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Fractal representation of the power demand based on topological properties of Julia sets

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ABSTRACT

In a power system, the load demand considers two components such as the real power (P) because of resistive elements, and the reactive power (Q) because inductive or capacitive elements. This paper presents a graphical representation of the electric power demand based on the topological properties of the Julia Sets, with the purpose of observing the different graphic patterns and relationship with the hourly load consumptions. An algorithm that iterates complex numbers related to power is used to represent each fractal diagram of the load demand. The results show some representative patterns related to each value of the power consumption and similar behaviour in the fractal diagrams, which allows to understand consumption behaviours from the different hours of the day. This study allows to make a relation among the different consumptions of the day to create relationships that lead to the prediction of different behaviour patterns of the curves.

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1. INTRODUCTION

Benoit Mandelbrot defined the concept of fractals as a semi-geometric element with a repetitive structure at different scales [1], with characteristics of self-similarity as seen in some natural formations such as snowflakes, ferns, peacock feathers, and Romanesco broccoli. Fractal theory has been applied to various fields such as biology [2, 3], health sciences [4-8], stock markets [9], network communications [10-12], and others. Fractal theory is one of the methods used to analyse data and obtain relevant information in highly complex problems. Thus, it has been used to study the price of highly variable markets, which are not always explainable from classical economic analysis.

For example, in [9], the authors demonstrate that current techniques have some issues to explain the real market operation and a better understanding is achieved by using techniques such as chaos theory and fractals. In their publication, the authors show how to apply fractal behaviour to stock markets and refer to multifractal analysis and multifractal topology. The first describes the invariability of scaling properties of time series and the second is a function of the Hölder exponents that characterizes the degree of irregularity of the signal, and their most significant parameters.

In [13], the authors discuss the basic principle of fractal theory and how to use it to forecast the short-term electricity price. In the first instance, the authors analyse the fractal characteristic of the electricity price, confirming that price data have this property. In the second instance, a fractal model is used to build a forecasting model, which offers a wide application in determining the price of electricity in the markets.

Similarly, the authors of [14] demonstrate that the price of thermal coal has multifractal features by using the concepts introduced by Mandelbrot-Bouchaud. Hence, a quarterly fluctuation index (QFI) for thermal power coal price is proposed to forecast the coal price caused by market fluctuation. This study also provides a useful reference to understand the multifractal fluctuation characteristics in other energy prices. Fractal geometry analysis has been also applied to study the morphology and population growth of cities, and electricity demand related to the demography of cities. In [15], a multifractal analysis is used to forecast electricity demand, explaining that two fractals are found that reflect the behaviour pattern of power demand. Two concepts linked to fractal geometry are fractal interpolation and extrapolation, which are related to the resolution of a fractal-encoded image. In [16], an algorithm is used to forecast the electric charge in which fractal interpolation and extrapolation are also involved; for the forecast dataset, the average relative errors are only 2.303% and 2.296%, respectively, indicating that the algorithm has advantages in improving forecast accuracy.

In [17], a slotted is introduced at each of the radiating elements on the 1st iteration log periodic fractal Koch antenna (LPFKA). The antenna is designed to testify the appropriate performance at UHF Digital television which operates from 4.0 GHz to 1.0 GHz. The dimension of the conventional 0th iteration LPKFA is successfully reduced by 17% with the implementation of slotted. The results show a good agreement with a stable radiation pattern across the operating bandwidth, stable gain more than 5 dBi and reflection coefficient of below -10 dB over the desired frequency range.

Finally in [18] a multiband and miniature rectangular microstrip antenna is designed and analyzed for Radio Frequency Identification (RFID) reader applications. The miniaturization is achieved using fractal technique and the physical parameters of the structure as well as its ground plane are optimized using CST Microwave Studio. The total area of the final structure is 71.6 x 94 mm^2. The results show that the proposed antenna has good matching input impedance with a stable radiation pattern at 915 MHz, 2.45 GHz, and 5.8 GHz.

In the literature reviewed there are no papers focused on the daily real and reactive power consumption based on the topological properties of the Julia sets. There are no graphical analyses that show the behaviour of the system by observing different fractal patterns. Most studies on fractals are focused on other types of applications such as medicine, biology, communications, electronics, leading to an important opportunity to perform the study on power systems. In addition, the characteristics of the real and reactive powers are not analysed in depth by applying fractal geometry, concluding that these techniques are not commonly used to study the different power consumption. Therefore, this paper studies a typical load demand curve of an electric power system with the fractal theory of Julia sets. The graphic study focuses on determining the characteristics that the fractal diagrams created from Julia sets related with the complex numbers of real and reactive powers and seeking for other graphical patterns of the load demand curve. For this reason, this work proposes the following hypothesis: The load demand curve has a clear fractal pattern obtained from the Julia sets, which allows to characterize the consumption behaviour. The main contribution of this article is related to the development of a new methodology, as a complement to those found in literature, which allows to characterize the daily load demand curve. This paper confirms that the density of the folds in the Julia sets reveal the transitivity in the electric power consumption registers, which is related to the irregularity of the hourly consumption. Eventually, the fractal topology that is obtained from the Julia sets reflects when the load is inductive or capacitive.

2. RESEARCH METHOD

This methodology is based on constructing an algorithm that allows an analysis of the fractal diagrams applied to the typical load demand curve. Below, this section shows the general procedure and the algorithms implemented to obtain the Mandelbrot and Julia sets, which are useful tools to graph fractals from the complex numbers related to the load demand.

2.1. General procedure

Figure 1 presents a step-by-step procedure applied to graph the fractal diagrams from the load demand with the Mandelbrot and Julia sets. This figure shows that the first step (P1) is to convert the initial data to manage the procedure to the Mandelbrot and Julia algorithms. Next, the Mandelbrot algorithm is programmed according to the mathematical theory (P2) to generate a new data set. Besides, the Julia algorithm is also programmed to perform the generation of the new sets, based on the Mandelbrot set. With these data sets, it is possible to plot the different fractals (P4) which are then analysed to present the different results in this paper (P5) and the corresponding conclusions.

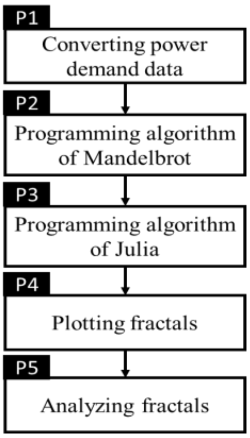


Figure 1. General procedure of the study

2.2. Load demand curve

The process begins by reading the typical load demand records of real and reactive defined for a 24-hour period as shown in Table 1 [19, 20]. The per unit values of the power demand are calculated with the following expression: $\text{per unit power} = \text{actual power} / \text{base power}$. In this case, the base power is $4000\ MVA$. These data are used to plot the diagrams with the programmed algorithms, in which the lowest and highest consumption points are considered to evaluate the different fractal diagrams.

Table 1. Daily power demand

$Hour$	P	Q	S	P_{pu}	Q_{pu}	S_{pu}
00:00:00	889	371	963	0.222	0.092	0.240
01:00:00	834	405	927	0.208	0.101	0.231
02:00:00	792	337	861	0.197	0.082	0.215
03:00:00	790	324	854	0.199	0.081	0.213
04:00:00	804	323	867	0.201	0.080	0.216
05:00:00	925	355	991	0.231	0.088	0.247
06:00:00	1041	482	1147	0.260	0.120	0.286
07:00:00	1105	556	1237	0.276	0.139	0.309
08:00:00	1191	610	1338	0.297	0.152	0.334
09:00:00	1256	704	1439	0.314	0.176	0.359
10:00:00	1309	744	1506	0.327	0.186	0.376
11:00:00	1366	775	1571	0.341	0.193	0.392
12:00:00	1385	793	1595	0.346	0.198	0.398
13:00:00	1356	774	1561	0.339	0.193	0.390
14:00:00	1337	759	1537	0.334	0.189	0.384
15:00:00	1350	774	1556	0.337	0.193	0.389
16:00:00	1336	773	1543	0.334	0.193	0.385
17:00:00	1312	749	1511	0.328	0.187	0.377
18:00:00	1287	687	1459	0.321	0.171	0.364
19:00:00	1420	683	1575	0.355	0.170	0.393
20:00:00	1389	660	1538	0.351	0.167	0.384
21:00:00	1311	605	1444	0.327	0.151	0.361
22:00:00	1175	544	1295	0.293	0.136	0.323
23:00:00	1030	489	1140	0.257	0.122	0.285

2.3. Algorithm to create the Mandelbrot set

The Mandelbrot set, denoted as $M = \{c\ \in C/J_c\}$, represents sets of complex numbers C obtained after iterating from the initial point Zn and the selected constant C as shown in Equation (1). The results form a diagram with connected points remaining bounded in an absolute value. One property of M set is that the points are connected, although in some zones of the diagram it seems that the set is fragmented. The iteration of the function generates a set of numbers called "orbits." The results of the iteration of those points outside the boundary set tend to infinity:

$$Z_{n+1} = F(Z_n) = {Z_n}^2 + C. \quad (1)$$

From the term C, a successive recursion is performed with $Z_0 = 0$ as the initial term. If this successive recursion is dimensioned, then the term C belongs to the Mandelbrot set; if not, then they are excluded. Therefore, Figure 2 shows the Mandelbrot set with points in the black zone called the “prisoners” while the points in other colours are the “escapists” and represent the escape velocity to infinity.

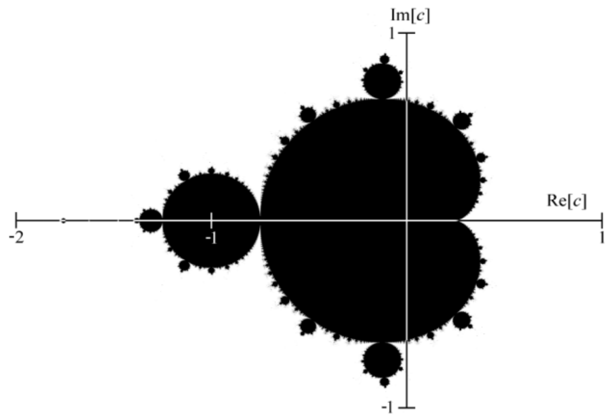


Figure 2. Graphical representation of the Mandelbrot set

In Figure 2, the value -1 is inside of the set while the number 1 is outside. In the Mandelbrot set, the fractal is the border and the dimension of Hausdorff is unknown. If the image is enlarged near the boundary of the set, then many areas the Mandelbrot set are represented in the same form. Besides, different types of Julia sets are distributed in different regions of the Mandelbrot set. If a complex number appears with a greater value than 2 in the 0 orbit, then the orbit tends to infinity. The orbits that are generated are part of a sequence of complex numbers and their characteristics depend fundamentally on the values of the initial point Z_n and of the selected C constant. The pseudocode of the algorithm that is used to represent the Mandelbrot set is presented as follows:

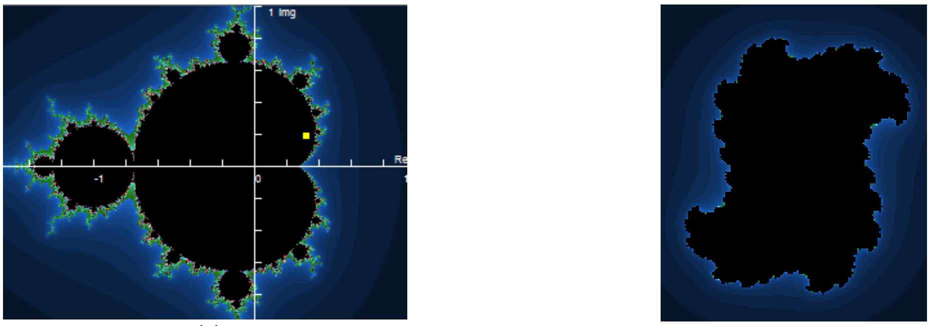
```
Start
    For each point C in the complex plane do:
        Fix Z_0 = 0
        For t = 1 to t_max do:
            Calculate Z_t = Z_t^2 + C
            If |Z_t| > 2 then
                Break
            End if
            If < t_max then
                Draw C in white (the point does not belong to the set)
            Else if t = t_max then
                Draw C in black (as the point does belong to the set)
            End if
    End For
End
```

In this research, the presented algorithm has been used to obtain the Mandelbrot set and the diagram that represents it. Some points related to the real and reactive powers with the respective signs, in the first quadrant of the complex plane, are studied in the Mandelbrot set and related to those points created for the Julia sets as explained in the following sections.

2.4. Algorithm to create the Julia sets

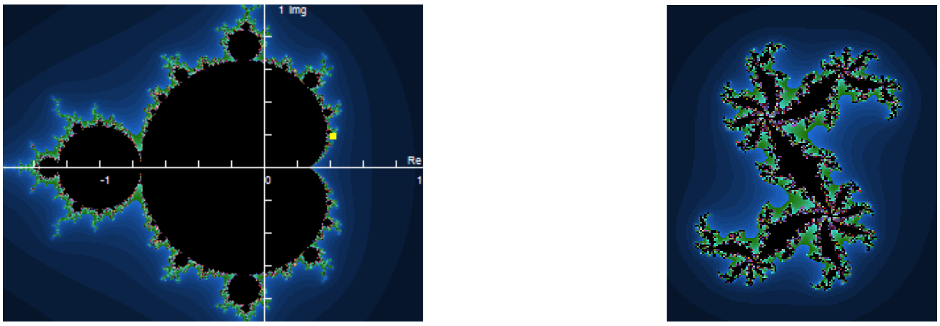
At the beginning of the twentieth century, mathematicians Gastón Julia and Pierre Fatou developed fractal sets obtained by iterating complex numbers. The Julia sets of a holomorphic function f is constituted by those points that under the iteration of f have a chaotic behaviour, and each point of the set forms a different set f that is then denoted by $J(f)$. The Fatou set consists of the points that have a stable behavior when they are iterated. The Fatou set of a holomorphic function f is denoted by $F(f)$ and it is a complement of $J(f)$. An important family of the Julia sets is obtained from the simple quadratic functions; for example, $Z_{n+1} = F(Z_n) = {Z_n}^2 + C$, where C is a complex number. The values obtained from this function are denoted J_C, with points of Z obtained from the parameter C that belong to the Julia sets. Other points obtained during the iteration are excluded from the Julia sets as they tend to infinity.

For example in Figure 3, the complex number C = 0.30 + 0.21i lies within the M set and produces Julia sets of connected points represented in black, and the points that go to infinity are represented in different colors according to the number of iterations necessary to escape. However, as shown in Figure 4, the complex number C = 0.40 + 0.15i lies on the boundary of the M set and produces a Julia set of points that are partially connected and distributed in different subgroups. Finally, Figure 5 shows a complete Julia sets of the complex number C = 0.50 + 0.21i, located outside of the M set.



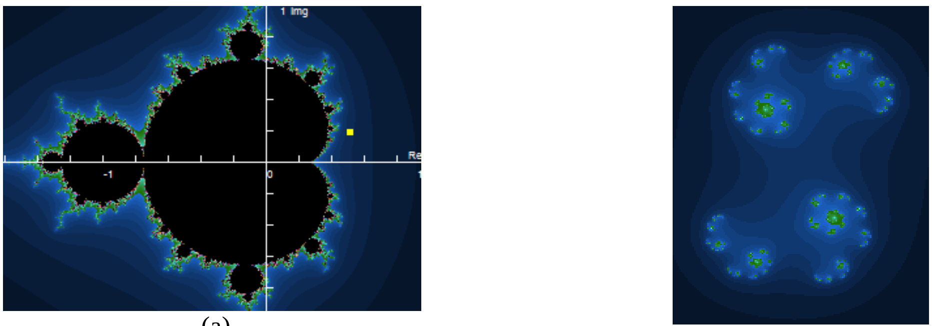
(a) (b)

Figure 3. Fractal diagrams when C is inside the M set, (a) M set, (b) J set



(a) (b)

Figure 4. Fractal diagrams when C is in the boundary of the M set, (a) M set, (b) J set



(a) (b)

Figure 5. Fractal diagrams when C is outside of M set, (a) M set, (b) J set

In summary, there are three types of Julia sets: the first set is formed by connected points that are obtained when the complex number C is inside of the Mandelbrot set; the second set is formed by partially connected points that are obtained when the complex number C is the boundary of the Mandelbrot set; and the third set is formed by non-connected points when the constant C is outside of the Mandelbrot set, resulting in infinite collections of isolated points with no discernible pattern. An important relation between the Mandelbrot and Julia sets is given when point C belongs to the Mandelbrot set; then, the Julia set $J(f_c)$ obtain a series of points that are connected. On the other side, when the point does not belong to the Mandelbrot set, the Julia set $J(f_c)$ is formed by non-connected points.

One property of the Mandelbrot set is that the different types of Julia sets are distributed in different regions of the set M. For all the above, it is concluded that in Figure 5, $C1$ is in the set of M and $C2$ is not in the set. In general, for any point within the M cardioid or its boundary, the Julia set of $J(f_c)$ has points that are connected. The most interesting C values are those near the boundary of the Mandelbrot set because the points can be transformed from connected points to non-connected points.

2.5. Algorithm to study the fractals of power demand

In order to obtain the results of the fractal topology patterns that represent the real and reactive power demand curves, the procedure shown in Figure 6.

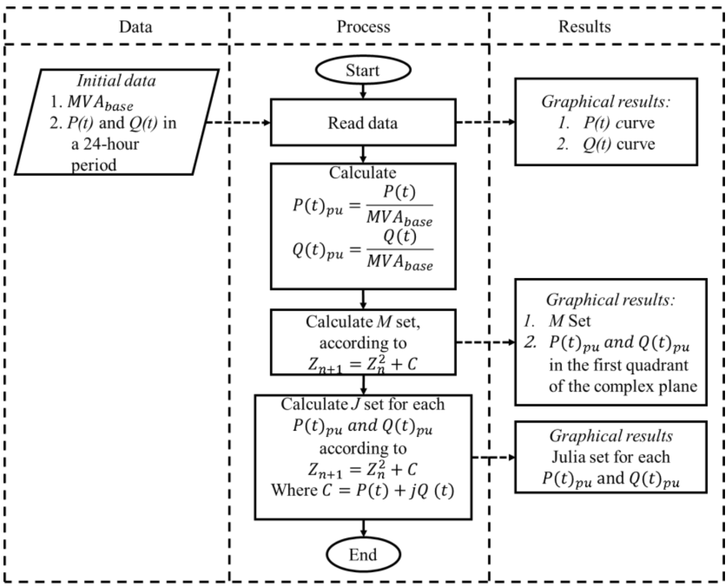


Figure 6. Algorithm with the steps used to obtain the fractal of the power demand

The initial process stars reading data of the power base and the real and reactive powers, followed by the calculation of each per unit value. In this case, the P and Q curves with respect to the time are plotted to represent the power demand during the day. Next, the M set is calculated and used to plot the fractal diagram. Now, the real and reactive powers of each point in the load demand curve are scaled into the M set and used to obtain the J sets. Then, the J sets are plotted into fractal diagrams to analyse qualitatively their geometries.

3. RESULTS AND ANALYSIS

Figure 7 presents the typical demand curves plotted with the data of Table 1 and Figure 8 presents the power demand plotted in the first quadrant of the complex plane. As real and reactive powers are positive, they represent a load consumption related to inductive elements. Under these conditions, the three most interesting values of the power consumption are selected such as the lowest consumption at 3:00, the highest consumption at 19:00, and the approximate average consumption at 09:00. Other hours of the day represent diagrams that are forms between the values as shown in the following results in this section. Figure 9 shows the fractal generated for each point of Figure 8. These fractals are created by performing iterations of the complex numbers obtained from the daily load demand.

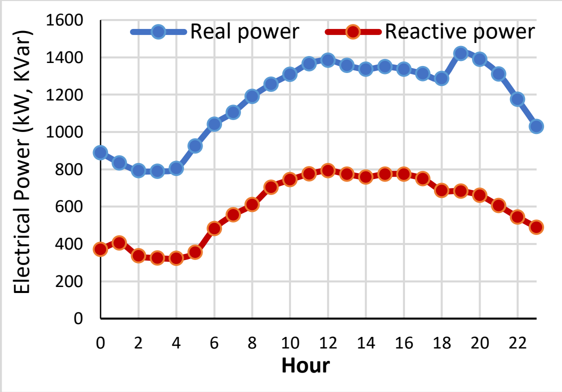


Figure 7. Typical load demand in a day

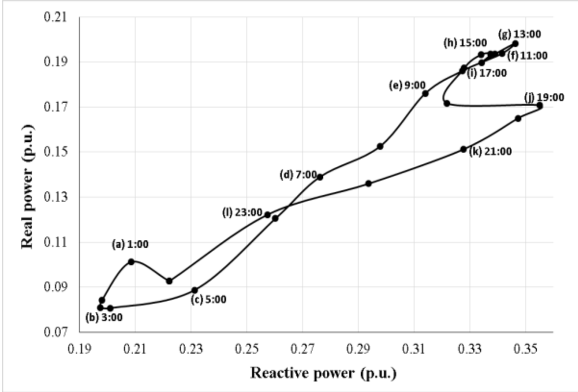
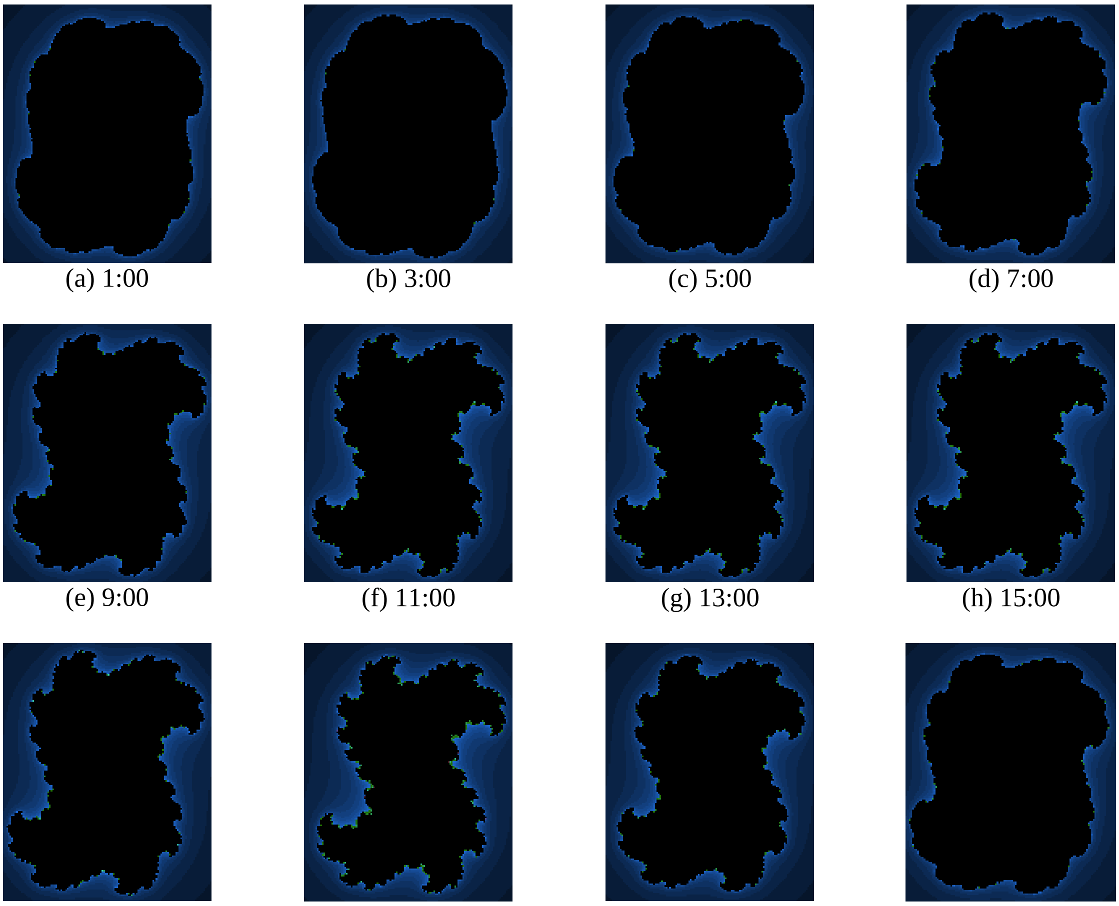


Figure 8. Real and reactive power plotted in the first quadrant of the complex plane of the M set



(a) 1:00 (b) 3:00 (c) 5:00 (d) 7:00

(e) 9:00 (f) 11:00 (g) 13:00 (h) 15:00

(i) 17:00 (j) 19:00 (k) 21:00 (l) 23:00

Figure 9. Representation of power demand in the first quadrant of the complex plane of J sets

All Julia sets plotted closed curves of connected points and represent the fractal topology of inductive power loads that belong to the first quadrant of the complex plane. The curves are transformed into fractal curves, where the semi plane save inverted reflections each other and with quadrants symmetrically inverted with respect to the origin. It is also true that, when the set of Julia is connected, the point C does not reach the boundary of the M set, and do not generate periodicity of the Julia set.

Now, with respect to the topological properties of the Julia sets registered in the lower demand period [00:00 - 05:00], the equivalent fractal topology is presented at 3:00 with an inverted reflective symmetry. Another feature of the sub-period is the practical invariance in the load demand, which is evident in the unmoving folding at the boundary of the fractal curve. At 05:00, the load demand begins to increase, generating greater fractal folds at the boundaries of the Julia set. At 09:00, the significant increase in the load demand is evidenced by the increase in the fractal folds of the Julia set. From 12:00 to 17:00, an average load demand is maintained, representing insignificant changes in the boundary of the Julia set. The point of greatest interest occurs at 19:00, when the greatest load demand, generating a topology with dense fractal folds at the boundary related to the properties of the peak load demand. From 19:00 to 24:00, the load demand decreases and the boundary of Julia set softens.

4. CONCLUSION

The paper presented a graphical representation of the power demand based on the topological properties of the Julia Sets, with the purpose of observing the different graphic patterns and relationship with each consumption in a daily load demand curve. An algorithm that iterates complex numbers of real and reactive powers is used to represent each fractal diagram of the consumption.

It is concluded that the load demand curve presents a clear fractal topology pattern of the Julia set and the following observations were obtained:

a. A new way of visualizing the state of the power demand curves is performed by using the fractal diagrams of Julia set.
b. The fractal topology of the Julia sets related to the properties of power demand does not give a quantitative but qualitative geometry information as results of studying the different images.
c. The topology of the Julia set reveals that the real and reactive powers studied for the load demand curve, which is related to an inductive load, belongs to the first quadrant of the complex plane.
d. The density of folds obtained from the Julia set is related to the proximity of the demand for real and reactive powers to the boundary of the Mandelbrot set.
e. From the electrical point of view, the densities of folds are related to: (a) power consumption through the different hours and (b) the combination of the real and reactive power magnitudes during the day.

The load demand curves studied in this article produce Julia sets with connected points because the points are within the Mandelbrot set. The fractals found with the Julia sets evidence that the load demand curves relate to the steady-state operation, which represents the zone of predictable values. After repeating the simulation for different real and reactive powers within the first quadrant of the complex plane, they produce the Julia set with symmetrically inverted fractal curves with respect to the origin.

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REFERENCES

[1] M. F. Barnsley, *et al.*, "The Science of Fractal Images," New York, NY, Springer New York, 1988.
[2] G. A. Losa, "Fractals and Their Contribution to Biology and Medicine," *Medicographia*, vol. 34, pp. 365-374, 2012.
[3] S. H. Strogatz, "Nonlinear Dynamics and Chaos," CRC Press, 2018.
[4] P. Moon, *et al.*, "Fractal images induce fractal pupil dilations and constrictions," *Int. J. Psychophysiol.*, vol/issue: 93(3), pp. 316-321, 2014.
[5] J. O. Rodríguez V., *et al.*, "Nueva metodología de evaluación del Holter basada en los sistemas dinámicos y la geometría fractal: confirmación de su aplicabilidad a nivel clínico," *Rev. la Univ. Ind. Santander. Salud*, vol/issue: 48(1), pp. 27-36, 2016.
[6] T. A. Garcia, *et al.*, "Fractal dimension in the evaluation of different treatments of muscular injury in rats," *Tissue Cell*, vol. 54, pp. 120-126, 2018.
[7] J. de D. H. Velázquez, *et al.*, "Fractal properties of biophysical models of pericellular brushes can be used to differentiate between cancerous and normal cervical epithelial cells," *Colloids Surfaces B Biointerfaces*, vol. 170, pp. 572–577, 2018.
[8] N. Popovic, *et al.*, "Fractal dimension and lacunarity analysis of retinal microvascular morphology in hypertension and diabetes," *Microvasc. Res.*, vol. 118, pp. 36-43, 2018.

[9] B. B. Mandelbrot and R. L. Hudson, "The (mis) Behaviour of Markets: A Fractal View of Risk, Ruin and Reward," London, Profile Books, 2004.
[10] R. Kumar and P. N. Chaubey, "On the design of tree-type ultra wideband fractal Antenna for DS-CDMA system," *J. Microwaves, Optoelectron. Electromagn. Appl.*, vol/issue: 11(1), pp. 107-121, 2012.
[11] D. Ye, *et al.*, "Average weighted receiving time on the non-homogeneous double-weighted fractal networks," *Phys. A Stat. Mech. its Appl.*, vol. 473, pp. 390-402, 2017.
[12] Y. J. Ma and M. Y. Zhai, "Fractal and multi-fractal features of the broadband power line communication signals," *Comput. Electr. Eng.*, 2018.
[13] H. Cui and L. Yang, "Short-Term Electricity Price Forecast Based on Improved Fractal Theory," *2009 International Conference on Computer Engineering and Technology*, pp. 347-351, 2009.
[14] Z. Zhao, *et al.*, "Multi-fractal fluctuation features of thermal power coal price in China," *Energy*, vol. 117, pp. 10-18, 2016.
[15] G. Salvó and M. N. Piacquadio, "Multifractal analysis of electricity demand as a tool for spatial forecasting," *Energy Sustain. Dev.*, vol. 38, pp. 67-76, 2017.
[16] M. Y. Zhai, "A new method for short-term load forecasting based on fractal interpretation and wavelet analysis," *Int. J. Electr. Power Energy Syst.*, vol. 69, pp. 241-245, 2015.
[17] N. S. M. Yaziz, *et al.*, "The Improvement of first Iteration Log Periodic Fractal Koch Antenna with Slot Implementation," *Int. J. Electr. Comput. Eng.*, vol/issue: 8(4), pp. 2564, 2018.
[18] M. Ihamji, *et al.*, "Design of Compact Tri-Band Fractal Antenna for RFID Readers," *Int. J. Electr. Comput. Eng.*, vol/issue: 7(4), pp. 2036, 2017.
[19] L. F. Acevedo, *et al.*, "Dynamic Voltage Stability Comparison of Thermal and Wind Power Generation with Different Static and Dynamic Load Models," *Int. J. Electr. Comput. Eng.*, vol/issue: 8(3), pp. 1401, 2018.
[20] K. Cabana, *et al.*, "Voltage sensitivity analysis to determine the optimal integration of distributed generation in distribution systems," *Int. J. Electr. Comput. Eng.*, vol/issue: 9(1), pp. 55-65, 2019.

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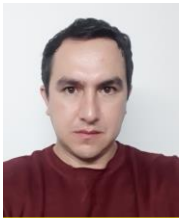

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