Research on fault feeder detection with adaptive notch filter in non-effective neutral point to ground system’ single phase to ground fault

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Abstract. It is difficult to detect single-phase grounding fault in non-effective neutral point to ground system because of its weak current and unstable arc. In this paper, a kind of self-adaptive notch filter is used to extract the fundamental wave of current signals. This method is verified by Matlab/Simulink simulation. The result confirms that the method can realize fault line detection timely and accurately.

1. Introduction
The non-effective neutral point to ground system is widely used in the power grids with the voltage level of 3-66kv in China, which is called the Neutral Un-directly Grounded power system (NUGS) [1]. It includes: Neutral Un-directly Power System (NUS), Neutral Resonant Grounded Power System (NES), Neutral Resister Grounded Power System (NRS) [2]. In case of NUGS single-phase grounding accident, the safety performance of power supply network operation will be greatly reduced and the entire network safety operation will be damaged. Therefore, when the relay protection has a grounding accident, the fault feeder must be found and dealt with without delay. In order to solve this problem, domestic and foreign scholars have carried out in-depth and extensive research, and proposed discrete Fourier transform (DFT) method, wavelet transform method, neural network method, etc. DFT method calculates the fundamental wave and frequency as the fundamental frequency integer by calculation. The fundamental amplitude information is obtained by multiplying the amplitude and phase of each harmonic. Since the method is based on the assumption that the fundamental frequency is known, it has good harmonic suppression and fast operation characteristics under static conditions. Since the actual grid is in a dynamic operating state, the DFT method is used to extract the spectrum leakage of the grid fundamental signal. The calculations of wavelet transform and neural network are very large. In this paper, the simulation model is made according to a single-phase grounding accident in NES. At the same time, an adaptive filter algorithm is presented. By setting appropriate parameters to
automatically track the change of fundamental wave signals, it can reduce the influence of the original signal on the tracking process of fundamental wave signal to a certain extent, and can extract the network fundamental wave signals in the polluted environment. The position of the fault feeder is determined by comparing the magnitude of the fundamental wave zero sequence current of the extracted fault phase with that of the non-fault phase, the fault feeder found and dealt with without delay.

2. Principle of self-adaptive notch filter

The characteristics of the frequency response of the ideal notch filter are: the gain at a certain frequency is 0, so that the signal of this particular frequency cannot pass; The gain at other frequencies is 1 and the frequency signal can pass through completely. Usually, a polluted signal can be expressed as [3]:

$$y(t) = \sum_{k=1}^{\infty} A_k \sin \varphi_k (t) + A_0 + n(t)$$

Where $\varphi_k(t) = w_k t + \phi_k$ is the phase Angle of the K item, $A_k$ is the amplitude of the K item, $k=1,2, \ldots$; $A_0$ is the dc component; $N(t)$ is the noise component. Unknown parameters are estimated and fundamental wave signals are extracted.

Dynamic response differential equation of self-adaptive notch filter is equation: $x$ is the state variable;

$$\ddot{x} + \dot{\theta}^2 \dot{x} = 2 \theta \varepsilon e(t)$$
$$\dot{\theta} = -\gamma \varepsilon \theta e(t)$$

$\theta$ is the estimated frequency; $\zeta$ and $\gamma$ are two adjustable parameters which determine the estimation accuracy and convergence speed of the self-adaptive notch filter. By setting appropriate values of $\zeta$ and $\gamma$, the signal can be extracted timely and accurately.

In order to verify the accuracy of the proposed fundamental detection method, the fundamental signal extraction is performed in the environment of fundamental wave, voltage swell/sudden/notch pollution. The system simulation model is established under Simulink of MATLAB 2016. The initial condition of the integrator with $\zeta = 1.5$, $\gamma = 800$, output frequency $\omega$ is $2\pi 50$, and the initial condition of the remaining integrators is 0. As shown in Figure 1. The system can effectively output the amplitude, frequency and total disturbance signal of the fundamental signal, and the 90-degree phase shift of the fundamental wave [4].

The self-adaptive notch filter consists of summator, multiplier and integrator. The amplitude of the fundamental wave signals is determined by the summator, two multipliers and a square root function. A closed - loop negative feedback control system is formed. It can output several useful signals. In graph 1, $\zeta$ determines the estimation accuracy of the self-adaptive notch filter. To determine the convergence rate of adaptive notch filter [5].

For the sinusoidal signal $y(t) = A_1 \sin(w_1 t + \varphi_1)$, the adaptive notch filter has a unique periodic orbit [6]:

$$O = \begin{pmatrix} \dot{x} \\ \ddot{x} \\ \dot{\theta} \end{pmatrix} = \begin{pmatrix} -A_1 \cos(w_1 t + \varphi_1) \\ A_1 w_1 \cos(w_1 t + \varphi_1) \\ w_1 \end{pmatrix}$$

The third term in the formula is the estimated frequency $w_1$.

The stability of the dynamic response differential equation is a prerequisite for ensuring the stability of the adaptive notch filter. The stability of the equation can be analyzed [6].

$$\dot{\theta} \approx -\frac{\varepsilon}{2\varepsilon} x^2 (\dot{\theta}^2 - w_1^2)$$

That is, it is stable during its approach to the periodic track $O$. The block diagram of the adaptive notch filter is shown in Figure 1 [4].
3. Establishment of the Simulink model of single-phase grounding accident in NES

3.1. The establishment of Simulink model

Simulink Module Library Interface After starting MATLAB, enter "simulink" in the command window or click the Simulink icon on the MATLAB toolbar to open the Simulink module library window as shown in Figure 2 [6].

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Figure 1. Adaptive notch filter structure diagram.

Figure 2. Simulink module edit window.
3.2. Module of ideal power supply

Usually, we need to simulate the power generation in the power system with the ideal power source. Find the ideal source module in the Simulink module library. Similar to the power supply network, we use the three-phase AC power source in the PSB module library in the modeling. The ideal source module is shown in Figure 3.

![Figure 3. Three-phase source module.](image)

Specifically include: Phase-to-phase rms voltage, Phase angle of phase A, Frequency, Internal connection, 3-phase short-circuit level at base voltage, X/R ratio. The parameter that needs to be modified in this module is shown in Figure 4.

![Figure 4. Source parameter chart.](image)

3.3. Module of main transformer

Different from the general power supply transformer, the Delta / Y Linear Transformer will be used in the main transformer model of this paper. Through the use of this step-down transformer, to simulate the 60KV voltage drop to 10.5KV voltage. High pressure side molding, low pressure side winding 2
then forming \([5]\). By the three single-phase linear transformer composed of step-down transformer. Find the main transformer model in the Simulink module library, as shown in Figure 5.

Specific include: Nominal power and frequency, Winding1 connection, Winding 2 connection, Winding parameters, Magnetization resistance. The parameters that need to be determined in this module are shown in Figure 6.

**Figure 5.** Three-phase transformer module.

**Figure 6.** Transformer parameter chart.
### 3.4. Module of Feeder

In this model, the distribution parameters of the Bergeron feeder model are used. Simulink also offers the above feeder-network feeder model. Find the feeder model in the Simulink module library, as shown in Figure 7.

![Simulink Library Browser](image)

**Figure 7.** main feed module.

Mainly include: Number of phases, Frequency, Resistance per unit length, Capacitance per unit length, Inductance per unit length, Line Length, etc, as shown in Figure 8.

![Block Parameters](image)

**Figure 8.** Line parameter chart.
3.5. Module of Ground Accident

The ground fault model is set up here to simulate the situation of the feeder to a certain point in the power supply system. As shown in Figure 9, the following module can be used to achieve general direct grounding or connection via a resistor. The module consists of circuit breakers, single-phase impedance and other electrical components. Just connect in series. We can use Simulink’s 3-phase Fault module simulation.

![Three-Phase Fault1](image)

**Figure 9.** 3-phase Fault module.

Various types of accidents can be simulated by setting options. The parameters to be determined in this module are shown in Figure 10.

![Block Parameters: Three-Phase Fault](image)

**Figure 10.** 3-phase Fault module parameter chart.
3.6. Module of Measurement

In order to investigate single-phase ground fault feeder, the key problem is how to obtain the fifth harmonic component of zero-phase current and zero phase sequence voltage of each feeder. The theoretical calculation is through the following equation (5) and equation (6) [7].

Zero-phase current:

\[ I_0 = \frac{1}{3} \times (I_A + I_B + I_C) \]  

(5)

Zero phase sequence volta:

\[ U_0 = \frac{1}{3} \times (U_A + U_B + U_C) \]  

(6)

Construct the simulation model by inserting a Three phase V-I measurement template at the beginning of each feeder. As shown in Figure 11.

![Figure 11. measurement module.](image)

The Demux module in the system can be decomposed into A, B, C phase voltages or 3 single signal currents, and the A, B, C phase voltages are decomposed by the adder module[8]. The gain module parameters to 1/3 and get the integral signal, at the same time, zero phase sequence voltage and current, zero phase current into the self-Adaptive filter module, the Fundamental wave current signal acquisition process is completed, the specific process shown below. as shown in Figure 12.

![Figure 12. Fundamental wave current signal extraction flow chart.](image)
3.7. Module of load

In the simulation system, the load module simulates the actual power user, which can modify the parameters through its parameters dialog box, as shown in Figure 13.

![Load model](image)

**Figure 13.** load model.

Mainly include: Configuration, Nominal phase-to-phase voltage, Nominal frequency, Active power, Inductive reactive Power, Capacitive reactive power. as shown in Figure 14.

![Load parameter chart](image)

**Figure 14.** Load parameter chart.
3.8. Establishment of simulation model

The NES single-phase grounding accident simulation model in this paper is imitated and improved according to the simulation model mentioned in the paper published by the laboratory research, which is suitable for the study[9], as shown in Figure 15.

![Figure 15. The simulation of NES single-phase earthing accident.](image)

In order to verify the correctness and timeliness of the harmonic current extraction of the power supply system after the single-phase grounding accident caused by the self-Adaptive filter proposed above, this section uses the module to build the simulation model. The figure shows In the simulation model, the inductive reactance of the arc suppression coil is checked to an appropriate value to make it in an overcompensated state. An adaptive notch filter is configured for each phase line of each feeder for the extraction of the fundamental wave distribution. Five transmission feeders were investigated for research[10]. Specific parameters such as is configured for each phase line of each feeder for the extraction of the fundamental component. Specific parameters such as:

Feeder 1: 11 km; Feeder 2: 13 km; Feeder 3: 3 km; Feeder 4: 14 km; Feeder 5: 16 km.

Feeder positive sequence parameter: \( R_1 = 0.4018 \, \Omega/km, L_1 = 1.116 \, \text{mH/km}, C_1 = 0.0104 \, \mu\text{F/km} \).

Feeder zero phase sequence parameter: \( R_1 = 0.5497 \, \Omega/km, L_1 = 4.074 \, \text{mH/km}, C_1 = 0.0135 \, \mu\text{F/km} \).

3.9. Simulation analysis

In this chapter, several typical single-phase grounding accidents are analyzed, and the self-adaptive notch filter is used to select the basic wave of the feeder in the accidents accurately. At the same time, in order to illustrate the extraction capability of the self-adaptive notch filter on the basic components
of zero phase sequence current. In this paper, by means of the Fourier transform of Powergui module in Matlab/Simulink softwares, the abnormal current situation in the ground feeder is processed and analyzed in detail, as shown in Figure 4, Figure 6 and Figure 8. Sampling time $T=0.018s$ (0.128s-0.11s) sampling points $n=36$ when 0.11s-0.13s are assumed.

1) A single phase to ground fault occurs on the phase feeder of the first feeder, which is grounded by intermittent unstable arcs.

![Scope7](image1)

![Scope13](image2)

![Scope18](image3)

![Scope23](image4)

![Scope28](image5)

**Figure 16.** Every line’s fundamental signal current in single-phase-to-earth fault through intermittent arc in line1.

2) When 0.11s-0.13s are assumed, when a single phase to ground fault occurs on the A-phase feeder of the fifth feeder, the grounding of the feeder is completed through a resistance, and the grounding resistance is 10 ohms.
Figure 17. Every line’s fundamental signal current in single-phase-to-earth fault through 10Ω earth resistance line5.

3) When 0.11s~0.13s are assumed, when a single phase to ground fault occurs on the a-phase feeder of the third feeder, the grounding of the feeder is completed through A resistance, and the grounding resistance is 100 ohms.
Figure 18. Every line’s fundamental signal current in single-phase-to-earth fault through 100Ω earth resistance line3.

From Figure 16, Figure 17 and Figure 18 above, we can clearly see that when a failure occurs in the line, the fundamental wave signal of the zero sequence current is bigger than that of non-fault phase. When fault phase occurs on the first feeder, the third feeder and the fifth feeder, the difference between the phase of fundamental wave current component and the rest of fundamental wave current component is 180°. When fault feeder can be happened to be the first, the second or the fifth, a single-phase grounding accident happens.

4. Conclusions
Carry out simulation analysis on several typical single phase to ground fault. It can be seen that the characteristics of the fundamental wave signal in the feeder in an accident and the normal feeder are different, and the difference is obvious. The phase of the current in the feeder after an accident is also opposite to that in the normal feeder. Accordingly, the feeder involved in an incident can be accurately identified.
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