Nonlinear Resistance Circuit Curve Intersection Method Algorithm Research

Wang Haiyue[1,2](✉) and Su Xunwen[1]

[1] Heilongjiang University of Science and Technology, Harbin 150022, China
2509614001@qq.com
[2] Shang Du Power Plant, Inner Mongolia, China

Abstract. The volt-ampere relation (VCR) of nonlinear resistance elements is a nonlinear function relation which does not satisfy ohmic law. In this paper, the curve intersection method of nonlinear resistance circuits is studied and analyzed. Firstly, the existence and uniqueness of the solution of nonlinear resistance circuit are discussed, and then the feasibility of the algorithm is verified by computer simulation. Then the actual operation is verified by Multisim software. The experiment is an algorithm used when the volt-ampere characteristics of nonlinear resistance are given by the actual test data. This is an algorithm for finding the intersection point of arbitrary straight line and polynomial curve function. Compared with the actual measured results, the results obtained by the algorithm are almost resulting in. It can be said that the algorithm is an efficient and simple method to solve the problem.

Keywords: Non-linear · Curve intersection method · Cubic polynomial · Simulation simulation

1 Introduction

Nonlinear circuit theory has always been one of the important research directions of circuit theory. Because all real circuits have nonlinear circuit properties from a realistic perspective. Therefore, strictly speaking, all circuits belong to nonlinear circuits in reality.

Linear circuit is a special form in nonlinear circuit. If the difficulties facing the nonlinear circuit are overcome, the difficulty that the linear circuit needs to solve is naturally solved.

In this paper, the nonlinear resistance circuit is solved by the method of curve intersection in MATLAB calculation software. The measured data points are fitted with the three-time polynomial fitting through the MATLAB software, the obtained function is used instead of the nonlinear resistance characteristic curve equation, and the intersection point of the load line and the fitting curve is obtained. The intersection of two volt-ampere characteristic curves is the static working point of the circuit.

A set of experimental data are generated by using Multisim software to simulate and test, and then the coordinates of intersection points are obtained by using interpolation and fitting algorithm in MATLAB software.

X. Jiang and P. Li (Eds.): GreeNets 2020, LNICST 333, pp. 108–116, 2020.
https://doi.org/10.1007/978-3-030-62483-5_12

2 Solution Method of Nonlinear Resistance Circuit

In linear circuits, the characteristic of linear components is that their parameters do not change with voltage or current. If the parameter of the circuit element varies with voltage or current, it is referred to as a non-linear element. A circuit comprising a non-linear element is referred to as a non-linear circuit.

All of the actual circuits in the reality are non-linear circuits. In general, those elements whose non-linear degree changes are not very obvious are treated as linear elements, and the accuracy and accuracy of various parameters calculation can be ensured while the circuit analysis is simplified. However, for the circuit whose nonlinear characteristics can not be ignored, it must be treated as a nonlinear circuit. Avoid the difference between the calculated value and the actual value without significance.

The method of analyzing the non-linear circuit has curvilinear intersection algorithm, piecewise linear method, small signal analysis. These methods can solve the nonlinear circuit with simple circuit diagram, but it is difficult to find the approximate solution satisfying the accuracy for the complex nonlinear circuit.

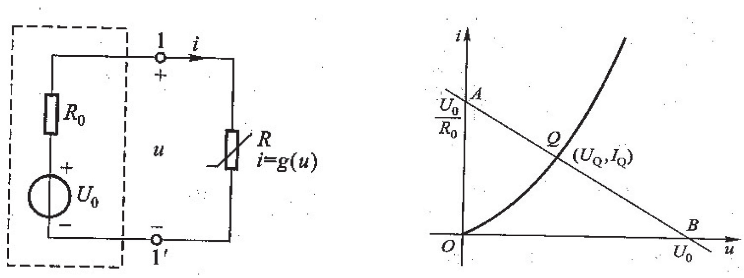
With the rapid development of science and technology. The computer algorithm replaces the traditional manual calculation. It not only can improve the computational efficiency, but also get the exact value.

In the following article, the non-linear resistance circuit is simply introduced, and several commonly used methods for solving the non-linear resistance circuit are mentioned.

2.1 Curve Intersection Method

The advantage of curve intersection is that it can depict the content by chart.

A simple nonlinear Resistance circuit by voltage source U_0 and linear resistance R_0 nonlinear resistance R composition. Figure 1(a) is Nonlinear Resistance Circuit.



(a) (b)

Fig. 1. Static operation point

The electrical network is consisted of the voltage source U_0 and the linear resistor R_0. The nonlinear resistance element R is an external circuit. The intersection of the volt-ampere characteristic curve of the two-part circuit is the static working point Q(U_Q, I_Q). Figure 1(b) is the resulting graph.

2.2 Small Signal Analysis Method

A nonlinear circuit that is usually encountered in an electronic circuit It not only has a DC power supply, but also has an input voltage that varies over time. Suppose in any case, there's an $|u_s(t)| \ll U_0 \cdot u_s(t)$ is called a small signal voltage. Small signal analysis can be used to analyze this kind of circuit.

The method of the small signal analysis method comprises the following steps of:

1. Solving the static working point Q of the non-linear circuit.
2. Solving the dynamic resistance of nonlinear circuits.
3. Make a small signal equivalent circuit for a given nonlinear resistance at a static operating point. Figure 2 is the equivalent circuit

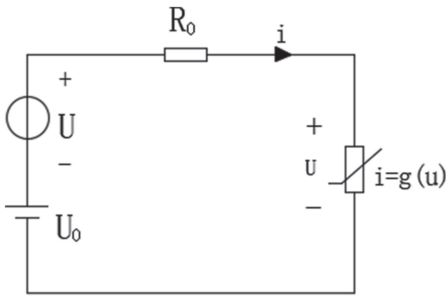


Fig. 2. Small signal equivalent circuit

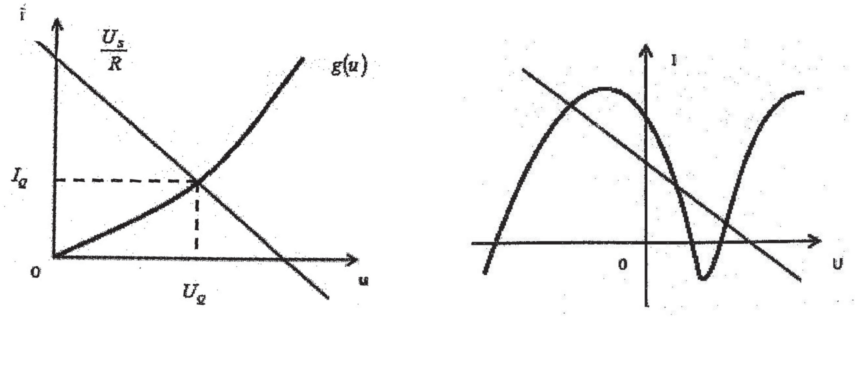
4. The Solution of the Equivalent Circuit Based on the Small Signal.

3 Existence of Solutions for Nonlinear Resistance Circuits

3.1 Solution of Nonlinear Resistance Circuit

Unique solution: In the voltage-controlled resistance circuit, if the volt-ampere characteristic curve is monotonous, and this set of voltage and current values satisfies the KCL, KVL at the same time. Figure 3(a) is a curve with only one solution.

Multiple solutions: The electrical network is consisted of the voltage source and the linear resistor. The nonlinear resistance element is an external circuit. In practice, the volt-ampere characteristic curves of some nonlinear resistance are not monotone. The load line and the non-linear resistance volt-ampere characteristic curve have a plurality of intersection points. The volt-ampere characteristics of nonlinear resistance curves with multiple solutions is shown in Fig. 3(b).



(a) (b)

Fig. 3. Solution of nonlinear Resistance Circuit

4 MATLAB Programming

4.1 Introduction of MATLAB Drawing Function

In MATLAB, the most basic and widely used drawing function is plot, which can draw different curves on two-dimensional plane, while the plot drawing statement used in this design is used in this design.

Plot function is used to draw the graph of linear coordinate on two - dimensional plane.

For example, when you draw a function image of y = cos (x), we can use the plot statement. Figure 4 is the function graph.

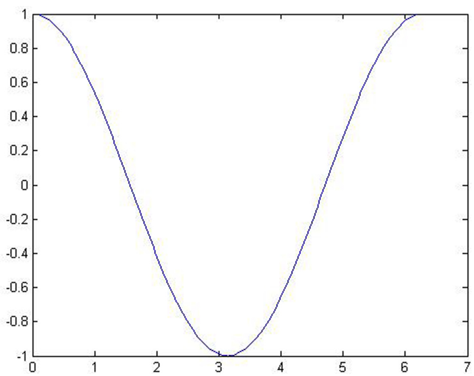


Fig. 4. y = cos(x) function graph

Enter the command in the command window:

$$\gg x = 0 : pi/100 : 2 * pi;$$
$$\gg y = \cos(x);$$
$$\gg plot(x, y);\ \text{drawing}\quad y = \cos(x)\ \text{images}$$

4.2 Cubic Spline Interpolation

With the rapid development of modern scientific and technological means. People often encounter that function expressions are too complex to be worked out in a short period of time. Therefore, it is necessary to study a new interpolation method-Spline interpolation method.

The term spline comes from life, and a set of data actually measured is expressed in plane coordinates. All the points in this set of data are connected smoothly to form a smooth curve that connects all the experimental data points. Such a curve is called a spline. It is actually connected by the cubic polynomial curve, and the so-called spline interpolation is obtained mathematically.

5 Multisim Simulation

5.1 Simulation Circuit Design and Measured Data

The simulation is simulated according to the schematic Fig. 5. Select a linear sliding rheostat with an adjustment range of 0–100 Ω. The regulated range of the DC voltage source is 1–10 V. Select model $1N4149$ Diode as nonlinear resistance. Adjust the size of the DC power supply and record the voltage u_i and current i_i of the nonlinear resistance. Table 1 is the actual measured data.

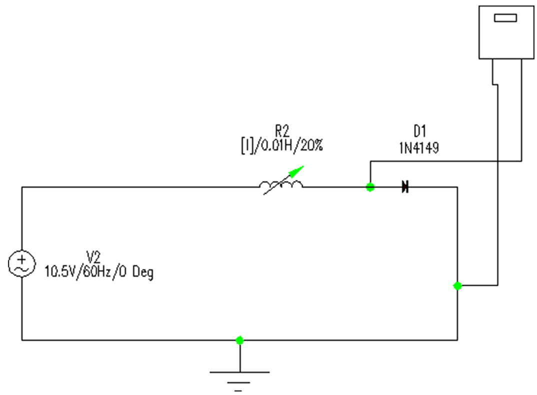


Fig. 5. Wiring diagram of the simulation circuit

Table 1. Measured data of simulation circuit

$i_i(A)$	1.452	1.555	1.773	1.804	2.110	2.318	2.553	4.295
$u_i(V)$	0.108	0.124	0.159	0.164	0.218	0.257	0.304	0.773

5.2 Volt-Ampere Characteristic Curve of Nonlinear Resistance

Enter directly in the command window.

The command is executed as shown in Fig. 6.

```
>>x=[1.452 1.555 1.773 1.804 2.110 2.318 2.553 4.295];
>>y=[0.108 0.124 0.159 0.164 0.218 0.257 0.304 0.773];
>>xi=1.4:0.01:4.3;
  yi=spline(x,y,xi);
  plot(x,y,'o',xi,yi);
  p = polyfit(xi, yi,3);
```

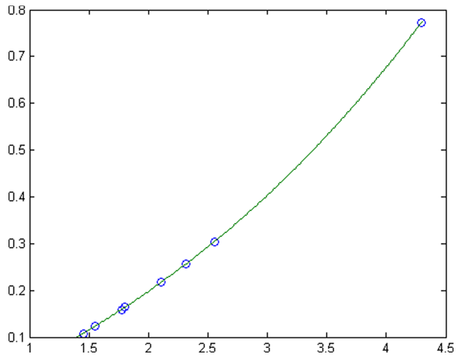


Fig. 6. Nonlinear resistance volt-ampere characteristic curve

5.3 The Principle of the Algorithm for Finding the Intersection Point

In this paper, the one-dimensional interpolation method is used. The plane volt-ampere characteristic curve of nonlinear resistance $g(u)$ is drawn by one-dimensional interpolation method and the analytical expression is obtained. In this method, the test data points are used as interpolation nodes and described by cubic splines interpolation function.

Use $s(u)$ if the allowable error is close to the wireless small Gradually approach $g(u)$. According to the derivative in the course of higher mathematics, $s(u)$ must be a convergence function and must have a second-order smoothness condition.

The principle of $l(u)$ and $s(u)$ intersection is shown in Fig. 7. The coordinate axis of independent variables is divided into infinitely many small intervals, and it is necessary to ensure that the interval length of each new interval is less than the length of the original interval. Until the coordinates of the intersection point within the allowable error range can be obtained, which is the solution of the circuit. In essence, the iterative process is gradually approaching to the real value, and the solution within the allowable range of the error is obtained. The specific algorithms are as follows:

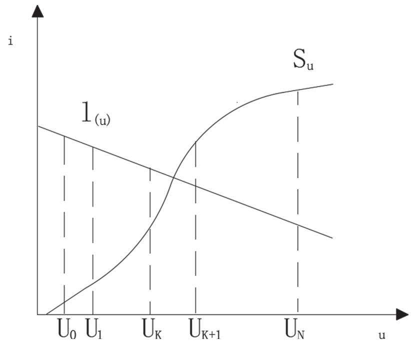


Fig. 7. Intersection of isometric cut

First average segmentation $\Delta_1 : a = u_0 < u_1 < \ldots u_j < \ldots u_N = b$, j = 0, 1, 2, … N, $u_j = u_0 + j[(b-a)/N]$, Interval length $\delta_1 = (b-a)/N$. Subtract each dividing point u_j, just as $f(u_j) = l(u_j) - s(u_j)$. If there is a unique intersection Q within the area [a, b], the two sides $f(u_j)$ and $f(u_k)$ of the Q point are opposite to each other.

Then the subinterval of the first isometric segmentation $\delta_1 = (b-a)/N$ is replaced by the total length of the original interval for the second isometric segmentation.

It is determined that the coordinates of the intersection point Q are in a narrower range of area, the width of which is $1/N$ of the length $[a_1, b_1]$ of the small section of the last isometric division. This cycle iterates until an interval length is obtained and within the allowable error range. The iterative process is ended and the intermediate value of the area is taken as the intersection coordinate Q.

5.4 Calculation of Static Working Point

The load line and the non-linear characteristic curve are both represented in the software, and the intersection points of the two curves are calculated by using the assembler language. This is the very important static working point we need to ask for. The programming content is as follows:

```
>> x = [1.452 1.555 1.773 1.804 2.110 2.318 2.553 4.295];
>> y = [0.108 0.124 0.159 0.164 0.218 0.257 0.304 0.773];
>> xi = 1.4 : 0.01 : 4.3;
   yi = spline(x, y, xi);
   plot(x, y, o, xi, yi);
>>hold on;
>>x2=0:4.5;
>>y2=-0.05*x2+0.435;
>>plot(x2,y2);
>>[x,y]=solve('0.003*x^3+0.0069*x^2+0.1132*x-0.0801','y2=-0.005*x2+0
.435');
x=
   2.671
 y=
   0.319
```

Figure 8 is intersection curve. By using the algorithm, the coordinates of the intersection point are obtained to be (2.671, 0.319). That is the static operating point of the diode.

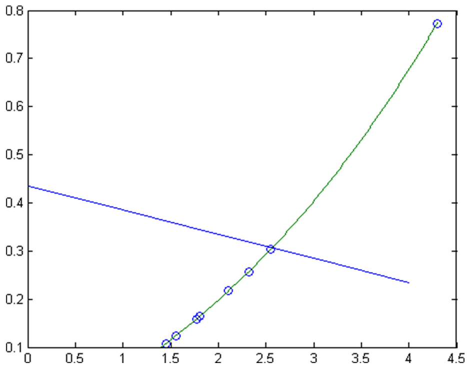


Fig. 8. Load line and characteristic curve

6 Conclusion

The static working point of the circuit is obtained by the curve intersection method, which has higher accuracy than the traditional graphic method. This practical solution can be applied to any monotonous nonlinear resistance circuit.

It is found that the curve intersection method is the best method with fast calculation, low complexity and high accuracy.

Acknowledgment. This work was financially supported by the National Science Foundation of China under Grant (51677057), Local University Support plan for R & D, Cultivation and Transformation of Scientific and Technological Achievements by Heilongjiang Educational Commission (TSTAU-R2018005) and Key Laboratory of Modern Power System Simulation and Control & Renewable Energy Technology, Ministry of Education (MPSS2019-05).

References

1. Martins: Validation of fixed speed wind turbine dynamic models with measured data. IEEE Trans. Power Electron. **28**(11), 5100–5110 (2012)
2. Bottrell, N., Prodanovic, M., Green, T.C.: Dynamic stability of a microgrid with an active load. IEEE Trans. Power Electron. **28**(11), 5107–5119 (2013)
3. Piyasinghe, L., Miao, Z., Khazaei, J., Fan, L.: Impedance model-based SSR analysis for TCSC compensated type-3 wind energy delivery systems. IEEE Trans. **6**(1), 179–187 (2015)
4. Huang, L., Li, J., Liu, X., et al.: Realization of complex torque coefficient method in time domain based on PSCAD/EMTDC and research on the Influence on Electrical Damping. Sensor World **24**(2), 13–18 (2018)
5. Li, G., Zhang, S., Zhang, Z.: Analysis of the possibility of subsynchronous resonance under the high series compensation level of the 330 Kv main network in Northwest China by frequency scanning method. Proc. CSEE **12**(1), 58–61 (1992)
6. Yang, X.: Study on Network Topology Analysis and Operation Modes Combination in Power System, vol. 27. Huazhong University of Science and Technology, Wuhan (2007)
7. Wen, B., Boroyevich, D., Burgos, R., et al.: Small-signal stability analysis of three-phase AC system in the presence of constant power loads based on measured d-q frame impedances. IEEE Trans. Power Electron. **30**(10), 5952–5963 (2015)
8. Wang, K., Xu, Z., Du, N., et al.: Subsynchronous resonance by thyristor controlled series compensation. High Volt. Eng. **42**(1), 321–329 (2016)
9. García-Gracia, M., Comech, M.P., Sallán, J.: Modelling wind farms for grid disturbance studies. IEEE Trans. Power Electron. **30**(10), 4952–4963 (2013)
10. Blaabjerg, F., Teodorescu, R., Liserre, M., Timbus, A.V.: Overview of control and grid synchronization for distributed power generation systems. IEEE Trans. Ind. Electron. **53**(5), 1398–1409 (2006)