르완다 전력 계통망 토폴로지 분석

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A Topological Analysis of the Rwandan Electric Power Grid

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Abstract - Energy is the basic necessity for the economic development of a country. As electric power has become an integral part for developing countries, power grids tend towards complex systems. Therefore, vulnerabilities of such systems would result in major losses; studies pertaining to these systems' topology would help to alleviate possible drawbacks. This study analyses the topology of Rwandan electric transmission line by using Complex network analysis. Then, it is compared to the US and Korea power grid topologies. The analysis have shown that despite the small-scale of Rwandan electric transmission line it has similar topology characteristics with other networks.

Keywords - Topological Analysis, Graph theory, Incidence Matrix, Laplacian Matrix

1. INTRODUCTION

The electric power grid is the most sophisticated and complex system which originates from human being conception. it comprises of several components connected or linked together to form a giant structure with distinct topology. several researches have studied the topology of electric power grid using the complex network analysis. [1]

In this interconnection, topology only refers to the geometry or the backbone of how infrastructures are interconnected between them without considering the properties of elements that form the network such as electrical properties. Using graph theory applied to electrical networks helps to understand topological characteristics. A main commonality is to treat the Power Grid as an undirected graph where each substation or transformer represents a node (or vertex) and each line transporting electricity is an edge (or link). [2]

It is obvious that electric systems are inherently exposed to various disturbances of which some result in large-scale blackouts. These blackouts are intrinsic drawbacks of the electric power system. Therefore, the study of power grid topology would help minimize or prevent possible disturbances before they occur.

The Rwandan power grid as other conventionally designed systems is comprised of generation, transmission and distribution. Our scope of work is the transmission line which comprises of 70kV, 110kV and 220kV voltage levels. In this study, we analysed all the transmission lines combined together as studying separately each transmission line would result in meaningless results due to a small number of nodes forming each network. We computed several topological parameters such as average nodal degree; Pearson node degree correlation coefficient, shortest path, etc.

2. SYSTEM MODELING USING GRAPH THEORY

2.1 Description of Parameters

The topology of the electric power grid can be easily represented using graph theory. [5]

A network having **m** links and **N** nodes, has an incidence rectangular matrix **A**, of size m x N. [1]

$$A:\begin{cases} A(t,i)=1 \\ A(t,j)=-1 \\ A(t,k)=0 \; with \; k\neq i \text{ or } j \end{cases} \tag{1}$$

If the t-th link is from node i to j.

The Laplacian matrix is obtained as $L=A^TA$ with

$$L(i,j)=\begin{cases} -1, & \text{if } there \; \exists \; link \; i-j, \text{ for } j\neq i \\ k, & with \; k=-\sum_{j\neq i} L(i,j), \text{ for } j=i \\ 0, & otherwise, \end{cases} \tag{2}$$

with i, j=1,2,...N

2.2 Statistical global graph properties

Parameters deriving from the Laplacian matrix are:

The number of links

$$m=\frac{1}{2}\sum_i L(i,i) \tag{3}$$

The average nodal degree $\langle k\rangle$ gives the information on how good a network is linked as an entity

$$\langle k\rangle=\frac{1}{N}\sum_i L(i,i) \tag{4}$$

The nodal degree vector is given by

$$\underline{k}=[k_1,k_2,...,k_N]=diag(L) \tag{5}$$

The average degree of a node seen at the end of a randomly selected link (i, j) is defined as

$$\bar{k}=(2m)^{-1}\sum_{(i,j)}(k_i+k_j) \tag{6}$$

The ratio parameter $r\{k>\bar{k}\}$ which deals with the maximum node degree of the nodes of graph of network is

$$r\{k>\bar{k}\}=\frac{\|\{k_i;k_i>\bar{k}\}\|\infty}{N}=\frac{\max(k_i)}{N} \tag{7}$$

The Pearson node degree correlation coefficient ($\rho \in [-1, 1]$) is given by [6]

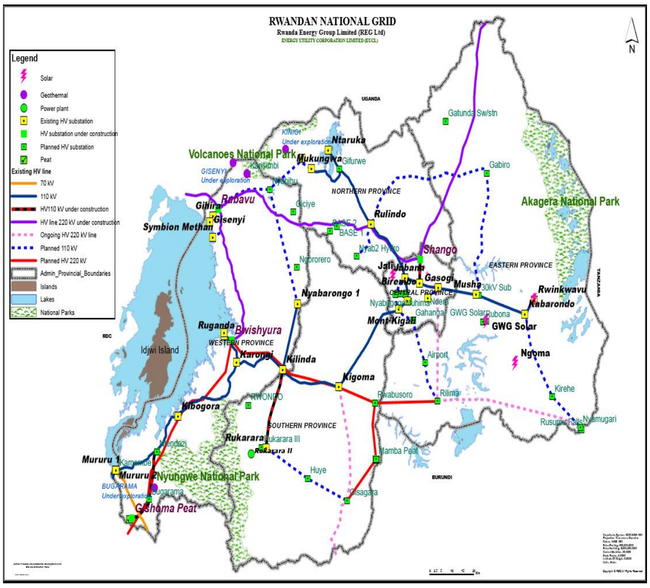
$$\rho=\frac{\sum_{(i,j)}(k_i-\bar{k})(k_j-\bar{k})}{\sqrt{\sum_{(i,j)}(k_i-\bar{k})^2\sum_{(i,j)}(k_j-\bar{k})^2}} \tag{8}$$

The average shortest path length in hops $\langle l\rangle$ is computed while running Dijkstra's algorithm [7] from the adjacency matrix M_{adj} of the network.

$$M_{adj}=-L+\Lambda(diag(L)) \tag{9}$$

Where $\Lambda(.)$ means taking the diagonal matrix from a vector.

2.3 Topological Features of the power grids: Rwandan case study



<Figure 1> RWANDA HV Transmission map

In this study we analysed the existing 110kV transmission line, the planned and under construction 110kV and 220kV networks. Note that in the future the results presented in this study might change because some changes may occur during the implementation of the planned network. Figure 1 illustrates the studied network.

2.4 Studied Topological Metrics and Results

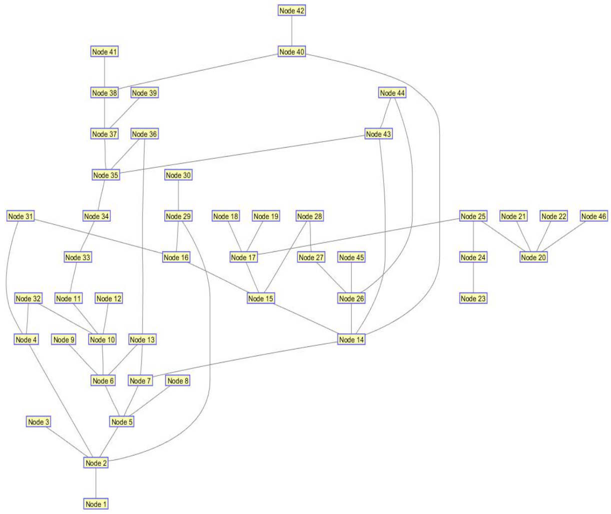
The incidence matrix is of order (54 x 46) for the Rwandan electric power grid. That is to say 54 edges and 46 nodes. we grouped the incidence matrices of all networks together. Using all formula introduced in section 2.1 and 2.2, we compute the topological characteristics and the results are presented in Table 1. Power grids indexed with IEEE represent different parts of the American electric power system [4] while KO [3] and RWA represent the electric power systems of Korea and Rwanda respectively.

<Table 1>Topological characteristics of compared networks

	(N,m)	$\langle k \rangle$	$\bar{k}$	ρ	$r\{k > \bar{k}\}$	$\langle l \rangle$
IEEE-30	(30,41)	2.7333	3.4390	-0.0875	0.2333	3.31
IEEE-57	(57,78)	2.7368	3.1795	0.2434	0.2105	4.95
KO-345kV	(93,118)	2.5376	3.2246	-0.1817	0.1828	6.86
RWA-46	(46,54)	2.3478	3.0000	-0.2470	0.4348	4.89

From Table 1, one can see that while the IEEE power systems and KO-345kV have $\langle k \rangle$ values ranging between 2.5 and 3 [1], The Rwandan network has an average nodal degree value slightly lower. This explains the sparsity of Rwandan power transmission lines. The Pearson node degree correlations for all networks are seen to be small, which explains that there are no special node correlation between some nodes that have similar number of degrees. The ratio of nodes with larger nodal degrees for Rwandan power grid (43.5%), is higher than those of IEEE and Korea power systems. And lastly but not least, the average shortest path length in hops have been calculated using Dijkstra algorithm implemented in Matlab. The shortest path length of Rwandan power transmission grid has similar number as those of IEEE and Korea power grids.

Figure 2 shows the logical topology for the Rwandan transmission line. From this biograph, we see some nodes with a tendency to cluster in the same group. Node 5 to 13 (excluding 10, 11 & 12) are concentrated in the Capital area, Kigali. Other huge clusters represent new connections to come with the construction of new transmission lines.



<Figure 2> Rwanda Transmission line biograph

3. CONCLUSION

In this work, we focused on the study of topological characteristics of the Rwandan power grid using the complex network analysis. Using this approach allowed us to calculate some important topological parameters. They are average nodal degree, Pearson correlation coefficient, the characteristic shortest path, etc. Through the complex network analysis, the connectivity of the Rwandan power grid has been shown in this case study work. As we are living in the revolution era where Smart grid operation is attracting much attention; studying the topology of the electric power grid using graph theory approach is of high importance due to its outcomes i. e the above calculated metrics. Further work will include the computation of statistical characteristics and also the consideration of electrical characteristics of the power system.

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