System Failure- Anatomy of a Blackout- Part 2

An Online Continuing Education Course for Engineers

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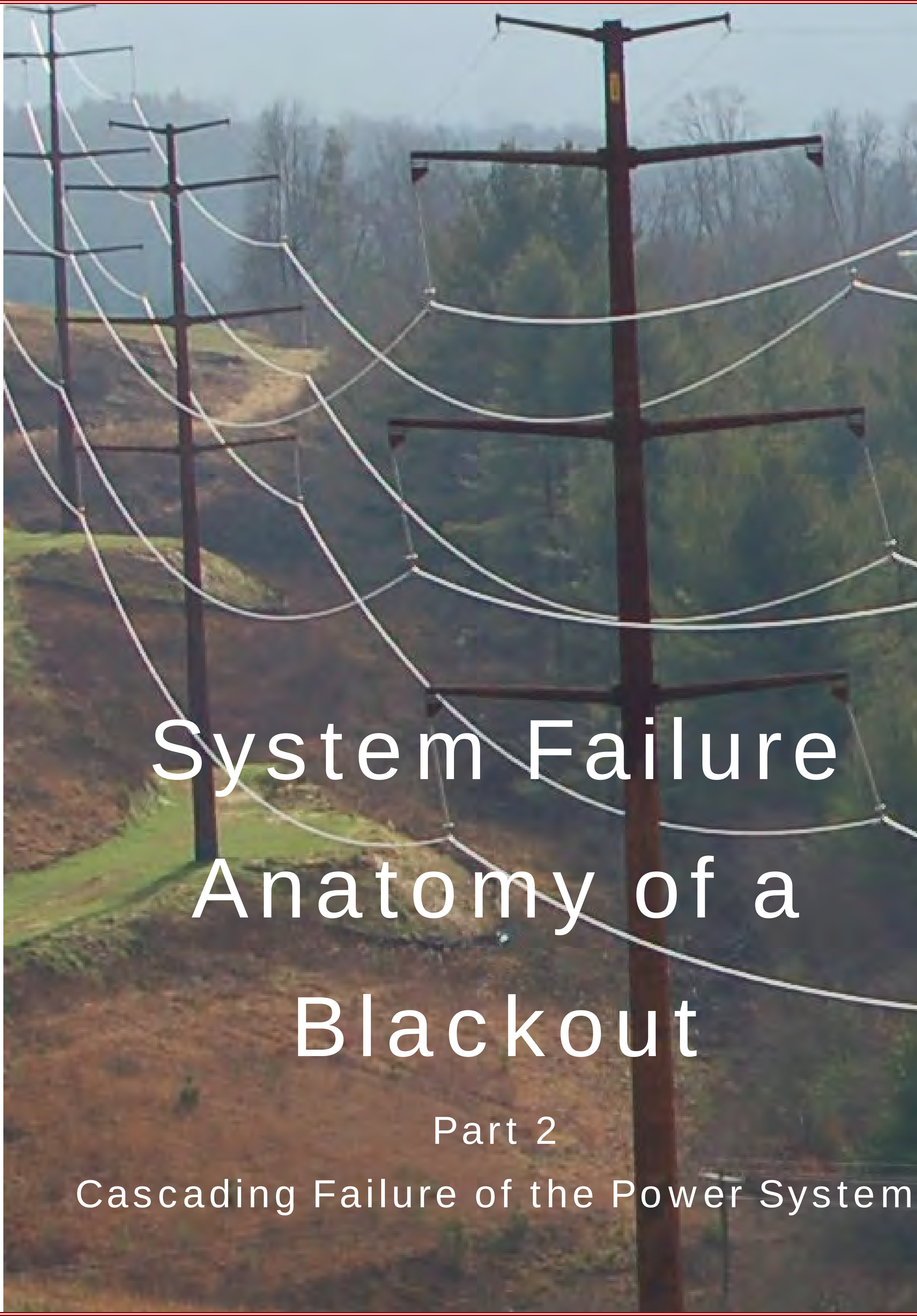

System Failure

Anatomy of a Blackout

Part 2

Cascading Failure of the Power System

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Preface

On August 14, 2003, just after 4 p.m. Eastern Daylight Time (EDT), the North American power grid experienced its largest blackout ever. The blackout affected an estimated 50 million people and more than 70,000 megawatts (MW) of electrical load in parts of Ohio, Michigan, New York, Pennsylvania, New Jersey, Connecticut, Massachusetts, Vermont, and the Canadian provinces of Ontario and Québec.

Although power was successfully restored to most customers within hours, some areas in the United States did not have power for two days and parts of Ontario experienced rotating blackouts for up to two weeks.

This course looks at the conditions on the bulk electric system that existed prior to and during the blackout, and explains how the blackout occurred. Note that since this report was originally written, several of the companies and organizations mentioned in the report have merged or reorganized.

Immediately following the blackout, NERC assembled a team of technical experts from across the United States and Canada to investigate exactly what happened, why it happened, and what could be done to minimize the chance of future outages. The scope of NERC's investigation was to determine the causes of the blackout, how to reduce the likelihood of future cascading blackouts, and how to minimize the impacts of any that do occur. NERC focused its analysis on factual and technical issues including power system operations, planning, design, protection and control, and maintenance.

This course is Part II of a two part series about the August 14, 2003 blackout. Part I covered the events leading up to the black and gave an overview of the conditions prior to the start of the system failure and described the conditions for the hours preceding the cascading failure of a large part of the Eastern Interconnect. Part II covers the actual cascading failure and describes how it spread, and finally stopped.

I. Background

The August 14, 2003 blackout affected the northeastern portion of the Eastern Interconnection, covering portions of three NERC regions. The blackout affected electric systems in northern Ohio, eastern Michigan, northern Pennsylvania and New Jersey, much of New York and Ontario. To a lesser extent, Massachusetts, Connecticut, Vermont, and Québec were impacted. The areas affected by the August 14 blackout are shown in Figure 1.

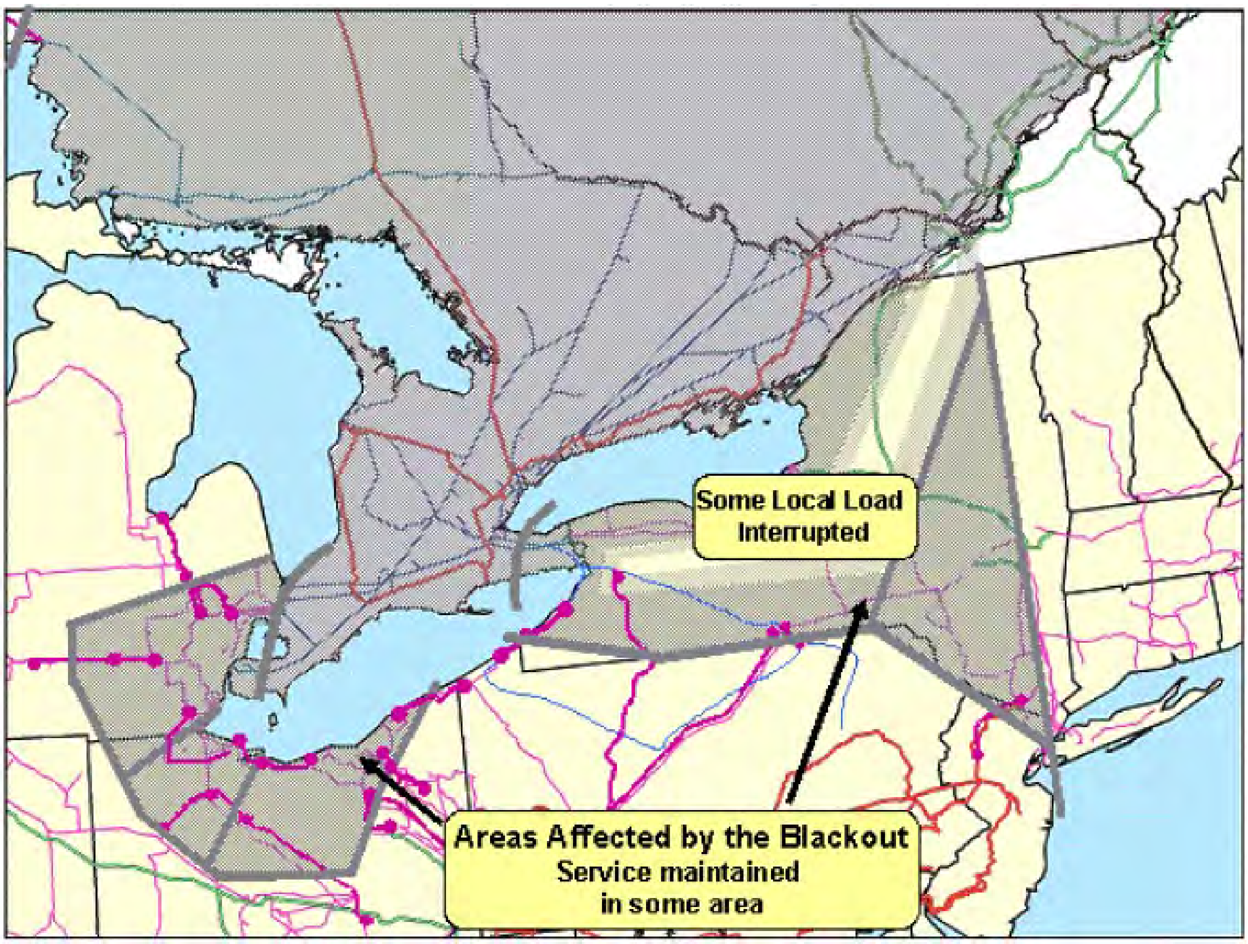


Figure 1 — Area Affected by the Blackout

Part I of this series described how uncorrected problems in northern Ohio developed to 16:05:57; the last point at which a cascade of line trips could have been averted. Part II details the sequence of events in the cascade, how and why it spread, and how it stopped in each geographic area.

The cascade spread beyond Ohio and caused a widespread blackout for three principal reasons.

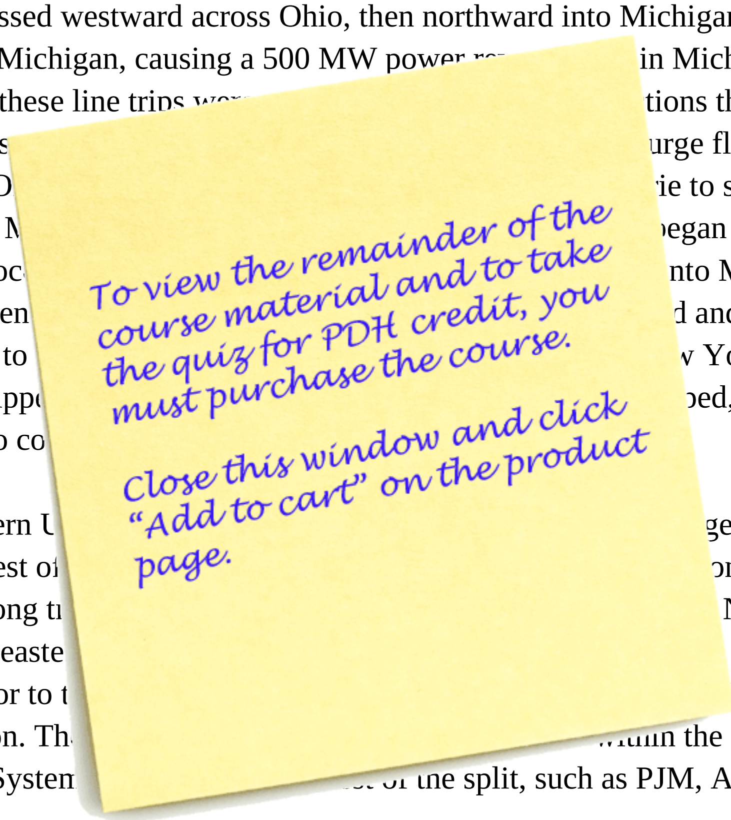
1. The loss of the Sammis-Star line in Ohio, following the loss of other transmission lines and weak voltages within Ohio, triggered many subsequent line trips.
2. Many of the key lines that tripped between 16:05:57 and 16:10:38 operated on impedance relays, which responded to overloads rather than faults on the protected facilities. The speed at which they tripped accelerated the spread of the cascade beyond the Cleveland-Akron area.
3. The evidence indicates that the relay protection settings for the transmission lines, generators, and under-frequency load shedding in the Northeast may not be sufficient to reduce the likelihood and consequences of a cascade, nor were they intended to do so. These issues are discussed in depth below.

II. How the Cascade Evolved

A series of line outages in northeastern Ohio starting at 15:05 caused heavy loadings on parallel circuits, leading to the trip and lock-out of the Sammis-Star line at 16:05:57. This was the event that triggered a cascade of line outages on the high voltage system, causing electrical fluctuations and generator trips such that within seven minutes the blackout rippled from the Cleveland-Akron area across much of the northeastern United States and Canada. By 16:13, more than 508 generating units at 265 power plants had been lost, and tens of millions of people in the United States and Canada were without electric power.

The collapse of the FE transmission system induced unplanned shifts of power across the region. Shortly before the collapse, large - but normal - electricity flows were moving through the FE system from generators in the south and west to load centers in northern Ohio, eastern Michigan, and Ontario. Once the 345-kV and 138-kV system outages occurred in the Cleveland-Akron area, power that was flowing into that area over those lines shifted onto lines to the west and the east. The rapid increase in loading caused a series of lines within northern Ohio to trip on impedance relays. A "rippling" effect occurred as the transmission outages propagated west across Ohio into Michigan. The initial propagation of the cascade can best be described as a series of line trips caused by sudden, steady state power shifts that overloaded other lines — a "domino" effect.

The line trips progressed westward across Ohio, then northward into Michigan, separating western and eastern Michigan, causing a 500 MW power re… in Michigan toward Cleveland. Many of these line trips wer… …tions that accelerated the speed of the line trips… …urge flowed from PJM into New York and O… …ie to serve the load still connected in eastern M… …egan after 16:10:38, and large power swings oc… …nto Michigan across the Canadian border. Then… …d and peaked at 2,100 MW from Michigan to… …w York saw massive power swings and tripp… …ped, leaving northwestern Ontario co…



The entire northeastern U… …ge electrical island separated from the rest of… …on split initially occurred along the long t… …New York, and then proceeded into northeaste… …which had been importing power prior to t… …ve transient swings and system separation. Th… …ithin the island to meet electricity demand. System… …of the split, such as PJM, AEP, and others