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Application of Fractals to Power System Networks

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***Abstract*— Fractal geometry and chaos theory are providing us with a new perspective to visualize the world. From the engineering point of view, these fractal principles evoked greater interest in recent times in trying to understand the complex behavior of the systems. Electrical power system network is with fractal characteristic. Fractal dimension is an index for characterizing fractal patterns. Box counting algorithm is used to find fractal dimension. This paper gives an overview on the types of fractals, their generation and application to power systems. Fractal dimension reflects the complexity of fractal set. The more is complexity, the larger is the fractal dimension.**

***Index Terms*—Box counting algorithm, Electrical power system, Fractal, Fractal dimension, Power systems.**

I. INTRODUCTION

The term 'Fractal' was coined by Benoit Mandelbrot from the Latin verb *frangere*, meaning to break or fragment. A fractal is a pattern that repeats itself at different scales. It is ideal for modeling nature: a tree is a branch of a branch of a branch; mountains are peaks within peaks; clouds are puffs of puffs, and so on. The concepts of fractal geometry could be applied to understand component parts and make postulations about what it will become in the future. This new way of viewing our surroundings, this new perception of reality, has since led to a number of remarkable discoveries about the worlds of nature and man. Fractal patterns have appeared in almost all of the physiological processes within our bodies. Fractal geometry and its concepts have become central tools in most of the natural sciences such as Physics, Chemistry, and Biology. At the same time, fractals have also captured the interest of graphic designers and film makers, because of their ability to create new and exciting shapes and artificial but realistic worlds. Fractal principles can be applied to feedback circuits, geometry of the lightning cluster etc. It is quite well-known fact that the power system networks are quite complex in structure and behavior. Most of the analytical tools in vogue today have greater limitations. Hence, in this paper an exploratory attempt is being made for the applicability of the Fractal principles to the Power Systems.

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II. CLASSIFICATION OF FRACTALS

Fractals can be distinguished into two classes based upon their generation and resulting structure.

A. Deterministic fractals have structures that are fixed uniquely by the algorithm employed in their creation. For a given set, a deterministic fractal generator will produce identical structures each time it is run.

B. Stochastic fractals are characterized by the fact that random processes play a central role in determining the structure of the fractal object.

Fractals can also be classified into four distinct classes based upon the nature of algorithm by which they are generated.

A. Linear Replacement Mapping works on the principle that a generator function maps a given structure onto a new more complex one as that of the Koch curve.

B. Iterated Function Systems generate fractals by the successive applications of a series of contractive affine transformations.

C. Complex Plane Mapping facilitates the generation of mathematical objects such as the Julia sets and Mandelbrot sets. They are generated by successive mapping on the complex plane.

D. Stochastic Processes employ random processes with a recursive algorithm.

Fractals can be classified mathematically into three types.

A. Self-similar fractals have parts. Each part of which is a scaled down version of the entire object, or is a scaled down generator.

B. Self-affine fractals have parts that are formed with different scaling parameters along the different axes.

C. Invariant fractal sets are formed with non-linear transformations. This class of fractals includes self-squaring fractals such as the Julia set, which are formed with squaring functions in the complex space.

III. GENERATION OF FRACTALS

A. Fractal Tree

Fractal trees are among the easiest of fractal objects to understand. They are based on the idea of self-similarity. Each of the branches is a smaller version of the main trunk of the tree. The main idea in creating fractal trees or plants is to have a base object and to then create smaller, similar objects

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protruding from that initial object. The angle, length and other features of these branches can be randomized for a more realistic look. Fractal tree concept is used in computer memory mapping principles. Simulation results of Fractal tree for different iterations are shown in the following figures.

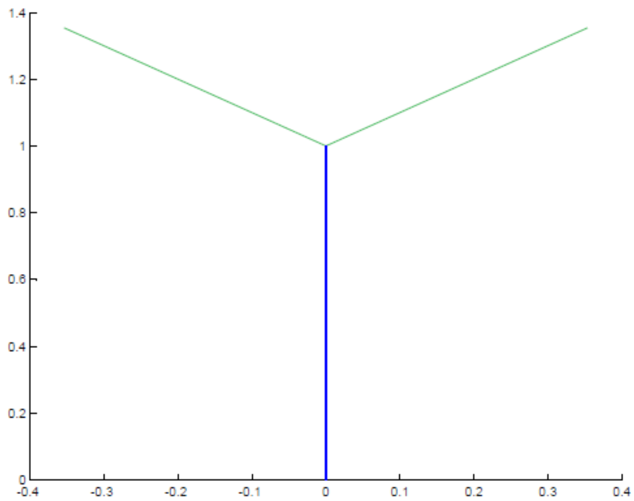

Fig. 1 Fractal Tree for iteration: 1

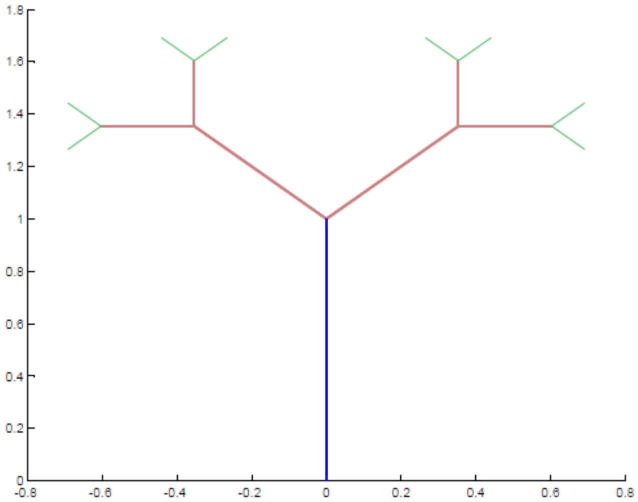

Fig. 2 Fractal Tree for iteration: 3

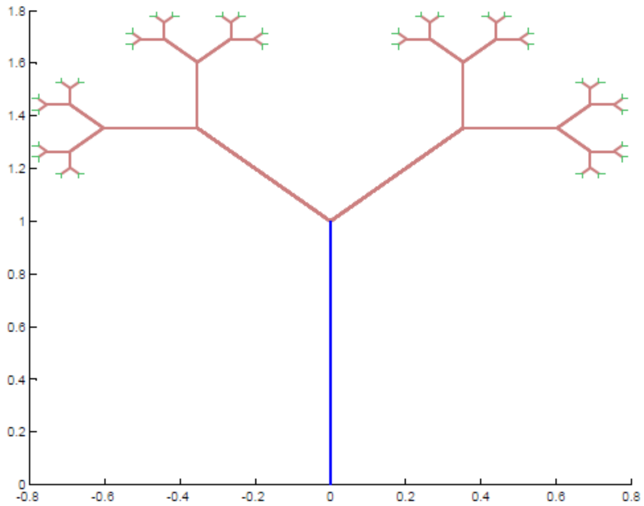

Fig. 3 Fractal Tree for iteration: 6

B. Koch Snowflake Curve

The Koch curve is named after the Swedish mathematician Niels Fabian Helge von Koch. To make a snowflake, we start with three similar lines, arranged as an equilateral triangle, and apply the process in parallel to each of three segments. Simulation results of Koch Snowflake curve from stage 0 to stage 5 are shown in the following figures.

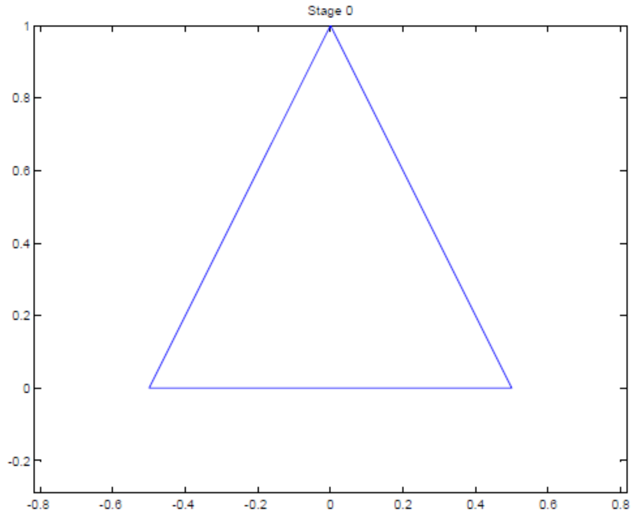

Fig. 4 Koch Snowflake Curve: Stage 0

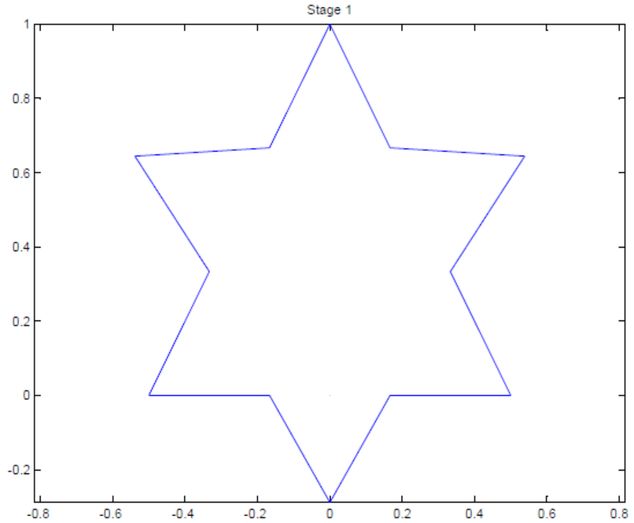

Fig. 5 Koch Snowflake Curve: Stage 1

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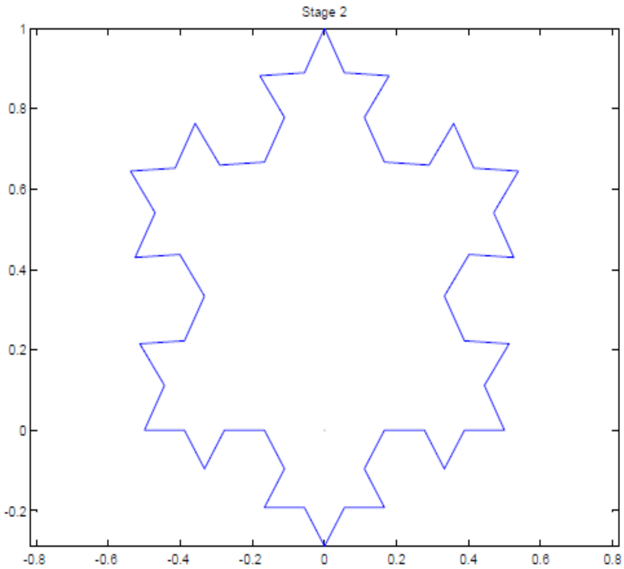

Fig. 6 Koch Snowflake Curve: Stage 2

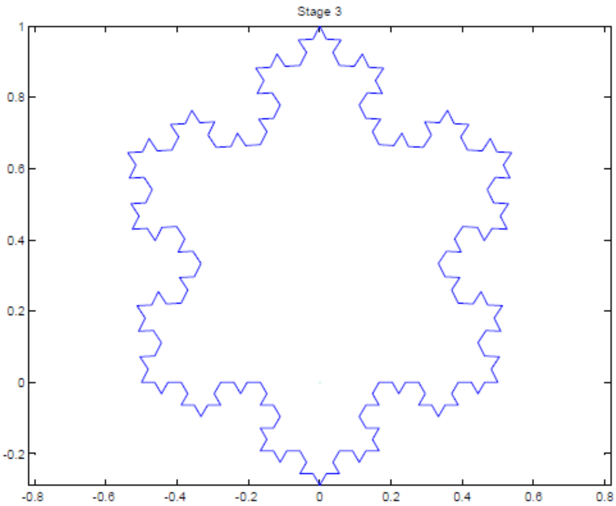

Fig. 7 Koch Snowflake Curve: Stage 3

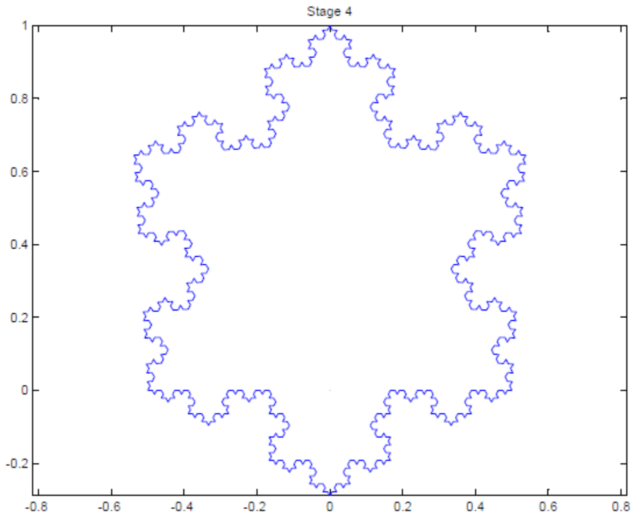

Fig. 8 Koch Snowflake Curve: Stage 4

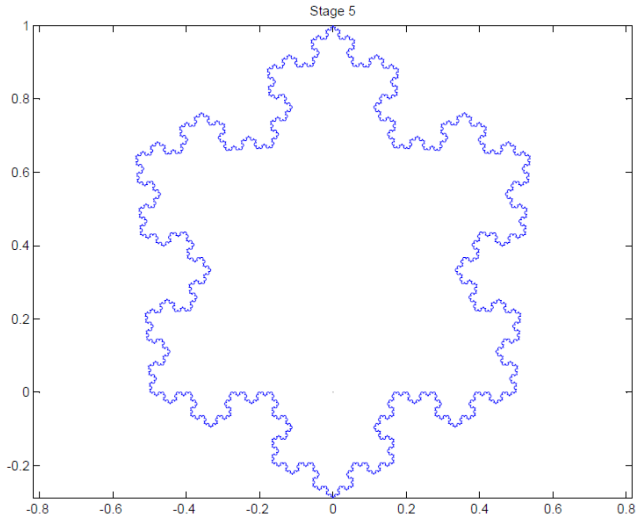

Fig. 9 Koch Snowflake Curve: Stage 5

IV. Fractal Dimension

A Fractal dimension is an index for characterizing fractal patterns or sets by quantifying their complexity as a ratio of the change in detail to the change in scale. In mathematics, more specifically in fractal geometry, a fractal dimension is a ratio providing a statistical index of complexity comparing how detail in a pattern (strictly speaking, a fractal pattern) changes with the scale at which it is measured. It has also been characterized as a measure of the space-filling capacity of a pattern that tells how a fractal scales differently from the space it is embedded in; a fractal dimension does not have to be an integer.

A. Significance of Fractal Dimension

The fractal dimension is a tool that allows us to characterize patterns and shapes in natures that have previously been outside the reach of mathematics. We can now quantitatively describe a pattern, and that allows us to study it. Fractal patterns tell a story about the repetitive processes that created them. Examining the fractal dimension can help shed light on the processes.Fractal dimensions are used to characterize a broad spectrum of objects ranging from abstract to practical phenomena, including turbulence, river networks, urban growth, human physiology, medicine, market trends etc.

B. Various methods to compute Fractal Dimension

Fractal dimensions can be determined using techniques that approximate scaling and detail from limits estimated from regression lines over log versus log plots of size versus scale. Several formal mathematical definitions of different types of fractal dimension are listed below. Let D be the fractal dimension. Although for some classic fractals all these dimensions coincide, in general they are not equivalent:

- Box counting dimension
- Information dimension
- Hausdorff dimension

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V. Box Counting Algorithm

In fractal geometry, the Minkowski–Bouligand dimension, also known as Minkowski dimension or box-counting dimension, is a way of determining the fractal dimension. Box Counting Algorithm is one of the most widely used methods for calculating the fractal dimension. The principle is simple and easy to implement. The box counting method is analogous to the perimeter measuring method we used for the coastlines. But in this case, we cover the image with a grid, and then count how many boxes of the grid are covering part of the image. Then we do the same thing but using a finer grid with smaller boxes. By shrinking the size of the grid repeatedly, we end up more accurately capturing the structure of the pattern.
Suppose that N(r) is the number of boxes of side length r required to cover the set. Then, the box counting dimension is defined as

$$D = \lim_{r \to 0} \frac{\log N(r)}{\log \frac{1}{r}} \qquad (1)$$

This algorithm revolves around the procedure for partitioning a single box. This procedure is applied recursively to the nonempty sub-boxes until a halting criterion is satisfied. Boxes are stored as records, each containing the corner closest to origin, the edge size, a pointer to the data held in the box, the population, and an array of pointers pointing to the sub-boxes which are created during the partitioning process. The advantage of using boxes is that in many cases N(r) may be easily calculated explicitly.

VI. Computation Of Fractal Dimension

The Fractal Dimension is calculated for the Fractal Tree and Koch Snowflake Curve using Box Counting algorithm

A. Fractal Tree

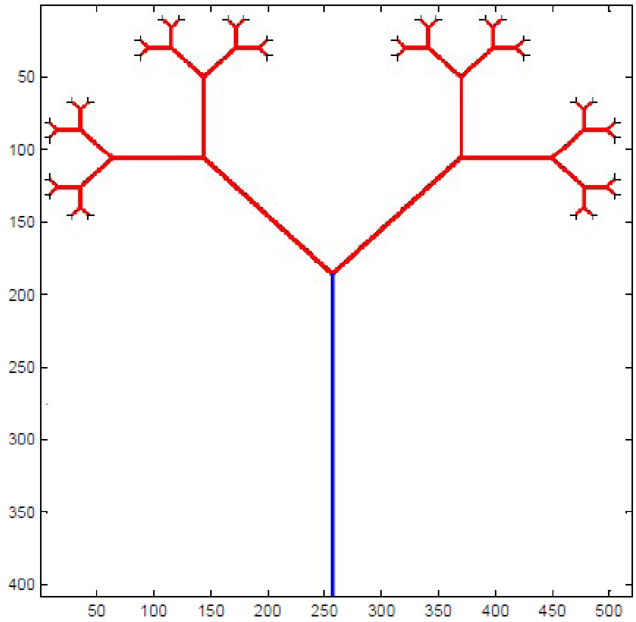

Fig. 10 Scaling of Fractal Tree iteration 6

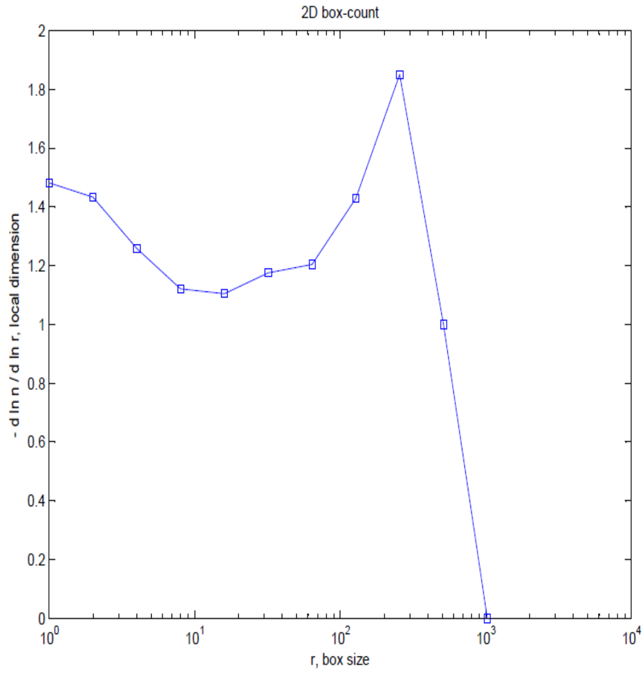

Fig. 11 Fractal dimension (D) versus Box size(r) for Fractal Tree iteration 6

The fractal dimension of the Fractal tree is found to be in the range of D= 1.2635 +/- 0.25146

B. Koch Snowflake Curve

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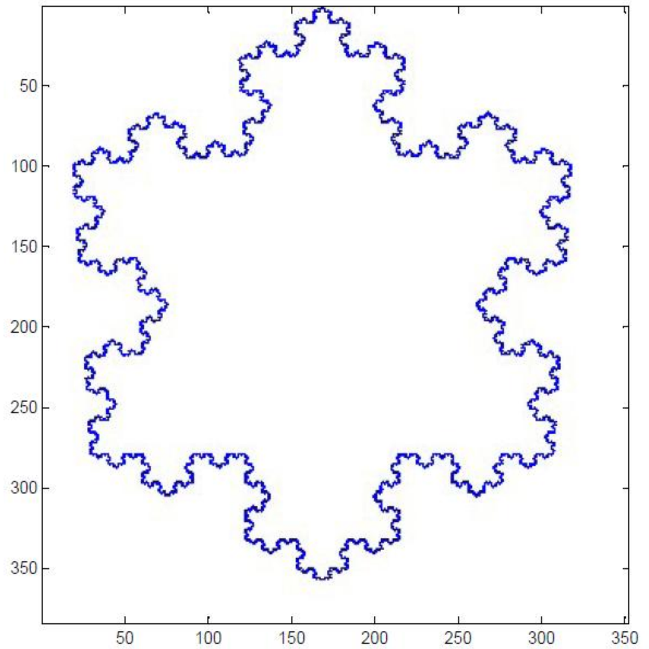

Fig. 12 Scaling of Koch Snowflake Curve Stage 5

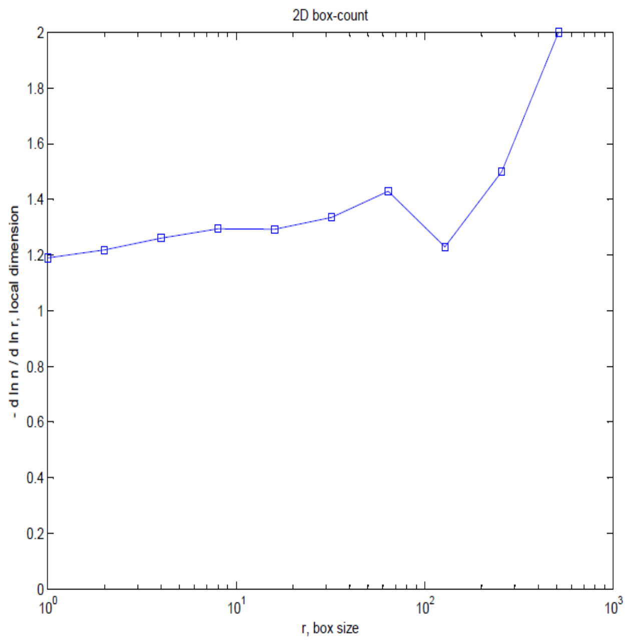

Fig. 13 Fractal dimension (D) versus Box size(r) for Koch Snowflake Curve Stage 5

The fractal dimension of the Koch snowflake curve is found to be in the range of D= 1.2886 +/- 0.17712

VII. Fractal Dimension For Electrical Power System Networks

In the electric power system network, the transmission line can be simplified as the line, and power plants as well as various substations at different locations.

Consider different typical power system network models as follows:

A. IEEE 14 bus system

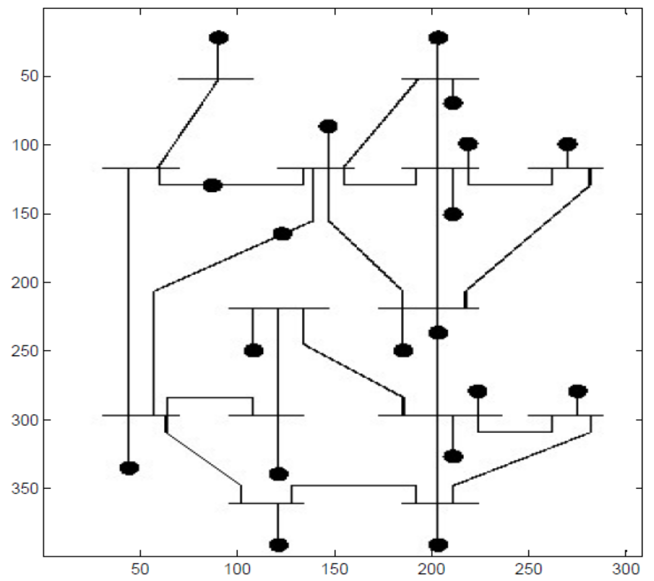

Fig. 14 Scaling of IEEE 14 bus system

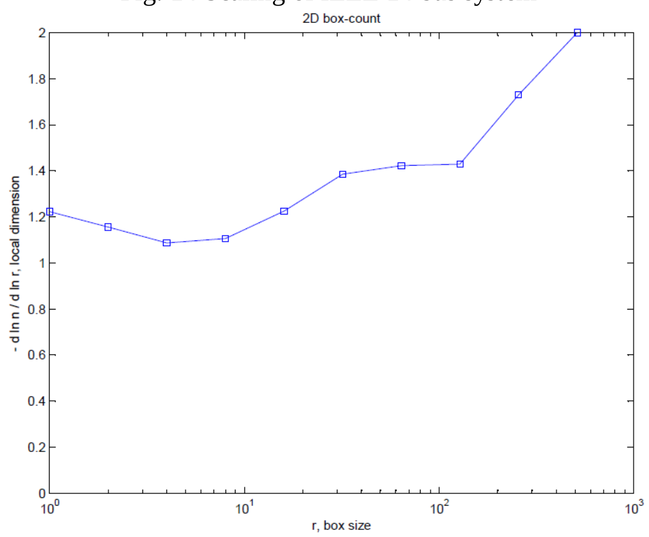

Fig. 15 Fractal dimension (D) versus Box size(r) for IEEE 14 bus system

B. IEEE 30 bus system

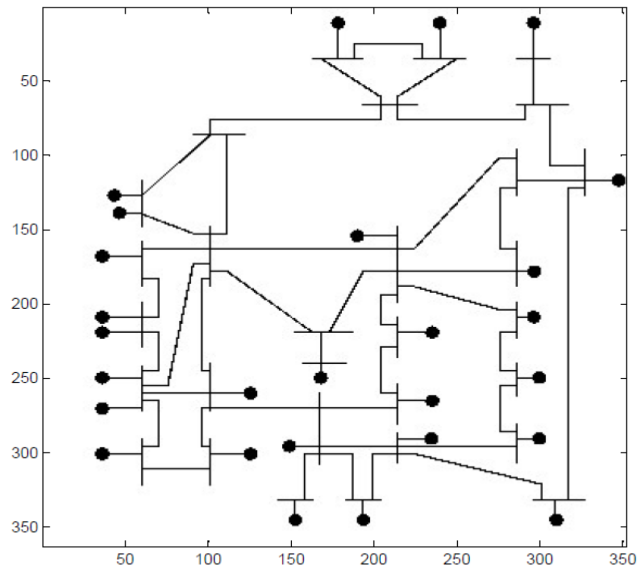

Fig. 16 Scaling of IEEE 30 bus system

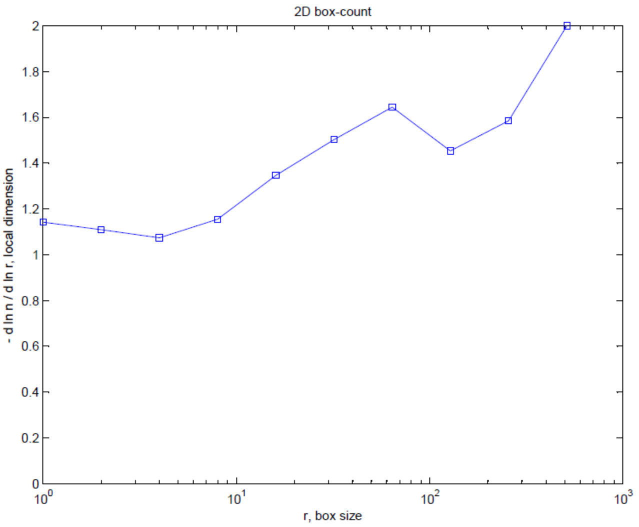

Fig. 17 Fractal dimension (D) versus Box size(r) for IEEE 30 bus system

C. IEEE 39 bus system

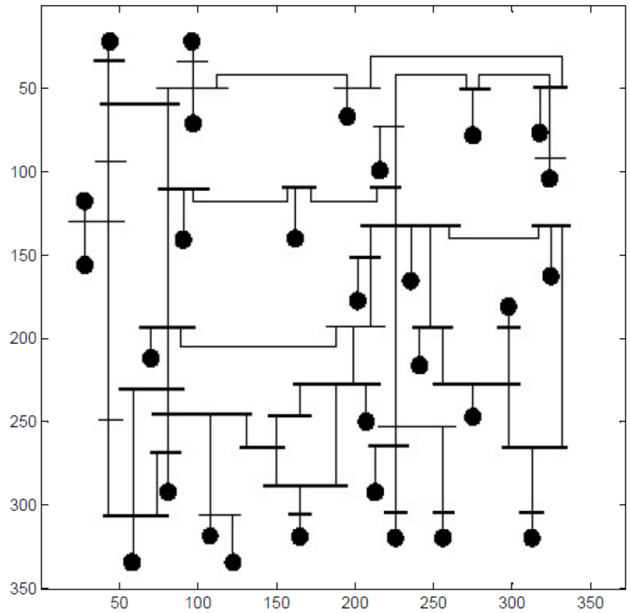

Fig. 18 Scaling of IEEE 39 bus system

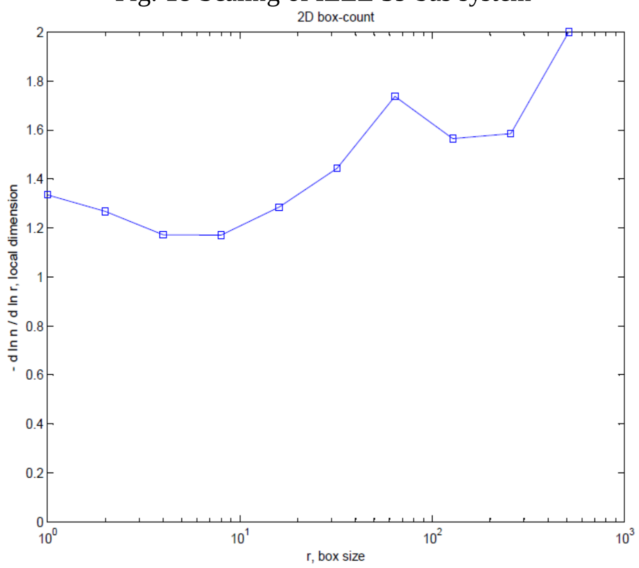

Fig. 19 Fractal dimension (D) versus Box size(r) for IEEE 39 bus system

D. IEEE 118 bus system

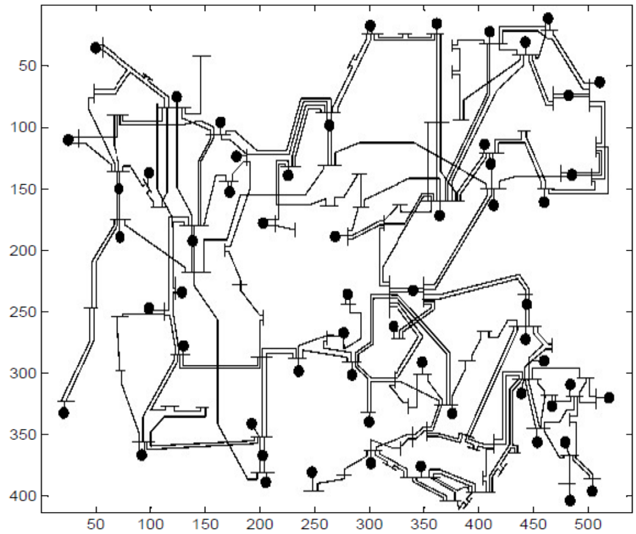

Fig. 20 Scaling of IEEE 118 bus system

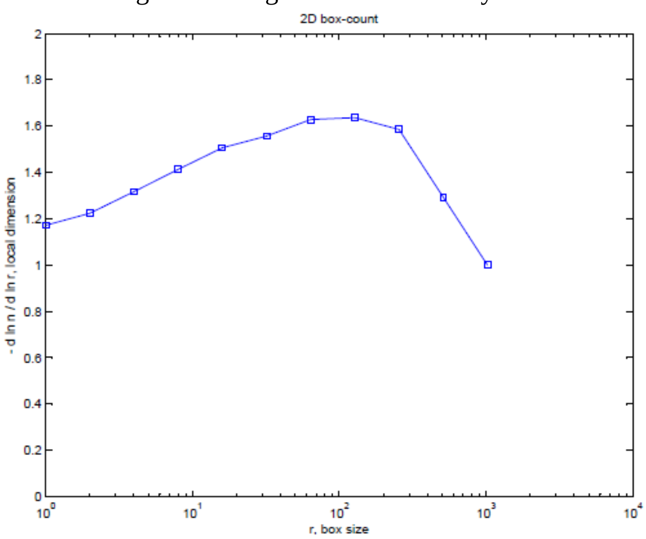

Fig. 21 Fractal dimension (D) versus Box size(r) for IEEE 118 bus system

E. IEEE 300 bus system

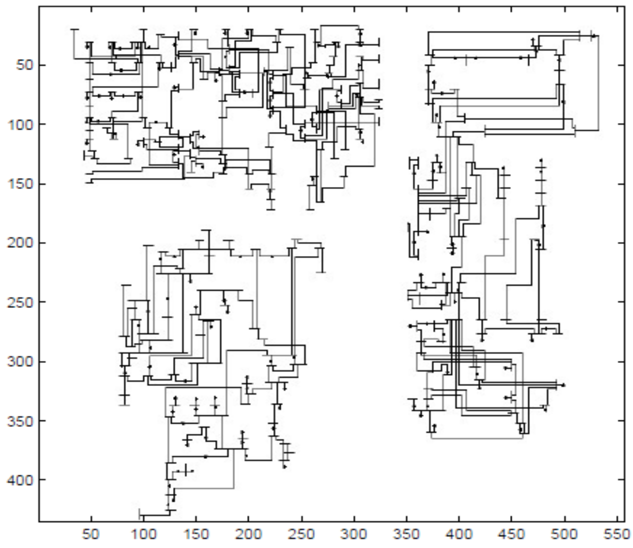

Fig. 22 Scaling of IEEE 300 bus system

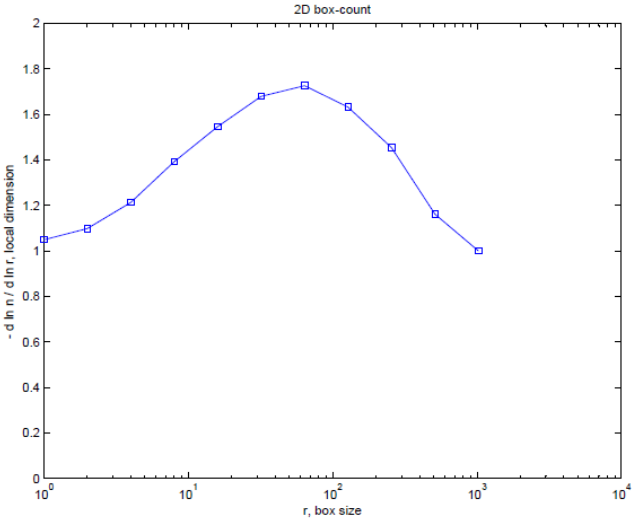

Fig. 23 Fractal dimension (D) versus Box size(r) for IEEE 300 bus system

VIII. Results

The Fractal dimension values for the above mentioned power networks is given on the following tabular form:

S.No.	Bus System	Fractal Dimension
1.	IEEE 14	1.351 +/- 0.13646
2.	IEEE 30	1.4305 +/- 0.23117
3.	IEEE 39	1.4429 +/- 0.32074
4.	IEEE 118	1.5708 +/- 0.079577
5.	IEEE 300	1.6254 +/- 0.10224

Table 1: Shows the Fractal Dimension for the IEEE buses

IX. Conclusion

The Fractal Dimension of the complex system is found to be more that means the fractal dimension value is increasing from IEEE 14 bus system to IEEE 300 bus system. The system with high fractal dimension value has decreasing stability values.

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