



## **Approaches to Resilience at TVA**

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### **SUMMARY**

The Tennessee Valley Authority is exposed to a wide range of high impact events. With the exception of tsunamis, all natural events including ice storms, tornados, floods, earthquakes, derechos, hurricanes, geomagnetic storms, and thunderstorms can occur in the TVA region. Like many others TVA is also exposed to man-made events including physical attacks, cyber attacks, and EMP and IEMP.

A resilience matrix format proposed by the North American Transmission Forum and EPRI has been adopted as a useful means of documenting high impact risks and how TVA develops resilience to them. The matrix serves as a single point for analyses, emergency and operating plans, procedures, and associated publications and is a useful reference during emergency events as well as a guideline for further improvements and an education source for employees.

This paper describes both the matrix and measures that TVA has taken to improve resilience.

### **KEYWORDS**

Resilience, high impact low frequency (HILF) risks, Geomagnetic disturbance (GMD) events, electromagnetic pulse (EMP , HEMP, IEMP), earthquakes, severe weather, floods, cyber attacks, physical attacks.

### **INTRODUCTION**

The Tennessee Valley Authority service area with the State of Tennessee and portions of six surrounding states covers 80,000 square miles, approximately 450 miles east-west and although irregular in shape, some points almost 400 miles north-south. The transmission grid consists of 2500 miles of 500 kV overlaying 11,500 miles of 161 kV, and is relatively densely interconnected so line lengths average 35 miles. There are eighty-five 500/161 kV transformer banks from various manufacturers with a range of designs dating from the earliest units in 1965. The two largest cities are Nashville and Memphis each with approximately 2 million residents in the cities and outlying areas.

The location and reach of the TVA system expose it to a wide range of natural events. Notable recent occurrences are the Kentucky ice storm of January 2009, heavy rain in May 2010 causing a river crest 25.5 feet above flood stage with severe flooding, and the multiple Tornado storm of April 2011. Severe thunderstorms with local strong winds and isolated tornados are common. Although the TVA service area is relatively southerly, GMD storms in 2000 and 2003 caused harmonics leading to nuisance trips of 161 kV capacitor banks. Earthquakes are often detected in the New Madrid region at the western end of the grid and also in the East Tennessee Earthquake Zone, but continue to be minor.

As public reactions to the power sector's recovery from Katrina, Hurricane Sandy, and in a different way Fukushima have shown, expectations have evolved and become more demanding. A grid is required to provide connectivity to transport power with minimal environmental impacts; it is required to be adaptable to changing types and locations of generation at relatively short notice; and it is required to provide reliable and high quality power in all circumstances. If extreme events occur it is expected that the grid will be resilient, both resistant to the events and quick to recover from them. As a rule of thumb, the limit of tolerance for loss of residential supply is considered to be three days. Emergency supply systems such as at hospitals, water plants, and critical industries are designed with the assumption that power will be restored quickly.

Regulatory and legislative agencies are increasingly active. In 2013 several States including New York, Oregon, and Maine released documentation relating to emergency planning. FERC and NERC have been active in Standards such as CIP-002, CIP-014, and TPL-007. DHS, DOE, NATF, NIST, and EPRI have all released reports and studies within the last 3 years. A follow-up report is also anticipated in 2017 from the reinstated Commission on EMP. At the Federal level we have the FAST Act and The National Defence Authorization Act, both in 2016, which anticipate federal control of the grid in a national emergency.

In addition to regulatory actions, power utilities are seeing increased interest in alternative supplies such as microgrids. While microgrids would not seem to be more resilient or reliable than the grid, their small size may provide an alternative to a backup or emergency supply.

## **RESILIENCE MATRIX**

Recognizing the difficulties of discussions without a framework, in October 2014 the North American Transmission Forum and EPRI proposed a matrix approach to risks. For each natural or man-made hazard, a matrix would document information on Assessment, Prevention and Hardening measures, Detection and Monitoring, and Recovery and Restoration. This would facilitate comparisons and enable superior practices to be identified and research topics defined to fill knowledge gaps.

TVA adopted the proposed format, expanding the risk categories to 12 and increasing the categories of information to 11, ranging from a basic description of the risk phenomenon to identification of Subject Matter Experts.

Figure 1 illustrates the TVA matrix in its present form. Once the format was established, it took approximately six months to complete the information for each risk.

The benefits of the matrix became increasingly clear as the material developed. First, it became an excellent repository as a single point location for documents, reports, and reference material that might otherwise be hard to find in different locations. Second, it serves as an excellent resource for educating new employees in past and present risk assessments and responses. Third, although not intended as a primary reference, it provides a useful backup information source in emergency or drill situations.

	CYBER ATTACK	EARTHQUAKE	EMP	GAS-ELECTRIC INTERDEPENDENCY	GMD	MAJOR EQUIPMENT	PHYSICAL ATTACK	SEVERE FLOODING	SEVERE STORMS	SINGLE POINT FAILURE	WORKFORCE AND SUPPORT	COMMUNITY RESILIENCY
Assess (Design Basis)	●	●	●	●	●	●	●	●	●	●	●	●
Prevent/Harden (Design Changes, Projects, etc.)	●	●	●	●	●	●	●	●	●	●	●	●
Detect/Monitor	●	●	●	●	●	●	●	●	●	●	●	●
Operating Guides	●	●	●	●	●	●	●	●	●	●	●	●
Recover/Restore	●	●	●	●	●	●	●	●	●	●	●	●
Emergency Checklist	●	●	●	●	●	●	●	●	●	●	●	●
Drills	●	●	●	●	●	●	●	●	●	●	●	●
Operational Integration	●	●	●	●	●	●	●	●	●	●	●	●
References	●	●	●	●	●	●	●	●	●	●	●	●
Subject Matter Experts	●	●	●	●	●	●	●	●	●	●	●	●

Figure 1: Resiliency Matrix as Adapted by TVA

The matrix has now been complete for over a year and its first revision is under way. It is not clear whether this should be an annual revision or whether a longer period could be allowed. Clearly as risk and threat discussions expand and risk mitigation thoughts mature the matrix will provide a format that can be expanded as needed. An example of that is the role that communications plays in many threats and it has become increasingly clear that hardened communications to load centres and power plants is needed along with a tactical system that can be deployed

## RISKS

The following sections briefly describe a selection of both high and low probability risks and some of the actions that TVA is taking to improve resilience.

### Cyber

The energy sector is an obvious strategic target and reported attacks on TVA infrastructure are escalating. In FY 2016 almost 14 billion events were visible against TVA operating technology of which 491 million were classified as potential security events and over 54000 required additional action. Key approaches, defence in depth, NERC CIP, NISF/FISMA, continuous monitoring, security vulnerability scans, equipment review audits, assessments, participation in EISAC and practice incidence response drills.

### Earthquake

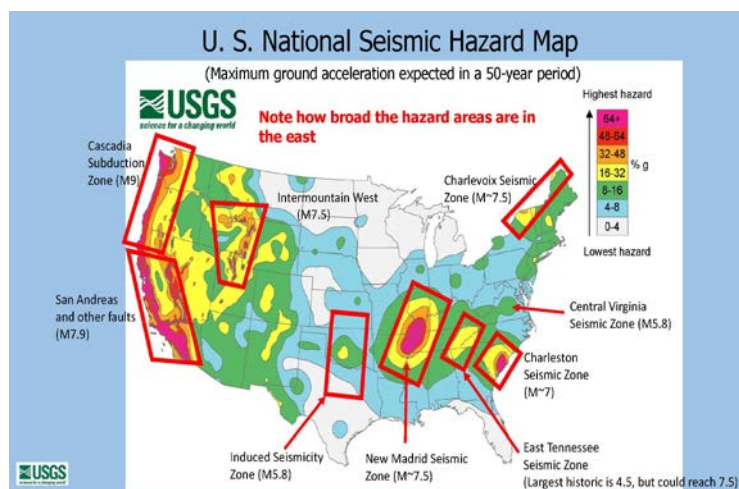


Figure 2: Earthquake Zones Affecting TVA

The New Madrid seismic zone which produced extreme seismic activity in 1811-1812. According to USGS a similar event has a 7 - 10% probability over the next 10 years. As shown in Figure 2 from the USGS, the East Tennessee Seismic Zone also has potential for strong events.

TVA started modifying substation design standards in the 1990s to enhance their survivability by tying down transformers, using seismically qualified equipment, and most recently, reinforcing existing masonry switch houses including anchorage of roof and relay racks.

### **GMD and EMP**

TVA has been proactively addressing GMD since the early 1990s. A network of 12 GIC detectors is being augmented with 12 magnetometers and studies have been performed with a system GIC model. Nuisance trips in the early 2000s have been addressed with replacement of vulnerable relays. Since January 2015, for the 10 GMD storms noted as K5 through K8 events on the EPRI Sunburst system the maximum GIC measured in 500 kV transformer neutrals at TVA has been less than 17 amps.

Hardening against EMP is being developed with participation in the EPRI EMP project and plans for a new fully shielded operating centre.

### **Gas-Electric**

Gas-electric interdependencies have been getting additional nation-wide attention in various studies. TVA specifically looked at one additional aspect that does not receive widespread attention. Traditionally pipeline companies self generate for their pumping stations but due to environmental quality regulations pipeline companies are converting to electric grid supplied pumping stations.

As TVA continues its transition to increased gas generation, we have worked with gas suppliers to identify all pumping stations supplied by the grid and identify power plants where gas supplies might be affected in the event of grid outages, with the intent of understanding how to prioritize restoration of these loads.

### **Major Equipment**

No resiliency plan can succeed without a very deliberate analysis of our needs under various scenarios. Utilities today operate equipment from the turn of the 20th century to the present and our EHV systems date from the 1960s.

In 2003 TVA analysed its transformer fleet, determined back-fit plans for transformers and established a small set of approved standard designs that today provide TVA with a high degree of interchangeability of EHV units, both in service and as spares. Spare bushings and components for these standard units are also stocked.

In addition we have a mobile transformer fleet, mobile switch houses with racks and portable truck-mounted GID switchgear. We have a large transformer oil reprocessing capability to support spare transformer relocations.

Recently we studied direct tornado hits on 500kV stations, identified vulnerable long lead-time equipment, did a gap analysis against existing stocks of spares, and began purchasing additional inventory specifically to speed restoration.

### **Physical Attack**

TVA has done extensive studies to identify levels of load loss or generation loss that posed a threat to stability of the grid and to identify stations that could also pose a threat. TVA's preferred way of dealing with critical infrastructure is to provide added levels of redundancy

that mitigates the risk. Improved high speed relays and protection schemes are also being deployed to address the simultaneous loss of a substation as a result of a physical attack in steady state and dynamic analysis. TVA like other utilities is making improvements in physical and process systems for detection intrusion and tampering, card readers, alarm contact, video monitoring, camera analytics and the use of new anti-cut anti-climb anti-ram fences.

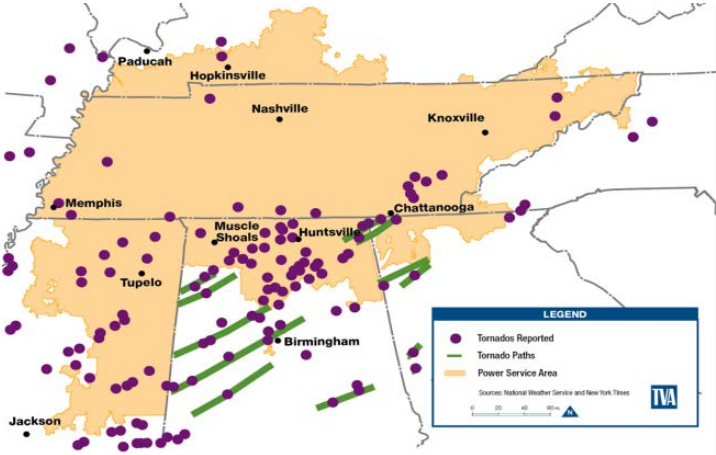
**Flooding**

In May 2010 15 inches of rain in two days in Middle Tennessee resulted in water levels over 25 feet above flood stage. One of TVA’s substations had water over five feet deep.

TVA relocated this station to higher ground and did an evaluation of all substations and switching stations considering 1% annual chance (1 in 100 year) events, 0.2% annual chance (1 in 500 year) event, regulatory floodways, special floodways, and maximum probable floods. The goal was to evaluate threats to the bulk grid and also evaluate whether local supply stations had adequate redundancy to cover the power supply need if a local station was flooded.

**Storms - Ice, Tornadoes**

Extreme weather events are the traditional emergencies we have all dealt with throughout our careers and a successful response requires a combination of well thought-out design standards (what you expect your system to withstand) and the material inventory, labour, and equipment support to rapidly begin restoration.



*Figure 3: Tornado Storm in April 2011*

In TVA’s case we have records of severe weather across TVA’s footprint since pre-TVA days with documentation of what emergency material was required in each case to restore service, and used that as the basis of our emergency stocking plan. Conscious decisions have been made on which structures offer the greatest flexibility for restoration and we also stock supplies of the steel core wire (a long lead item) for our common conductor sizes which can in an emergency be sent to a conductor manufacturer to speed up replacements.

**Workforce Support**

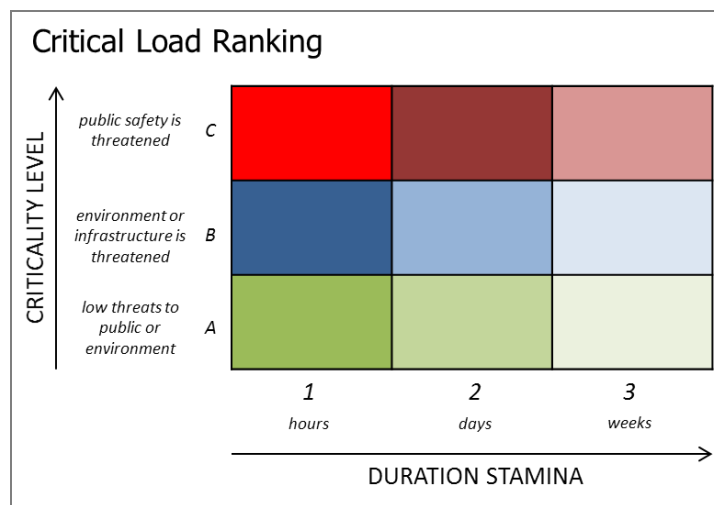
The workforce and support function cannot be overlooked as a part of an overall emergency plan. This requires planning for the availability of skilled labour and the ability to house, feed and maintain them in emergency areas. Agreements with labour organizations, mutual assistance agreements, logistical support including fuel sustainability (gasoline, diesel, aviation fuel and propane) become critical. The ability to pre-locate teams pre-loaded with

materials in certain conditions such as anticipated severe storms where post-storm access may be restricted is also part of our planning.

Recently we have enhanced our planning in the heavy haul area through the use of scenario evaluations that presume a requirement to move significant numbers of large power transformers.

**Community**

For any of the low-probability/high-impact events such as EMP/GMD that might damage large portions of the grid, it may become necessary for large numbers of the public to be able to wait out events at home. To do this potable water and waste water systems must have a high degree of priority during recovery. Community resiliency is about fully understanding critical loads in the local communities and integrating that information in emergency plans. The critical loads could also involve others of the 16 critical infrastructures that pose risks to the public or are needed immediately to support national interests.



**Figure 4: Identification of Critical Loads for Community Resiliency**

**CONCLUSIONS**

TVA’s extreme grid planning ensures that we provide the connectivity and flexibility to meet our mission of service and reliability commitment to the nine million consumers of the Tennessee Valley.

Grid resiliency activities are being factored into our regional grid planning studies and discussions are being held with our local power companies to enhance community resiliency. Outreach discussion and collaboration with State Emergency Services have been well received and will improve how we work together in the event of real emergencies. Our next steps in the evolution of our plans will be the enhancement of communication with generating plants and load centres together with visibility of the grid during emergency operations.