

Simulation Analysis of Suppression of Resonant Overcurrent by Nonlinear Components

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Abstract

For the development of distributed power supply active distribution network system, the instability of the power supply side causes the system frequency to be disturbed, and harmonics, voltage fluctuations, or ferromagnetic saturation causes resonance and other series of power quality problems; what resulting in the over-voltage and over-current can easily damage components and threaten the system's safe and stable operation. In order to solve these problems, this paper compares some harmonic detection and filtering methods, devices and methods for suppressing resonance in recent years, and combines the principle of resonance to design a nonlinear inductive circuit that can suppress resonant overcurrent according to the characteristics of nonlinear inductors. Compared with the Resistance (R) series Induct Capacitance (LC) parallel circuit composed of common inductors, the circuit described in this paper is not affected by overcurrent, and the influence of overvoltage is relatively greatly reduced. The simulate-on proves that this circuit suppresses the effects of resonant overvoltage and overcurrent.

Keywords

Power Quality, Resonance, Nonlinear Inductance, Suppression of Overcurrent

1. Introduction

Due to the rapid development of new energy sources, wind, water, geothermal, and photovoltaic power generation are gradually moving toward the direction of Distribution generation (DG) supply. Its rapid development and high load penetration rate may reach 50% - 60% in the future and 110% in extreme.

Since a great deal of distributed power access requires many power electronic devices, such as compensation devices, a large number of inverter devices, and

the influence of the power generation conditions of the DG, the power quality requirements of the active distribution network are great [1]. The power quality requirements of the active distribution network are highly valued. It actively controls the distribution network, energy storage, power supply instability, and load coordination to ensure the stability of the power system. The classification of power quality problems in DG mainly includes the following aspects:

1) The problem of voltage fluctuation.

Since distributed power sources such as photovoltaics, wind power, and tidal power have strong dependence on natural conditions. Therefore, the irregular operation of the power supply easily causes voltage fluctuations and over-limit phenomena to cause frequency oscillation, and the unstable system.

2) The problem of three-phase imbalance.

This is a problem due to the lack of coordination information for distributed power single-phase access of variable capacity, resulting in an imbalance in the capacity of a certain phase. Similarly, the unreasonable control of the inverter can also lead to unbalanced voltage output, which may become a mainstream problem in the future.

3) The problem of harmonic.

The output of the distributed power supply contains a large number of power electronic devices with a wide output spectrum. At the same time, with the complexity of some original filtering devices and impedance structures of the power grid, the probability of resonance is obviously improved. These cause harmonic pollution of the power grid and damage to electrical equipment. Although the quality of domestic inverters has gradually increased, due to the rapid development speed, the speed of inverter replacement is temporarily unable to popularize all power stations. So the problem is still grim [2].

It can be seen that most of the power quality problems, including the imbalance problem, are directly reflected in the instability of the voltage and current causes the grid to be unbalanced. And the damage to electrical equipment components results in a system that does not operate stably. The control of power quality has the following steps: monitoring early warning, analysis, active control, and developing power technology. The methods used in the current detection are: Fourier transform, wavelet transform, transform, dynamic measure [3].

Literature [4] proposed that the dynamic measure method can detect time domain distortion points, but the frequency domain information cannot be fed back. S-transformation and generalized S-transformation are more redundant, and the real-time performance is poor. The S-transformation time-frequency performance is insufficient. The wavelet transform upgrades the Fourier transform, but its frequency and resolution relationship is susceptible to interference. In short, the method, speed and curacy of the detection are constantly improving, but there are certain deficiencies. After the failure and the problem occur, it is difficult to deal with the large operation problem in time.

Reference [5] uses compensation capacitor capacity, packet capacity, and series reactors to avoid large-capacity resonances. And improve filters based on

various algorithms. However, in the case of switching operations or failures, some oscillating frequency loops in the power system may resonate with the external power supply, resulting in severe re-resonant overvoltage or overcurrent in some parts (or components) of the system. Reference [6] pointed out that the interaction between ferromagnetic saturation and poor parameters mainly led to the occurrence of Resonance. The detection and filtering alone can only solve the source of a part of the resonance but cannot solve the resonance problem comprehensively.

The literature [7] [8] [9] studied the existing protection devices against overpressure and overcurrent. Such as ferromagnetic resonance adaptive protection, lightning arrester, surge protector, reclosing, overcurrent release and so on. The former two are widely used in non-controllable fault factors, due to weather factors or accidents caused by large scale power system parameter deviations to prevent large area major accidents. Reclosure is more used in overcurrent relay protection, and it has poor applicability to permanent faults and is more likely to be rejected after refusal. The overcurrent release has higher requirements for Current Transformer (CT) saturation and degaussing treatment, and is greatly affected by CT.

This article will design a new circuit. The Wei'an characteristic curve of the nonlinear inductor is used to change the parameters of the original impedance of the circuit in the overvoltage or overcurrent state, so that the circuit impedance is recombined and calculated to achieve the purpose of suppressing the overcurrent protection circuit and the component device.

2. Principle and Structure of Resonant Circuit

Resonance is divided into series resonance and parallel resonance [10].

2.1. Series Resonance

$$Z(j\omega) = R + j\left(\omega L - \frac{1}{\omega C}\right) \quad (1)$$

Since the inductive reactance and capacitive reactance in the series circuit can cancel each other out, when: $\omega = \omega_0$, $X(\omega_0) = 0$.

At this time, the voltage on the port is equal to the current. This operation of the circuit is called resonance in electric engineering. Since it occurs in the RLC series circuit, it is called series resonance.

$$\text{Im}[Z(j\omega_0)] = 0 \quad (2)$$

$$\omega_0 L - \frac{1}{\omega_0 C} = 0 \quad (3)$$

2.2. Parallel Resonance

The principle of parallel resonance is the same as the series connection that the reactance part of the impedance is zero, resulting in overvoltage and overcurrent

of the circuit.

The basic structure of the complex impedance of the parallel is as **Figure 1**.

The input admittance according to **Figure 1**:

$$Y(j\omega_0) = G + j\left(\omega_0 C - \frac{1}{\omega_0 L}\right) \quad (4)$$

Resonance condition:

$$\text{Im}[Y(j\omega_0)] = 0 \quad (5)$$

$$Y(jW_0) = G + j\left(W_0 C - \frac{1}{W_0 L}\right) = jW_0 C + \frac{R}{R^2 + (W_0 L)^2} - j\frac{W_0 L}{R^2 + (W_0 L)^2} \quad (6)$$

$$W_0 C = \frac{W_0 L}{R^2 + (W_0 L)^2} = 0 \quad (7)$$

Solved by the above formula:

$$W_0 = \frac{1}{\sqrt{LC}} \sqrt{1 - \frac{CR^2}{L}} \quad (8)$$

It can be seen that when: $R > \sqrt{\frac{L}{C}}$ the circuit does not resonate.

This paper mainly proposes and parallels the complex impedance structure as the research object:

$$Z(j\omega_0) = R + \frac{\frac{L}{C}}{j\left(\omega_0 L - \frac{1}{\omega_0 C}\right)} \quad (9)$$

Parallel resonance condition:

The same formula as (5)

$$\text{Im}[Y(j\omega_0)] = 0$$

Get the same as formula (3):

$$f(t) = f(t + kT), \quad \omega_0 L - \frac{1}{\omega_0 C} = 0$$

The first resonance can avoid the occurrence of the resonant circuit as long as the complex impedance is matched at $R > \sqrt{\frac{L}{C}}$.

However, the second structure of the circuit in the higher harmonics, external circuit failure or disturbance causes the internal impedance combination to be confused so that the formula (3) is satisfied, it will cause: $\dot{I}_L + \dot{I}_C = 0$. Therefore, also referred to as the parallel resonance current resonance, Branch current $I_R \rightarrow 0$, Overcurrent occurs in the inductor and capacitor, but the equivalent susceptance seen from both ends of L and C is equal to zero, that is, the impedance is infinite, which is equivalent to an open circuit.

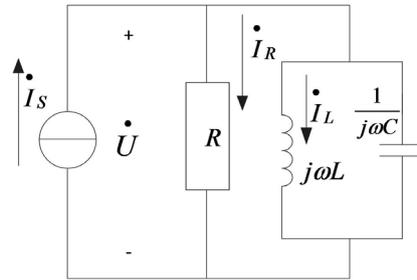


Figure 1. RLC parallel circuit.

2.3. Non-Sinusoidal Periodic Circuit Applied in Resonance

As we all know that the linear circuit operates under the action of a sinusoidal power supply or multiple power supplies of the same frequency. The steady state voltage and current of each part of the circuit are sinusoidal quantities of the same frequency. However, in engineering practice, there are power supplies and signals that change according to non-sinusoidal laws. The current is a non-sinusoidal function of time and is called a non-sinusoidal current. Non-sinusoidal currents are divided into two types, periodic and non-periodic. Frequency changes are divided into two cases: gradual change and sudden change. Since the resonance occurs at a certain frequency due to the combination of circuit impedances, the frequency gradation can be regarded as a kind of sudden change. The method of suppressing overcurrent used herein can function.

Non-sinusoidal periodic voltage and current signals can be represented by a periodic function, which is: $f(t) = f(t + kT)$, where T is the period of the periodic function $f(t)$, $k = 0, 1, 2 \dots$ If a given periodic function satisfies the Dirichley condition, it can be expanded into a convergent Fourier series, which is:

$$f(t) = A_0 + \sum_{k=1}^{\infty} A_{km} \cos(k\omega t + \theta_k) \quad (10)$$

The power supply of this circuit can be regarded as a time-frequency AC source. This article simulates the realization of such a signal in MATLAB, providing the basis for the next step of building a resonant circuit:

Due to the use of the complex impedance of the circuit in this paper:

$$jX = jk\omega_0 L - j \frac{1}{k\omega_0 C} \quad (11)$$

Then for the impedance in the parallel circuit, if

$$k\omega_0 L - \frac{1}{k\omega_0 C} = 0, k\omega = \frac{1}{\sqrt{LC}} \quad (12)$$

It is said that parallel resonance occurs when the (k) th harmonic occurs.

3. Circuit Design and Calculation

Different from other methods of governing resonance phenomena, the characteristics of nonlinear components can be utilized to make the characteristics of the

components change when the characteristics of the resonance are found, and then operate in the non-resonant state at the original resonant frequency, avoiding overcurrent. For a conventional parallel resonant circuit, as shown in **Figure 2** in an impedance structure with a power factor above 0.9, the overcurrent at the time of resonance is negligible for the main impedance, so the structure circuit of **Figure 3** is selected herein. This figure focuses on a section of the curve that utilizes the characteristics of the inductor of a particular Wei'an curve to account for overcurrent in the parallel circuit.

1) Custom Nonlinear Module

The voltage v and the current i on the inductive component have the following relationship:

$$v = L \frac{d_i}{d_t} = \frac{d_\Psi}{d_t} \quad (13)$$

where Ψ is the self-inductive flux linkage on the inductive component.

Flux Ψ is:

$$\Psi = \int v dt \quad (14)$$

Therefore, the current on the inductor is:

$$i = \frac{\Psi}{L} = \frac{\int v dt}{L} \quad (15)$$

It can be seen that the non-linear inductive component can be represented by a controlled current source that is controlled by the voltage across the current source.

2) Selecting the Wei'an curve and its inductive components through the circuit.

Because when resonance occurs: by the formula (12) and the **Figure 3** circuit, then L and C will withstand all the voltage of the circuit and thus cause overcurrent of the L and C components, If the inductance changes due to the set curve, the circuit can get rid of the resonance state, but it does not mean that it can completely return to the rated operating state, and may enter the secondary overvoltage or overcurrent state, but at this time the voltage. The current Value of validity is already below the I_f or V_f .

We assume that resonance occurs in the state of k th harmonic, and the current voltage formed by the parameter that changes the voltage of the inductance element after exceeding the threshold can be close to or even the same as the current value in the steady state. The following calculations were made:

$$\begin{cases} k\omega_0 L - \frac{1}{k\omega_0 C} = 0 \\ \frac{\frac{L_1}{C}}{\frac{1}{k\omega C} - k\omega L_1} = \frac{\frac{L_2}{C}}{\frac{1}{k\omega C} - k\omega L_2} \end{cases} \quad (16)$$

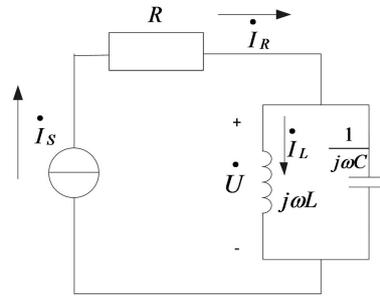


Figure 2. LC parallel and R series structure.

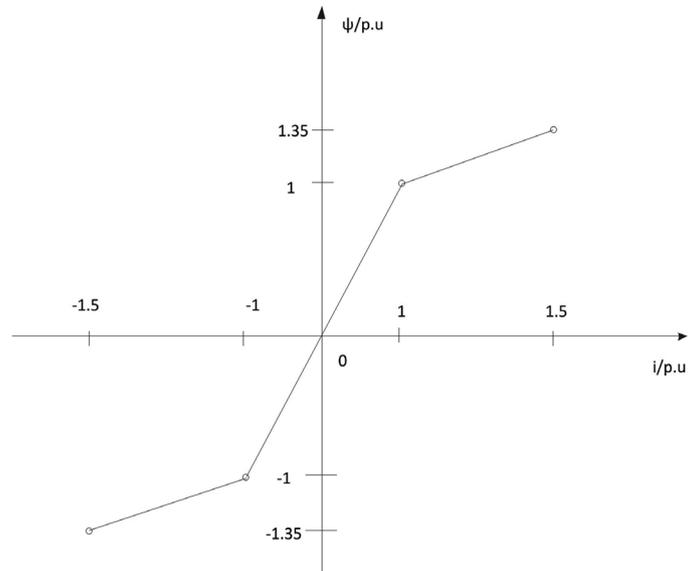


Figure 3. The wean characteristic curve designed in this paper.

Since L_1, k, C can be known to the original circuit, Therefore L_2 can be found to satisfy the assumptions.

3) According to the above design idea, an inductor has the following Wei'an characteristic curve. When the operating environment is 0 - 180 V, the inductance is constant at 2 H. When the voltage exceeds 180 V, the inductance component is saturated. The nonlinear variation of the inductance value is shown in Figure 3.

4. Simulation Analysis

1) Construct a Nonlinear Inductance Simulation Model.

The model includes a voltmeter module, a controllable current source module (current direction of the current source is indicated by the arrow), an integration module, and a look-up table module for describing flux-current saturation characteristics. There is a signal output port m that outputs the magnetic flux on the nonlinear inductive module like Figure 4 and the voltage across the module.

2) Set and optimize the parameter fluxcurrent characteristics according to the curve in Figure 3. The parameters of the remaining modules are set by default.

Establish the model of (5) parallel resonant overcurrent protection circuit, set the component parameters: the system voltage is 20 V, the withstand voltage is much larger than its operating rating, according to its Wei'an characteristic voltage threshold is 180 V, which is the original operation rating current, $U_s(t) = 400 \cos(\omega t) V$, After calculating the maximum value of each parameter at the steady state, $I_L = 4 A$, $U_L = 16.63 V$, when at resonance state: $U_L = 400 V$, $I_L = 4 A$.

3) Before directly running the model as **Figure 5**, first simulate the parameters of the circuit when the parallel resonance occurs under normal conditions, and then simulate the resistance and nonlinear inductance of the power supply with the frequency variative when the parallel inductance is connected when the nonlinear inductance model is connected in the simulation diagram (2). Parameter curve. And get the following original voltage and current curves.

4) According to the diagram (3), after the nonlinear pressure-sensitive inductor is connected to the simulation, the voltage current exceeds the threshold when the circuit resonates, and the voltage and current curves are triggered after changing the inductance value according to the original Wei'an curve:

It can be seen from **Figure 6** and **Figure 7** and **Table 1** that the inductor still has a certain degree of overvoltage at the time of resonance, but it is far within the range of withstand voltage that does not cause breakdown. However, the inductance of the Wei'an characteristic curve in the inductor part is saturated when the curve threshold voltage is encountered, so that the inductance value changes. This also causes the current to drop from the original resonant state overcurrent to its current value after changing the inductance value. Its magnitude is very close to the steady-state current value where no resonance occurs. Due to the change of the parameters of the inductive component, the circuit destroys the original resonant state and steps to the normal operating state at the original resonant frequency. When the circuit returns to the original frequency, the inductor voltage returns to the threshold, and the inductance value returns to the previously set state of 2 H, and the circuit returns to the normal operating point to continue operation.

It can be seen from **Table 1** that the model has obvious effects of suppressing overcurrent and overvoltage.

Table 1. A comparison of the parameters of the inductor in two states.

Circuit state:	Steady state current (A)	Steady state voltage (V)	Resonant current (A)	Resonant voltage (V)
using common Inductive Component	0.85	16.66	3.98	399.8
Access set nonlinear Inductive component	0.85	16.66	0.852	178

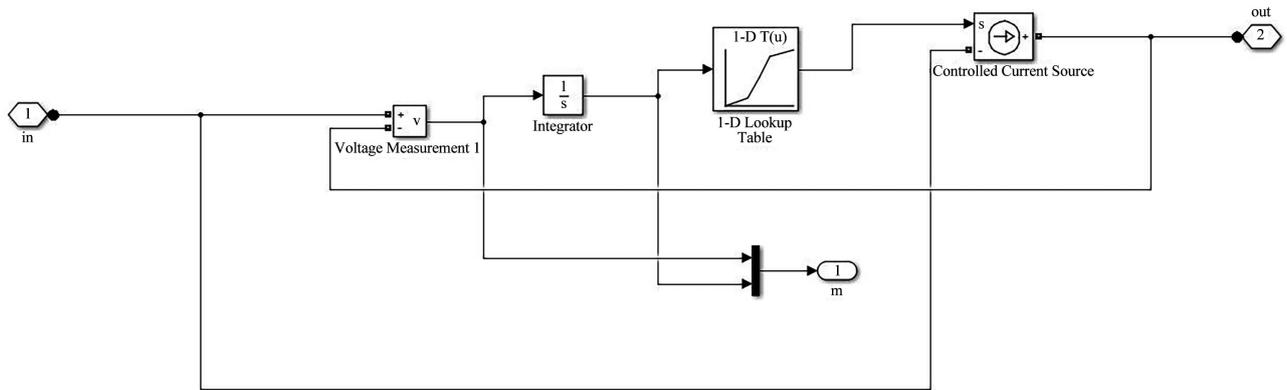


Figure 4. Simulation model of nonlinear pressure sensitive inductor.

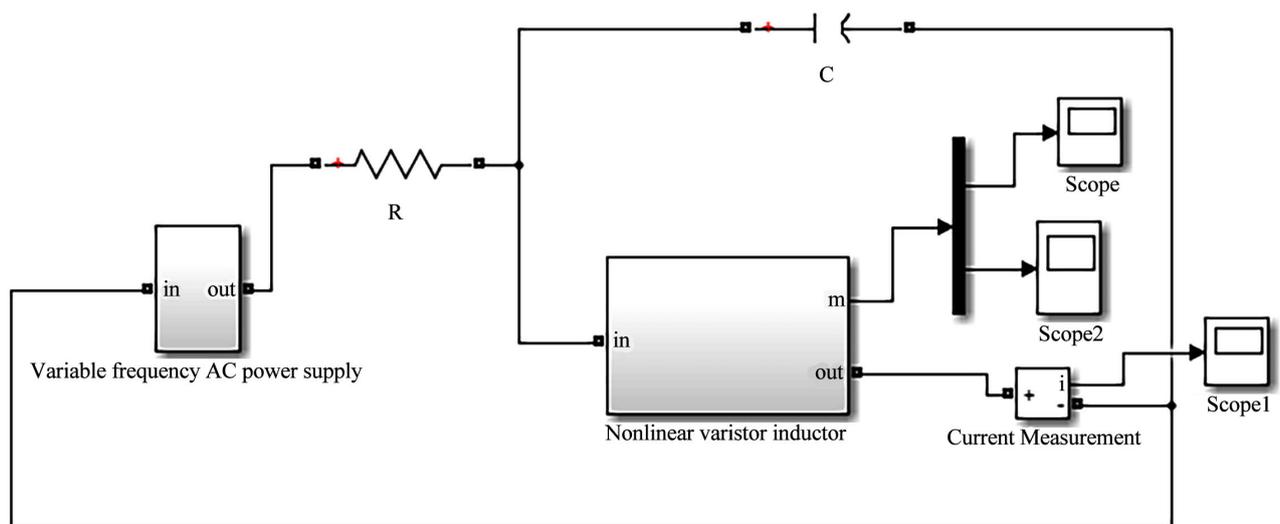
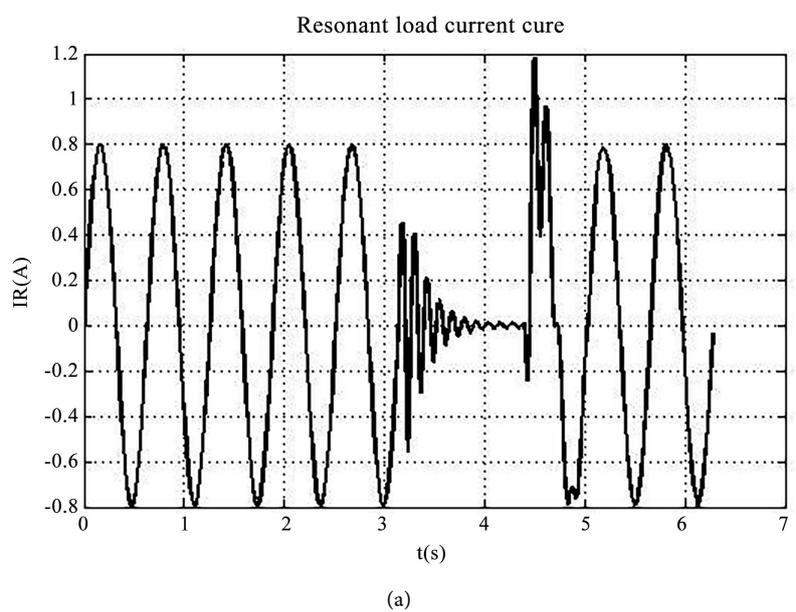
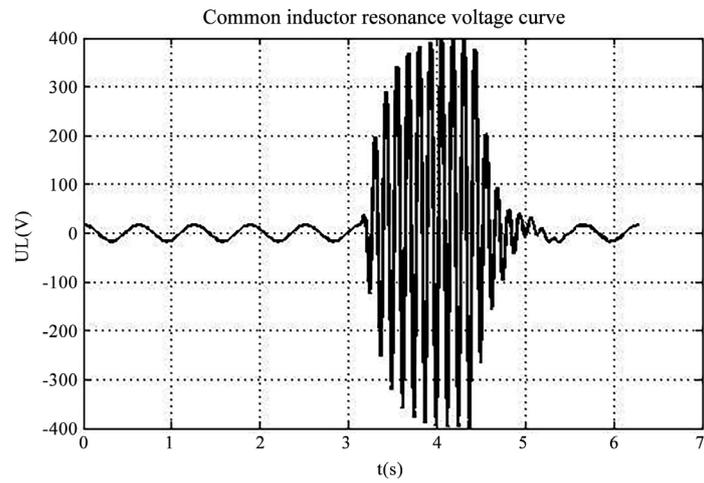
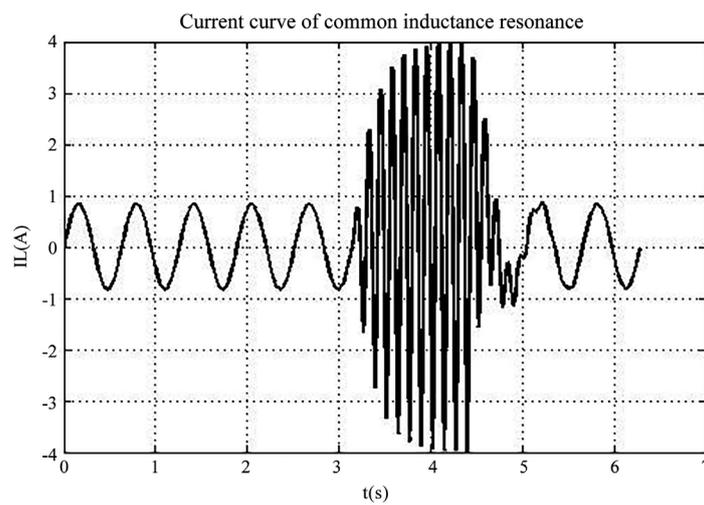


Figure 5. Parallel resonant overcurrent suppression circuit model.



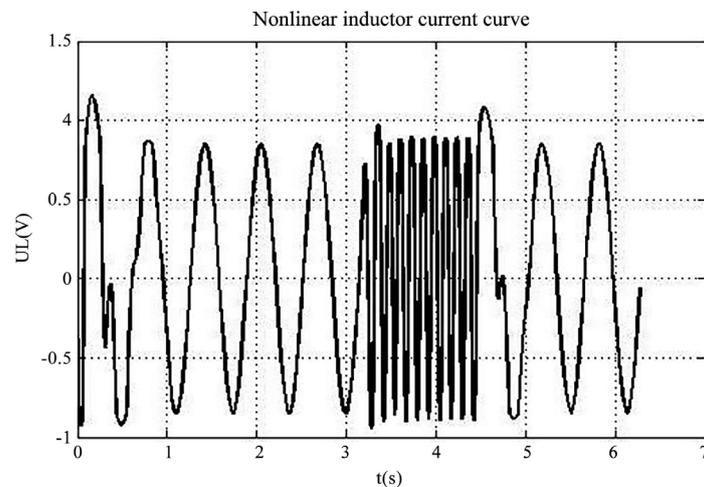


(b)



(c)

Figure 6. Simulation waveforms of parallel resonance without connecting with nonlinear inductance. (a) Current through the resistor; (b) Common inductor voltage in resonant state; (c) Ordinary inductance current in resonant state.



(a)

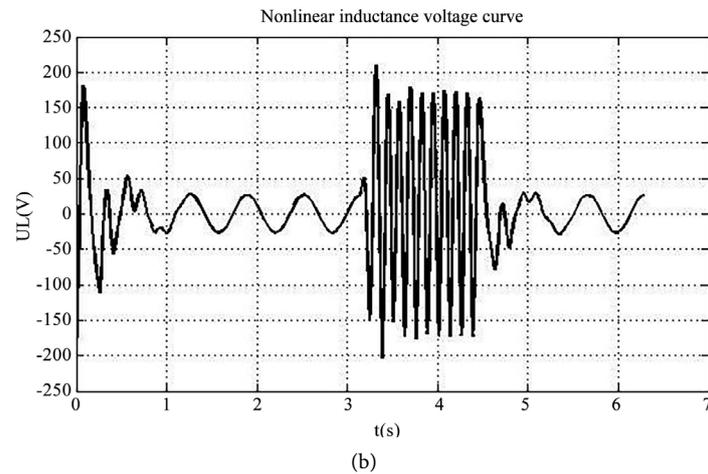


Figure 7. Simulation experiment waveforms under the condition of setting up nonlinear inductance. (a) After the set nonlinear inductance is applied, the current at resonance; (b) Connected to the set nonlinear inductor after resonance.

5. Conclusions

This paper mainly discusses some research and methods in the field of power quality detection machine control in recent years. Their advantages and disadvantages are compared, and a new overcurrent suppression circuit that can be used to suppress severe voltage fluctuations is proposed. The MATLAB/Simulink simulation was carried out by using a certain characteristic of the Wei'an characteristic curve of the inductor in conjunction with the parallel resonant overcurrent circuit. It is verified that the circuit designed in this paper can change the parameters of the component itself when the high current flows through the component, so that the impedance is recombined to get rid of the resonance state and protect the circuit.

Different from the existing research on resonant over-current and over-voltage, the other topics focus on the methods of detecting and suppressing harmonic sources and ferromagnetic resonance, and the solutions after system failure, but cannot guarantee 100% will not resonate. The proposed method is mainly to prevent the resonance from occurring under such low probability conditions, and the nonlinear characteristics of the hardware can be utilized to make the system avoid the overvoltage and overcurrent effects and hazards caused by the resonance. This makes the system no longer dependent on these detection and prevention measures and post-fault processing.

However, the breadth of application of such circuit components has not been verified. If it is to be applied to more impedance combination circuits, it is necessary to calculate the required inductance characteristics first, and then have sufficient physical experiment support and find the parameter inductance of the matching circuit after continuously testing the Wei'an characteristics of the inductor. Batch applications in life still need some time due to the high requirements for physical experiments. However, in practice, there is no need to detect resonance, and some power quality control protection devices mentioned at the

beginning of this article are not needed to cut off the fault. Cooperating with these devices can also make the stability of the power system higher. It is hoped that such circuits can be applied in batches to the structure of the load in the future.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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