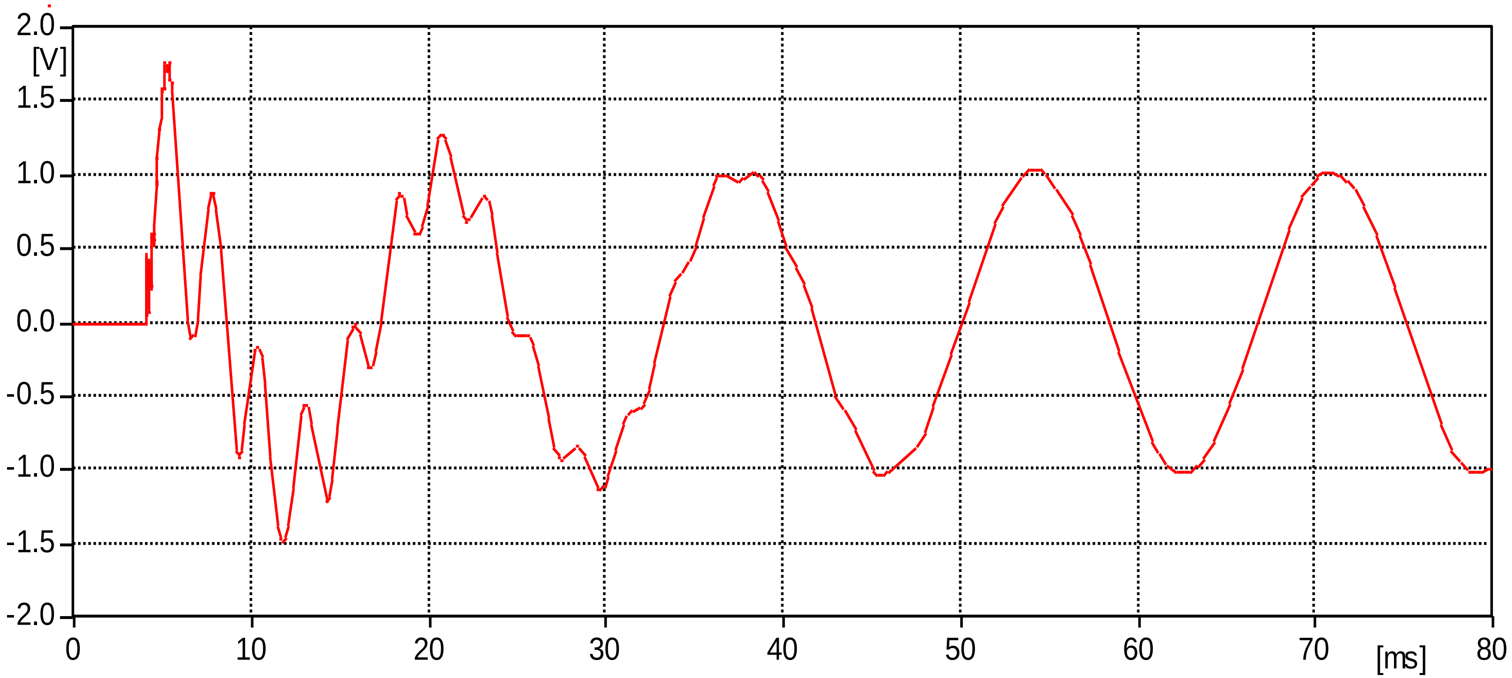
- The load you restore is not the load that was on-line when the blackout occurred
- Very dependant on the time the load was out and customer response



## Transient Analysis: Work to be Performed

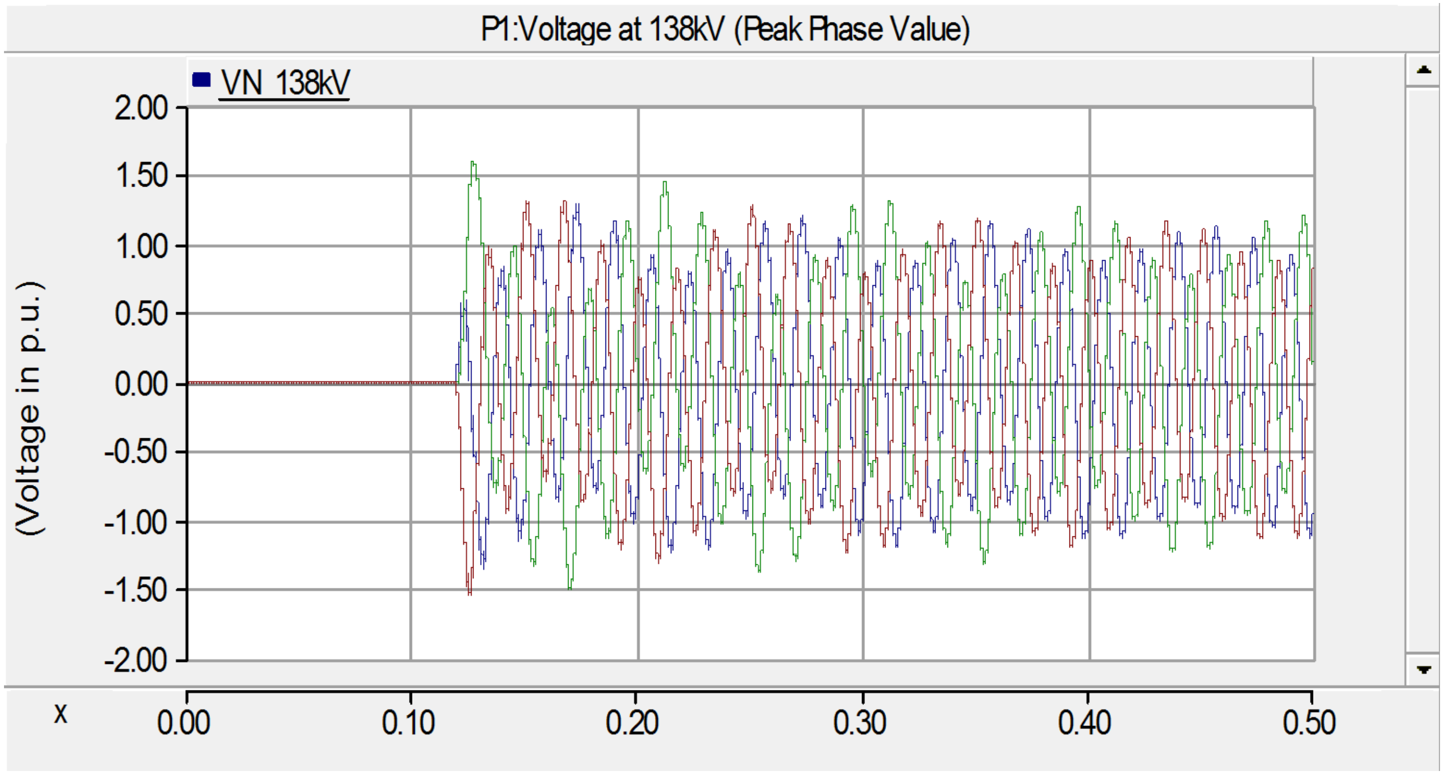
- **Build PSCAD/EMTDC (EMTP) models for those successful paths identified previously**
- **Conduct PSCAD/EMTDC studies of transient over-voltages for select cases**
- **Surge Phenomena and Electrical Resonance issues:**
    - Switching Surges from energizing transmission circuits
    - Temporary Overvoltages (TOV) from energizing large transformers
    - Surge arrester performance

# Example - Energizing of an Overhead Line




- **Voltage in per unit of nominal peak voltage rating**
- **Switching surges – high frequency components and decay quickly (few cycles)**

# Example - Energizing an Autotransformer Unit




**Temporary overvoltage (TOV) – longer duration**

# Questions?

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