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Topological Analysis of Transmission Networks to Identify Vulnerable Links.

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ABSTRACT

Electric Transmission System (ETS) is a highly interconnected and dynamic system catering to the power needs of a country. ETS, a potential target, is susceptible to internal as well as external threats like disruption of infrastructure utilities and natural disasters. Such disruptions might have a cascading effect on the integrated system, resulting in mass blackout over a wide area for a prolonged time, leading to chaos and confusion. The links that have high connectivity and weak control access are vulnerable to threats, leading to devastation. This paper proposes a method to identify the vulnerable links of a transmission system by computing the connectivity of the transmission network.

Keywords: Permanent of a matrix, Complex systems, Connectivity, Blackout

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Power Transmission System

Electric power system is one of the largest engineering system which spreads across the whole country to supply power to millions of people produced by a few thousand generating units. The system consists of a power generating unit, transmission lines to transmit power and the load where it is consumed. Due to mismatch in number between the generating units and population, the network is bulkier and complex. There is an evolution from disjoint electric networks with small loads to highly integrated networks catering to the needs of the whole country. The demand in power has increased in many folds over the years due to wide scale industrialization across the country. Industrialization is the first step towards a nation becoming an economic powerhouse and cannot be compromised upon.

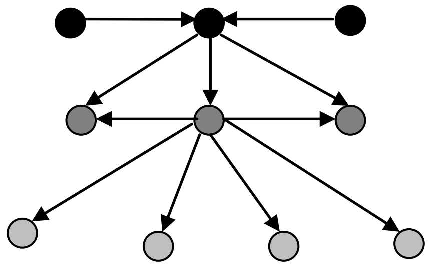

Fig 1: Topology of a power transmission system

To achieve a reliable and sustainable electricity supply, proper planning, operation and management should be put into practice. ETS should strike a balance between commercial and domestic use. The capacity of a transmission line is defined as the maximum load the line can accommodate from a generating node to the consumer nodes subjected to generator and transmission capacity constraints. Modern transmission systems are acquainted with long distance transmission, to provide power to far flung areas, considering the capacity of transmission lines. Infrastructure should be stepped up so as to meet the innovations, demand and constraints of the network.

Transmission System as a Complex Network

There is a transformation from a decentralized transmission system to an optimized central transmission system in the recent past, making the system more complex. Synchronization of regional grids helps in transferring power from a resource centric region to load centric regions. The transmission system is facing an unprecedented challenge of an ageing infrastructure, since no step has been taken to upgrade the system. Black out is a phenomena which makes the transmission system impaired due to faults like ageing and overload.

A non collapsible transmission network is required to provide uninterrupted power supply to the people. The transmission line which is vulnerable to blackout should be guarded properly with adequate infrastructure and maintenance. On the forehand, potential links which are highly connected and whose failure should cause chaos among the people be identified. These links with high connectivity, when impaired, have a cascading effect on the adjoining terminals. A mathematical model depicting the connectivity of the transmission system is in the need to analyze the vulnerable links.

Connectivity Matrix of ETS

Vulnerability of transmission lines using connectivity can be analyzed using graph theory approach. It is difficult to model the topology of an electric transmission system as the system is complex. A directed graph represents the flow of energy between two terminals of a transmission system. Directed graph *G*, is the best method to represent a transmission system since the flow of energy is complex and directional. Adjacency matrix, an equivalent to directed graphs is used to represent the transmission system using binary values. Adjacency matrix A_{ij} is given by

$$A_{ij} = \begin{cases} 1, \text{if an edge exist} \\ 0, \text{if an edge doesnt exist} \end{cases}$$

The adjacency matrix thus constructed gives the existence of direct linkages between the terminals in a transmission system. However the indirect links in the system also needs to be identified to predict the cascading effect on the adjacent terminals of the system. The direct as well as the indirect links of a terminal can be computed using the permanent operation on the adjacency matrix A_{ij}. Permanent *T*, of a matrix is given by

$$T_{ij} = |\min {}^{\bullet} A|^{T}$$

The computed matrix gives the connectivity between the nodes 'n' and grows factorially with *n*. The permanent operation calculates the number of times a particular link is crossed during transmission.

Consider a general matrix A, where

$$A = \begin{bmatrix} a & b & c \\ d & e & f \\ g & h & i \end{bmatrix}$$

Permanent of the above matrix is given by

$$T = \begin{bmatrix} aei + afh & bdi + bfg & cdh + ceg \\ dbi + dch & ecg + eai & fbg + fah \\ gec + gbf & hcd + haf & iae + icd \end{bmatrix}$$

Using the above technique the connectivity of each and every node in a network can be computed. The node with the highest connectivity should be identified and necessary security systems to monitor the disruptions in the transmission link should be incorporated, as a part of the transmission system.

Conclusion

Consider an electric transmission system as shown in Fig 2. The digraph model is used in depicting the flow of energy between the nodes of the system. The digraph model uses binary values to represent the communication between the nodes of the system. The adjacency matrix Aij, a collection of all the relationships between the nodes in a binary representation, gives the entire connectivity between the nodes, but they are only direct connectivities. The permanent operation on the adjacency matrix yields direct as well as indirect connections between the nodes. The computed matrix gives the number of ways the energy can flow through a particular link.

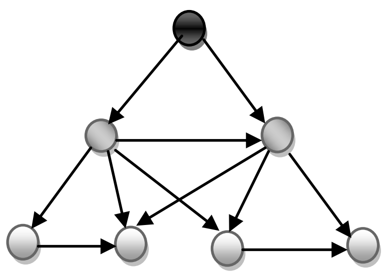

Fig 2: An example of ETS

Adjacency matrix for the considered system is given by

$$A = \begin{pmatrix} 0 & 1 & 1 & 1 & 0 & 0 & 0 \\ 1 & 0 & 1 & 1 & 1 & 1 & 0 \\ 1 & 1 & 0 & 0 & 1 & 1 & 1 \\ 1 & 1 & 0 & 0 & 1 & 0 & 0 \\ 0 & 1 & 1 & 1 & 0 & 0 & 0 \\ 0 & 1 & 1 & 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 & 0 & 1 & 0 \end{pmatrix}$$

Permanent matrix for the considered system is given by

$$T = \begin{pmatrix} 13 & 10 & 8 & 14 & 13 & 8 & 14 \\ 10 & 4 & 4 & 4 & 10 & 4 & 8 \\ 8 & 4 & 4 & 4 & 8 & 4 & 8 \\ 14 & 4 & 4 & 4 & 14 & 4 & 8 \\ 13 & 10 & 8 & 14 & 13 & 8 & 14 \\ 8 & 4 & 4 & 4 & 8 & 4 & 24 \\ 14 & 8 & 8 & 8 & 14 & 24 & 16 \end{pmatrix}$$

The links with large weights contribute maximum to the power transmission network.These links should be safegaurded,against internal and external threats,to avert chaos due to outage of power.

Future work should focus on constructing a model which includes the factors like the cost of establishing the individual links of a transmission system and development of the area over which it is traversing, along with the connectivty of the network.

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