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On Control of Power Supply Process of Marine Shaft Generator

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***Abstract*—Marine silicon-controlled-rectifier (SCR) shaft generator is driven by ship main propulsion shaft. Firstly, the structure of SCR shaft generator is introduced and its characteristics of power supplying both in normal operation process and in output decrease process are analyzed. Then dynamic mathematical model of field current control process and that of inversion angle control process of an SCR shaft generator are established. Afterwards, the simulation results show that the operation properties based on the established mathematical model coincide with that of a practical SCR shaft generator, which is to say that the established mathematical model of power supply control processes of marine SCR shaft generator established is reasonable.**

***Keywords*—SCR shaft generator, Normal operation process, Output decrease process, Mathematical model**

I. INTRODUCTION

During the last decades, electrical power demand for ship use has increased heavily, mostly due to the increment of electrical facilities in ships [1]. And fuel consumption has also increased continuously. In order to save fuel consumption, a practical method is to apply main shaft generators to ships [2].

Main shaft generator is a kind of electrical power supply device whose prime mover is the shaft of main engine. The efficiency of the operation of main engine is rather high, and the fuel it consumes is very cheap, mainly heavy oil. These factors make the running of main shaft generator economical. For this reason, more and more main shaft generators have been applied to ocean ships to optimize fuel consumption to lower the power production costs. Nowadays, SCR shaft generator, also called shaft generator of converter type, is the most popular kind of shaft generators for marine use.

II. MODEL OF SCR SHAFT GENERATOR

A. Structure of SCR Shaft Generator

The main function of a marine SCR shaft generator is to supply constant frequency constant voltage electrical power to main electric network in a ship. It has two sets of main converters, one is for rectifying, and the other is for converting.

Fig. 1 shows the structure drawing of a kind of marine SCR shaft generator [3]. In the figure, 1 stands for the generator, 2 stands for main SCR rectifier. It consists of SCR bridge rectifier. Under normal conditions, it works as a diode rectifier and converts three phase alternating current (AC) generated by shaft generator into direct current (DC) current, 3 stands for main converter. It consists of all-control SCR bridge rectifier and works under the state of active conversion. That converts DC into AC of constant frequency constant voltage to supply the whole ship electrical power, 4 stands for system reactor, 5 stands for a synchronous compensator which supplies reactive component of power, 6 stands for SCR rectifier of field current, 7 stands for trigger control system of SCR, 8 stands for three phase 440v 60Hz power supply system, 9 stands for loads.

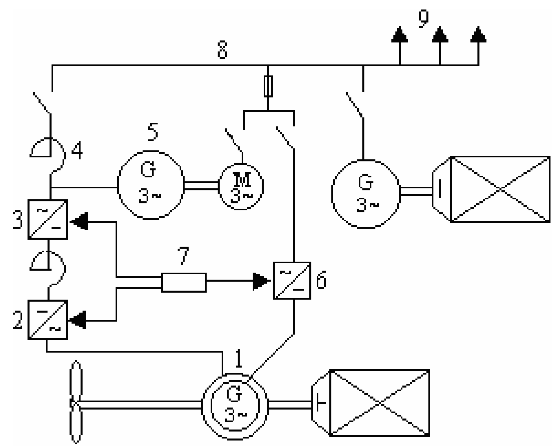

Figure 1. Structure drawing of SCR shaft generator.

Another type of popular marine SCR shaft generator is designed in Japan whose synchronous compensator is driven by diesel engine through a set of electromagnetic clutch [4]. But this type of system is similar to the system described in Fig. 1 concerning structure and function of the aforementioned system, and will not be detailed.

B. Power Supplying Characteristics of SCR Shaft Generator

Characteristics of power supplying of SCR shaft generator [5] is shown in Fig. 2. In the figure, p stands for practical output power of main shaft in proportion to rated power of main shaft, r stands for practical rotation speed of main shaft in proportion to rated speed of main shaft.

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It can be found out from Fig. 2 that when the rotating speed of main shaft ranges from 75% rated value to 100% rated value, the output power of generation is rated (area "III" in Fig. 2). This area is called normal operation area and shaft generator operates in normal operation process. In this area, variation of electric network load causes automatic regulation of field current of shaft generator, which makes the generator supply demanded active power to electric network. And together with automatic regulation of reactive power which is supplied by synchronous compensator, the electric network maintains constant frequency and constant voltage. Simultaneously, inversion angle of main converter of the shaft generator is 30°, the minimum value. While rotating speed of main shaft decreases, field current gets larger. When rotating speed of main shaft declines to 75% of rated value, field current reaches its maximum. In this area, the main shaft generator is also able to maintain running for 30 seconds under overload conditions if demanded power is up to 120% of rated power.

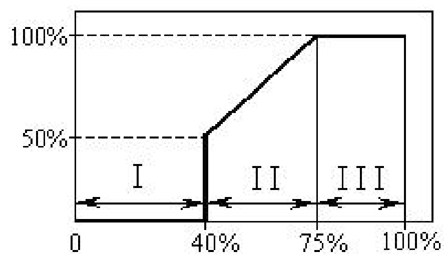


Figure 2. Characteristics of output power of SCR shaft generator.

When rotating speed of main shaft ranges from 75% rated value to 40% rated value, output power of generator declines linearly just as descending of rotating speed. (area "II" in Fig. 2) And this ensures power supply for part of important loads before the main engine stops work. This area is called speed-down area and shaft generator operates in output decrease process. When shaft generator runs in this area, inversion angles of main converter of the shaft generator becomes larger as the rotating speed of main shaft declines, which makes output power of shaft generator decline linearly. In this area, field current maintains its maximum.

When rotating speed of main shaft is under 40% rated value, shaft generator stops work. (area "I" in Fig. 2)

While concerning characteristics of output power of shaft generator designed in Japan [4], there are a few differences from that of shaft generator designed by Siemens. When rotating speed of main shaft ranges from 80% to 110% rated value, shaft generator works in normal operation area. When rotating speed of main shaft ranges from 60% to 80% rated value, shaft generator works in speed-down area. When rotating speed is under 60% rated value, shaft generator stops work

C. *Mathematical Model of SCR Shaft Generator*

It can be found out from Fig. 1 that a shaft generator mainly consists of six segments: main shaft generator, segment of rectifying and inversion, electric network, compensator of reactive power (synchronous compensator), field current regulator and inversion angle controller [6]. In order to establish mathematical model of a marine SCR shaft generator, it is necessary to make concise analysis of the mentioned segments.

To a shaft generator, its output potential is directly proportional to its field current and rotating speed of its rotor, which is decided by rotating speed of main shaft. That is,

$$E = k \times n \times I_f \,. \tag{1}$$

In (1), E is output potential of shaft generator; k is a constant coefficient; n is rotation speed of rotor; I_f is field current [7].

To rectifying and inversion unit of SCR shaft generator, also named DC link, its direct current is [8],

$$i_a = 2.34(E\cos\alpha - U\cos\beta)/R \,. \tag{2}$$

In (2), α is rectifying angle and always maintains 0° to make the rectifying unit - mainly SCR components - work as a diode; β is inversion angle and maintains the minimum value, 30°, when shaft generator is in normal operation area [9]. But β acts as a controlled parameter when shaft generator runs in speed-down area; U is electric network voltage; R is total equivalent resistance of DC link.

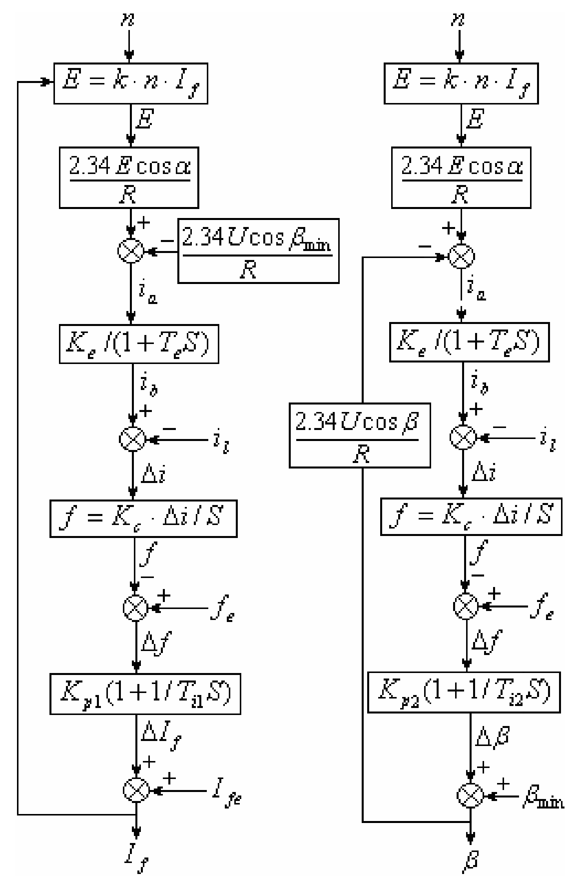
Though an electric network is a nonlinear complicated system, its open-loop transfer function can be considered as a first order inertia link after the system being linearized and its order being reduced by means of analyzing the principle of electric network current variation. Then it is more convenient to make analysis and calculation of the whole generator. Here, the transfer function of the electric network link is $K_e/(1+T_eS)$. Where, K_e is a constant which stands for the ratio of desired output current of the electric network link to the desired value of i_a; T_e is time constant of the electric network link.

When synchronous compensator of marine shaft generation system is concerned, its output frequency is directly proportional to integral of variation in its input current. To a generator, torque variation is directly proportional to its current variation, the first order derivative of its angular velocity to time is directly proportional to torque variation and its output frequency is directly proportional to the angular velocity, so the frequency is directly proportional to integral of input current variation. For this reason, transfer function of synchronous compensator link is $f = K_c \times \Delta i / S$. Where, f is output frequency; Δi is input current variation; K_c is a constant and can be obtained by approximate calculation.

To unit of field current regulation of SCR shaft generator, field current is regulated according to variation of electric network frequency. And to inversion angle controller of SCR shaft generator, inversion angle is regulated according to variation of electric network frequency. Since the principles of both the aforementioned units yield to principle of PI control, transfer functions of the two units are described as $K_{p1}(1+1/T_{i1}S)$ and $K_{p2}(1+1/T_{i2}S)$ respectively. Where,

K_{p1} and K_{p2} are proportional action coefficients; T_{i1} and T_{i2} are integral constants. And these four coefficients can be regulated manually.

Accordingly to principle of an SCR shaft generator operation and transfer functions of the mentioned units, mathematical model of SCR shaft generator is able to be obtained. Fig. 3 is block diagram of an SCR shaft generator. Where, Fig. 3(a) shows that an SCR shaft generator works in normal operation process and Fig. 3(b) shows that an SCR shaft generator works in output decrease process. In the established mathematical model, β_{min} is minimum of inversion angle -30˚; i_b is output current that SCR shaft generator supplies to electric network; i_l is load current; f is output frequency of synchronous compensator; f_e is desired frequency of electric network; I_{fe} is desired field current; I_{fmax} is maximum field current.



(a) (b)

Figure 3. Block diagram of SCR shaft generator.

III. Simulation Results

According to mathematical model of marine SCR shaft generator, simulation results are shown in the following. All referenced data come from a 2700TEU ocean container ship of Shanghai Ocean Shipping Company in China.

Fig. 4 and Fig. 5 show simulation results when SCR shaft generator runs in normal operation process. Fig. 4 shows dynamic process while rotation speed of main shaft varies. Where, Fig. 4(a) shows a dynamic process when the rotating speed of main shaft raises from 85rpm to 93 rpm at a moment of "t_0" and Fig. 4(b) shows a dynamic process when rotating speed of main shaft reduces from 85rpm to 76rpm at a moment of "t_0".

Fig. 5(a) shows a dynamic process when active load current increases from 1968A to 2150A at a moment of "t_0" and Fig. 5(b) shows a dynamic process when active load current decreases from 1968A to 1700A at a moment of "t_0".

Fig. 6 is simulation result when SCR shaft generator runs in output decrease process (the rotating speed of main shaft is 55rpm). It shows a dynamic process while part of load is cut down (the load current decreases from 1800A to 1500A) at a moment of "t_0".

In Fig. 4, Fig. 5 and Fig. 6, curve 1 stands for field current, curve 2 stands for frequency of electric network, curve 3 stands for active power current of load and curve 4 stands for inversion angel.

IV. Conclusions

The aforementioned simulation results show that dynamic processes of operation of marine SCR shaft generator conform to reality. It indicates that relevant analysis of principle of SCR shaft generator in this paper is reasonable. It also indicates that the established mathematical model of SCR shaft generator is rather integrated and is a practical real time control system.

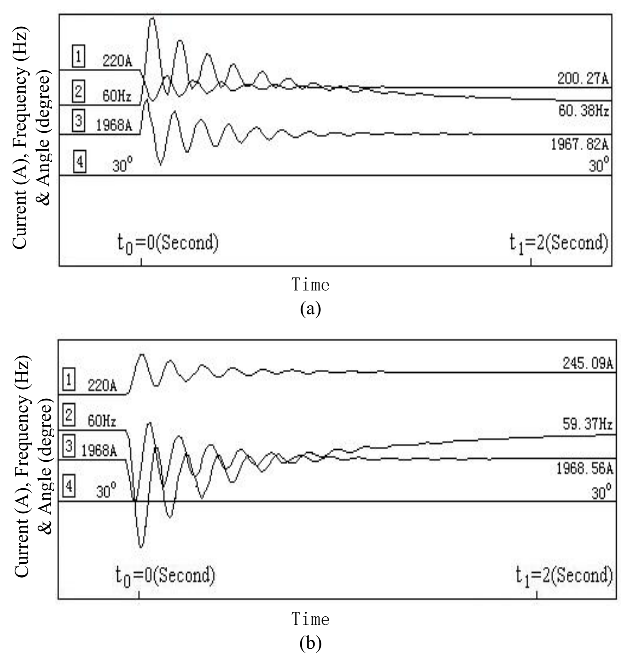


Figure 4. Dynamic process of SCR shaft generator while rotation speed of main shaft varies.

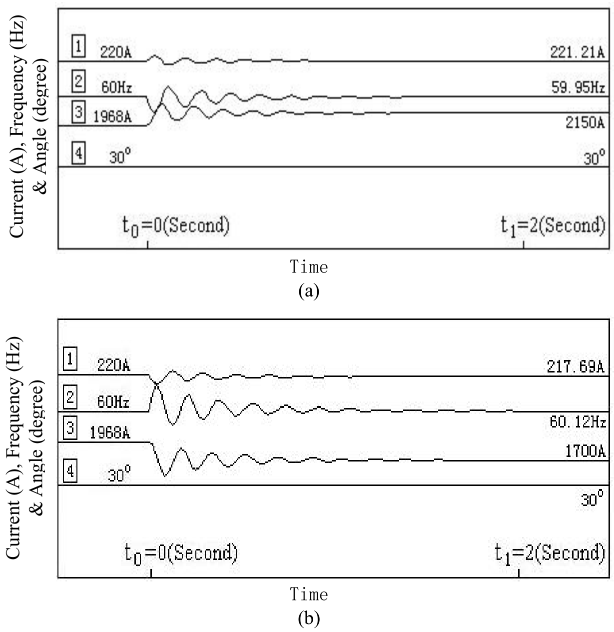


Figure 5. Dynamic process of SCR shaft generator while variation of load happens.

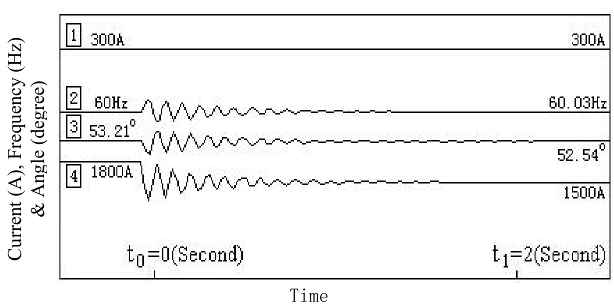


Figure 6. Dynamic process of SCR shaft generator while in output decrease process.

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