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The Extraction of Feature Signal of All-electric Ship Electric Power System Based on Wavelet Analysis

Bao Yan, Shi Weifeng and Zhou Zuohan

Logistics Engineering College, Shanghai Maritime University
baoyan_smu@163.com

Abstract

The unit capacity of propulsion motor is greater than that of generator in all-electric ship electric system, in this high power load changes under the impact of random overload, the generator is extremely easy to have the fault causing system crashes. In this paper, a mathematical model of all-electric ship power system was established, and wavelet analysis was used to extract the feature of heavy load of power grid fault condition based on MATLAB. The simulation results prove that the simulating model of All Electric Ship Power System (AESPS) is reasonable, and by using the method wavelet analysis the feature information can be effectively extracted, which provides the basis for fault diagnosis.

Keyword: *Electric propelling ship, Power system, Digital simulation, Heavy load, Wavelet transform, Feature extraction*

1. Introduction

China, a worldwide big shipbuilding country, is in a critical period of development to a shipbuilding power; while the electrification and informationization of sea transport ships and naval ships is the inevitable trend of development, electric propulsion ship will definitely develop into the direction of the All Electric Ship, and it will become an important direction of the development of marine ship. AESPS (All Electric Ship Power System) uses high power propulsion system as the power device of ship motor, forming a "generator, distribution and transformation, high-power propulsion motor" ship power chain, which is the great change of ship power system [1]. Compared with traditional high-power engine propulsion system, AESPS has characteristics of flexible control, easy to realize automation, small vibration, low noise, less pollution, cabin arrangement convenience and economical efficiency, *etc* [2].

The factors of move by need, isolation of helplessness, limited resources and other factors on the sea ship, contributes to the high safety reliability of AESPS; At the same time, AESPS system generally adopts the high-power propulsion motor to drive the propeller, more than 70% of the power system electrical energy is used for propulsion motor. Frequent changes of high-power propulsion motor control and load exhibit oscillatory phenomenon of periodic / aperiodic / chaos, which causing the stability of the system greatly influenced [3], makes the power quality decline, even the failure cause of collapse, and the consequences are disastrous[4]. Therefore there is an urgent need to find out the key features of the system operation and the unexpected fault to take corresponding measures, to maintain safe operation.

At present, there are some certain research in the electric power system of ship had been done at home and abroad, Document [5] studied on the energy management and control of electric power system of ship; Document [6] studied on the simulation of ship electric propulsion system by using EMTP; Document [7] analyzed the harmonic situation when PWM inverter controlling an induction motor; Document [8] focused on promoting the study of motor and generator respectively placed in marine power system; Document

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[9] studied on the model of generator fault. While these works mentioned above all focused separately on speed control of motor propulsion a well as simulation and control effect on individual generator regulator, lacking simulation of AESPS overall, and how to describe and achieve the characterization and identification of power parameters is not yet mature method.

In this paper, we modeled and simulated the AESPS to do research on the dynamic characteristics of the fault occurred in the heavy load impact of the system, and we extracted feature information through the wavelet transform analysis of transient process of symptom of fault, providing evidences for AESPS fault diagnosis and isolation, fault tolerant control decision-making.

2. Modeling of AESPS

AESPS consists of generators, switchboards, transformer, harmonic suppressor, inverter and load several parts [10], its basic structure as shown in Figure 1.

2.1. Modeling of Generator and its Excitation System

The generator adopts AC synchronous generator. The operation characteristics and the internal electromagnetic transient process of synchronous generator is a complex nonlinear dynamic process, it's very difficult to make a detailed mathematical modeling for it, and its dynamic performance has great effect on the dynamic performance of the whole power system. Synchronous generator model often adopts order 5 salient pole machine model, which takes into account the electromagnetic transient process of stator winding, the electromagnetic transient process of the rotor winding, and the mechanical motion transition process of rotor, bringing accurate analysis of the system and motor dynamic process.

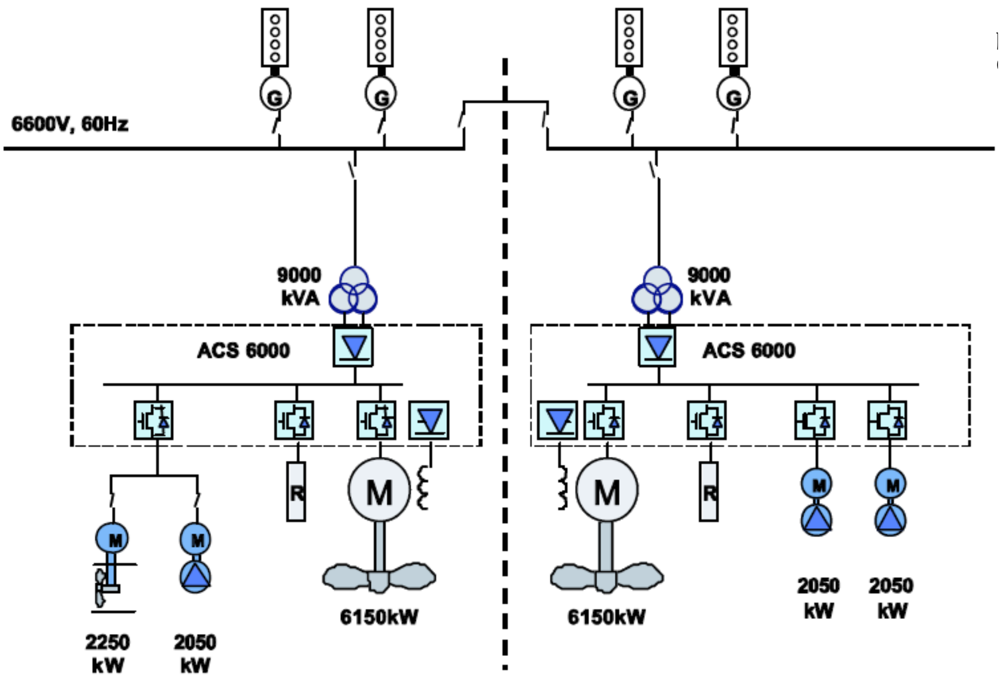

Figure 1. Structure of all-electric Ship Electric Propulsion System

The stator voltage equation:

$$\begin{cases} u_d = \dot{E}_d + \dot{x}_q - r_a i_d \\ u_q = \dot{E}_q - \dot{x}_d i_d - r_a i_q \end{cases} \tag{1}$$

The rotor f winding voltage equation:

$$T'_{d0} \frac{d}{dt} \dot{E}_q = E_f - \frac{x_d - x_1}{\dot{x}_d - x_1} \dot{E}_q + \frac{x_d - \dot{x}_d}{\dot{x}_d - x_1} \dot{E}_q - \frac{(x_d - \dot{x}_d)(\dot{x}_d - x_1)}{\dot{x}_d - x_1} i_d \tag{2}$$

The rotor d winding voltage equation:

$$T'_{d0} \frac{d}{dt} \dot{E}_q = \frac{\dot{x}_d - x_1}{x'_d - x_1} T'_{d0} \frac{d}{dt} \dot{E}_q - \dot{E}_q - (x'_d - \dot{x}_d) i_d \tag{3}$$

The rotor q winding voltage equation:

$$T_J \frac{dw}{dt} = T_m - [(\dot{E}_q i_q + \dot{E}_d i_d - (\dot{x}_d - \dot{x}_q) i_d i_q] - D(w-1) \tag{4}$$

Another rotor motion equation:

$$\frac{d\delta}{dt} = \omega - 1 \tag{5}$$

Equations (1) ~ (5) constitute a practical synchronous generator five order model. Commonly used in the actual situation (3) instead of (2).

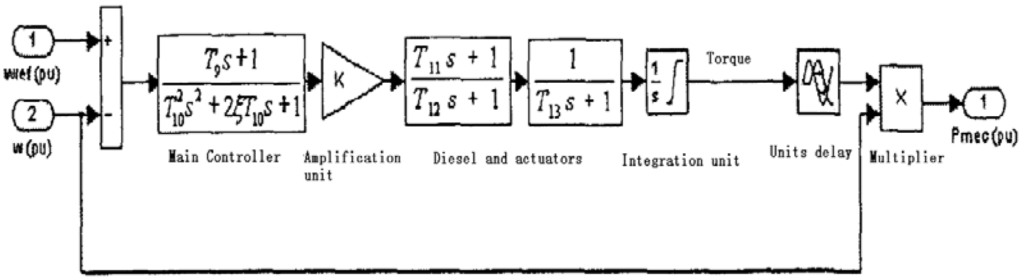

Figure 2. Mathematic Model of Motor and Variable Speed System

Driven motor of generator was a combination of marine diesel engine, diesel engine and the throttle actuator, adopting two step processes for modeling, and the system model and structure as shown in Figure 2. Excitation system adopted as rotating rectifier system, DC output was fed directly to generator excitation windings. In simulink interactive simulation environment in MATLAB, based on PSB module set and continuous system module set, we built a controllable phase compound excitation system simulation model and the three-phase synchronous generator model, consisting of a simulation model of synchronous generator and its excitation system, as shown in Figure 3.

The electrical parameters and standard parameters of marine synchronous generator:

$$P = 2500KVA, V = 400V, f = 50Hz; RS = 0.008\Omega, p = 4;$$
$$X_d = 5.86, X_{d'} = 0.230, X_{d''} = 0.132, X_q = 0.441, X_q = 0.168, X_{q''} = 0.092;$$

Time constant of d axis: $T_{d'} = 0.145, T_{d''} = 0.006$; pole-pairs $p = 4$.

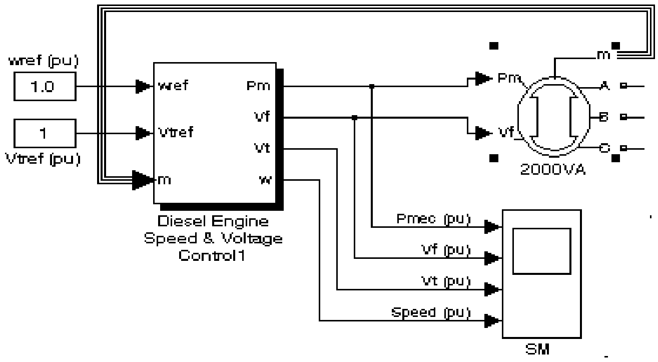

Figure 3. Simulation Model of SYN Motor and Excitation System

2.2. Modeling of AC Power Propulsion System

Shipboard AC power propulsion system consists of AC-DC-AC frequency conversion device, propulsion motor, propeller and its control system. Rectifier unit adopts three-phase uncontrolled bridge, each bridge consists of six thyristors; the unit capacity of propulsion motor is greater than or equal to the capacity of an individual generator, which belongs to the heavy load. It adopts the three-phase squirrel-cage asynchronous motor, whose dynamic process is very complex and structure is simple.

The following equation mathematical model describing the dynamic process:

$$\begin{cases} U_s = R_s i_s + \dfrac{d\phi_s}{dt}, 0 = R_r i_r - j\omega_r \phi_r + \dfrac{d\phi_r}{dt}, \\ \phi_s = L_s i_s + L_m i_r, \phi_r = L_r i_r + L_m i_s, \\ \dfrac{d\omega_r}{dt} = (T_e - T_L)/J \end{cases} \tag{6}$$

As we can see from the mathematical model, we can control the running status of the asynchronous motor by controling is, φ_s , φ_r ,in above formulas. Generally, " inverter-induction motor" drive control system has the high performance compared with DC motor speed control. There are mainly two kinds of AC speed control strategy: vector control and direct torque control. Vector control emphasizes the decoupling of rotor flux and torque to control continuously. Compared with direct torque control, it has wide speed range and good low-speed performance; it is suitable for the propulsion motor control of high-power speed. We use vector control method on speed governing system, the control model is shown as Figure 4.

For the propeller, due to the particularity of the oars movement, especially during the operation of the ship, there are effects of many complex external conditions, at the same time the ship itself also influences the movement of propeller. Either of the ship speed and propeller speed changes, the movement of propeller will be influenced. Thus, the propeller movement is quite complicated. According to the characteristics of ship navigation, a typical characteristic curve of propeller has the following three kinds of circumstances:

a. free navigation performance $M_y = f(n), P_y = f(n)$;

b. Mooring performance or anchoring performance $Mx = f(n), P_x = f(n)$;

c. Reversal characteristics $M_f = f(n), P_f = f(n)$.

As the main purpose of this paper is on the performance of the control system, the paddle model and other load models are replaced of the load impedance to simplify the system.

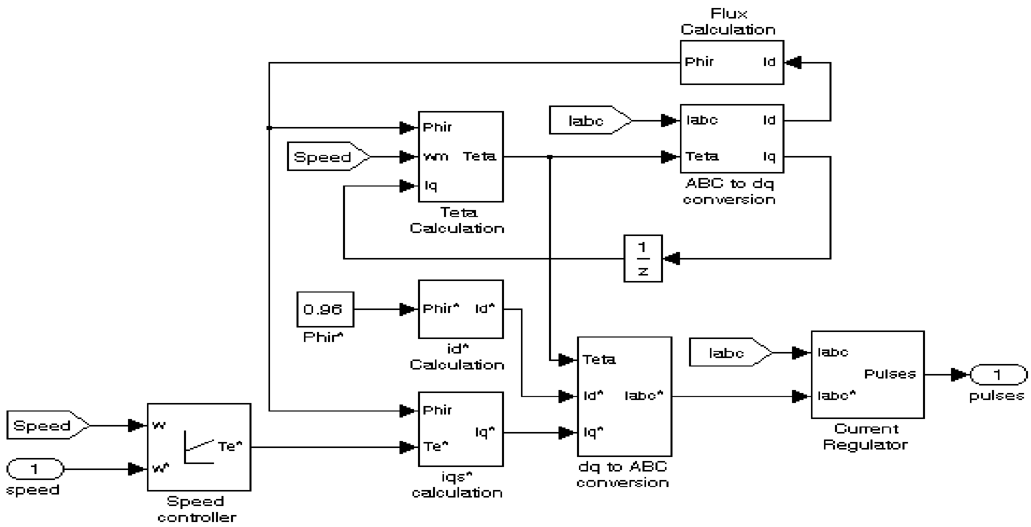

Figure 4. Model of Vector Control

2.3. Simulation Experiment of AESPS Power System

On the platform of MATLAB, we carry out the simulation of AESPS's half side, the main electrical connections are shown as Figure 5. The central stationing the system is consisted of two 2000kVA diesel generating set, AC propulsion system adopts AC-DC-AC frequency conversion, the rectifier part adopts 6 pulse rectifiers, and the inverter part adopts vector control, propulsion motor adopts a 2500kW asynchronous motor. No. 1 and No. 2 generating units are put into operation, AC propulsion motor starts at 0.1s, the phase voltage of the generator decreases during startup, the phase voltage of the generator recovers under the effects of field system. The voltage of stable operation with load is still lower than the voltage of no-load run, as shown in Figure 6.

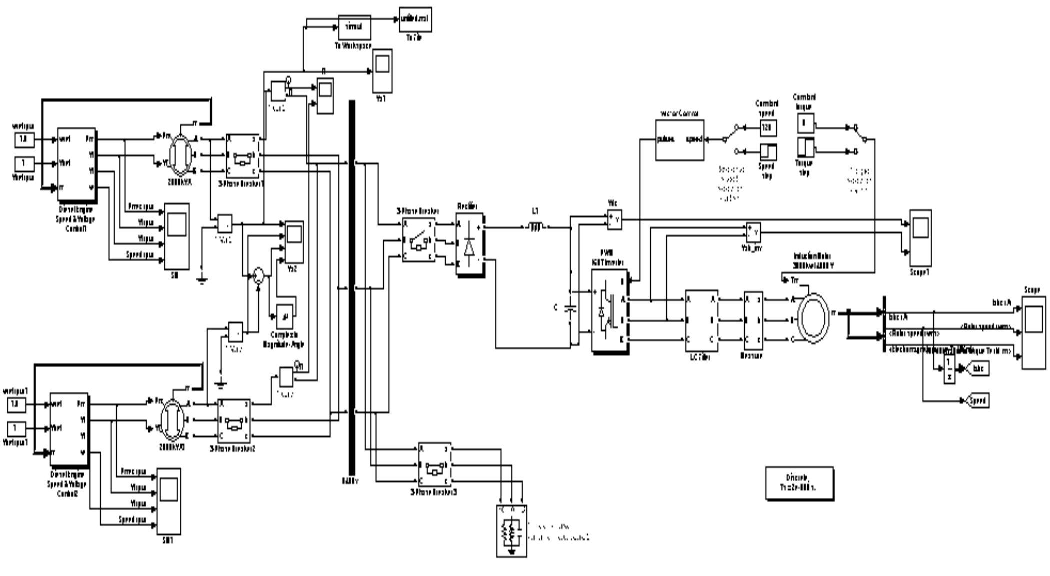

Figure 5. Simulation Model of AESPS

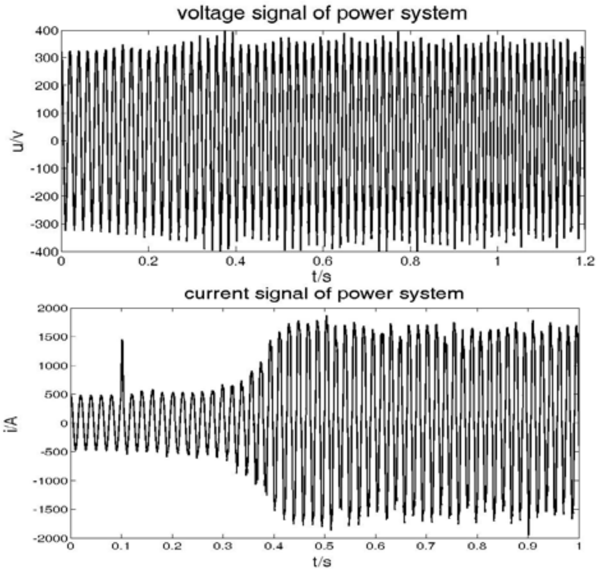

Figure 6. Voltage and Current Signal of power

3. Signal Feature Extraction based on Wavelet Analysis

Characteristic parameters of AESPS contains current, voltage and frequency, and voltage is the most important and the most common signal. Long-term studies of the voltage signals are mainly concentrating on the voltage deviation, harmonic, flicker, unbalance, sag, no matter for voltage monitoring or for voltage disturbance control equipment, the first task is to detect the occurrence of voltage disturbance [11]. The current voltage perturbation analysis mostly adopts the method of signal processing, it mainly does time-frequency analysis for voltage sag signal, detects voltage sags and extracts voltage disturbance signal feature with advanced digital signal, processing tools.

Wavelet analysis is a new theory that has developed rapidly in the mathematical analysis and signal processing. It is a kind of multi-scale transform method which show not only the signal picture, but also analysis of the partial feature of the signal [12, 13]. Therefore, it is suitable for dynamic power quality signal analysis. Through making wavelet transformation in the signal, the modulus maxima can closely approximate the original signal, so the modulus maxima of wavelet transform contains the complete information of the original signal approximation, which shows the characteristics of signal.

This paper do formulation experiments about sudden load, generator side 3 phase short circuit fault, A grounding fault in AESPS system. Choose db5 wavelet function which has better orthogonal properties to do five wavelet decomposition for the obtained signal. After 5 layers of db5 wavelet function decomposition, it is shown as Figure 7, Figure 8, Figure 9.

In heavy load conditions, the waveform in Figure 7 has a clear singularity; generally, singularity is described quantitatively by Lipschitz index. This index is calculated by the transformation of modulus of wavelet transform W2'f(x) along with scale, The singularity characteristics of signals is positive Lipschitz exponent, and the singularity of noise is negative Lipschitz index. Remove the modulus maxima which increases obviously along with the decrease of scale of Wavelet transform signal in Figure 7, the rest of the modulus maxima shows the main characteristic of voltage signal in heavy load conditions. When a fault occurs, the signal wavelet analysis are as shown in Figure 8, Figure 9, due to the mutation of the generator stator voltage in d1, d2 layer, we can find the accurate fault and carry out fault diagnosis. At the same time, we can ensure the exact time of the fault.

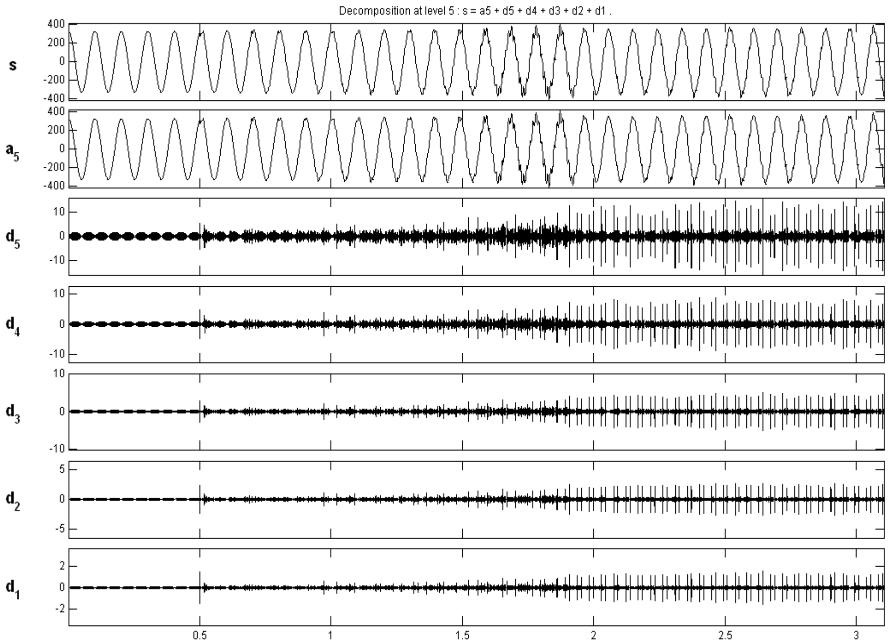

Figure 7. Wavelet Spectrum of ua at Generator Side when Load is Sudden Increased

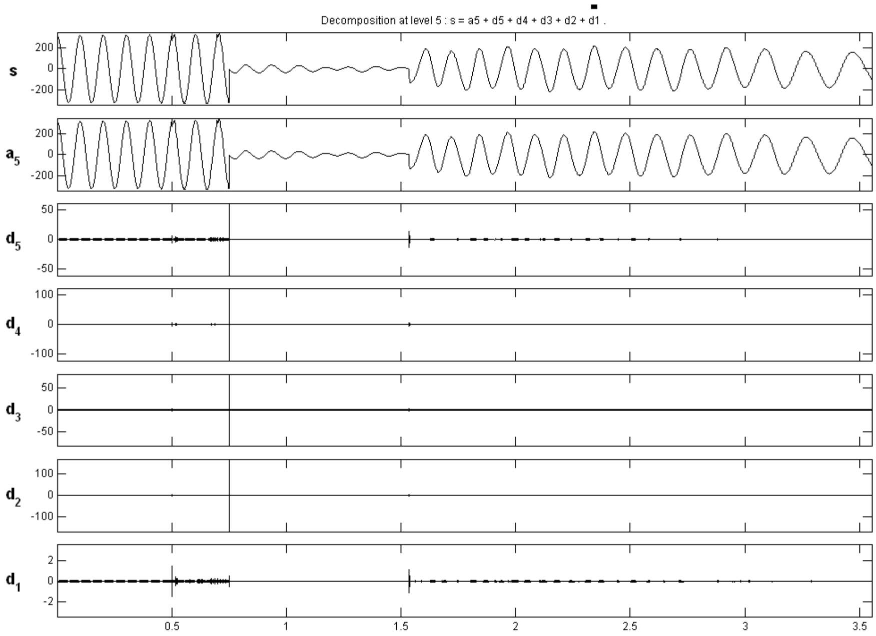

Figure 8. Wavelet Spectrum of Ua at Generator Side When Three-Phase SHORT CIRCUIT

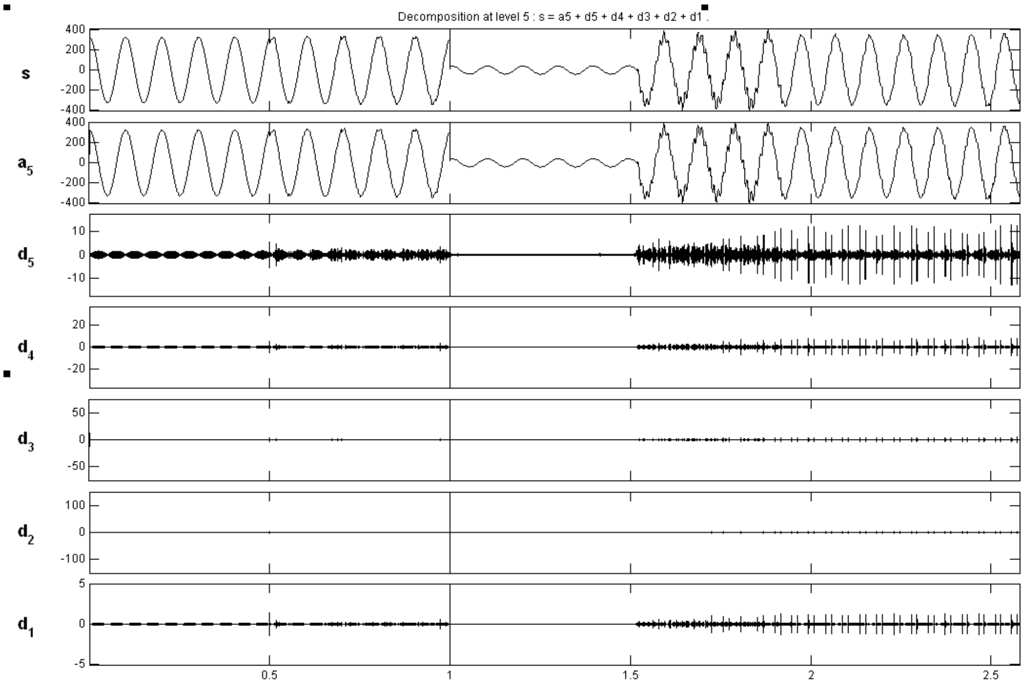

Figure 9. Wavelet Spectrum of ua at Generator Side when Single-phase Short Ground

4. Conclusions

This paper formulated the dynamic process of AESPS power system with MATLAB, and several transient state processes such as heavy load, generator side 3 phase short circuit fault, a grounding fault, were studied. Using wavelet analysis of the simulation signal, fault features of specific fault can be extracted to provide the basis for later fault diagnosis.

On one hand, the simulation results reaches the expected assumption and requirement, also display the dynamic change process of all variable quantities, which proves that the formulation model is effective and reasonable. On the other hand, the wavelet transform can effectively extract the characteristics of signal, the AESPS fault and fault type can be detected effectively. However, when under the real complex composite fault of power system, it should be used by further combining with the intelligent method.

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Authors

BAO Yan, pursuing her PhD of power electronics and power transmission at Shanghai Maritime University, Shanghai, China. Currently, she is working in Logistics Engineering College, Shanghai Maritime University (SMU) as a lecture. Her research interests include power system control and power electronics and power transmission, etc.

SHI Wei-feng, received the Bachelors, Masters and the Ph.D. degrees from the Shanghai Maritime University, Shanghai, China. He joined Shanghai Maritime University in 1989, and is currently a Full Professor of Department of Electrical Engineering and Automation of SMU, and is the Founding Director of the Shanghai Maritime University and Schneider Electric Combine Laboratory. He is Vice Dean of the College of Logistic Engineering. He has over 40 papers and 1 monograph published. His current research interests are in Electric power system and automation, Power electronics and electric drive, Control theory and engineering, Shipboard power system modeling and control.