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A Hybrid Simulation Test Platform for Verifying the Protection Settings of SPS

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Abstract

To verify the effectiveness and correctness of the protection settings in ring structure Shipboard Power System (SPS), a digital-physical hybrid simulation platform at China Ship Development and Design Center (CSDDC) has been built, which aims to give double verification effect of design scheme and physical device. The platform consists of eMEGAsim digital simulator, signal power amplifiers and digital-analog interface equipments. With this platform, the multiple protection device of ring structure grid can be accessed to form a close-loop test system. Since eMEGAsim model-simulated faults and actual protection device actions are on real time, the tripping settings of each device as well as their coordinate performance between multiple devices can be verified in this close-loop test.

Keywords

Hybrid Simulation, Shipboard Power System (SPS), Protection Settings, Close-Loop Test, Verify

1. Introduction

Various protection rules for regional power distribution in ring structure grid are one aspect of the key technologies of shipboard integrated power system [1]. These rules have been well implemented in ship overall design and device manufacturing. However, there is an important link in the ship power engineering project process has still been in a state of absence, *i.e.* verifying the validity of the fault protection design scheme and the effectiveness of the protection devices. The Shipboard Power Systems (SPS) have features of close source-load electrical distance, short transmission cable, complex topology structure and high-concentrated load. Therefore, the fault protection performance (speed, selectivity, sensitivity and reliability) has a much higher demand than the terrestrial power grid.

The protection performance is mainly embodied in the protection modes and their trip settings that depend on the quality of both design and device. Furthermore, verifying the validity of design scheme and verifying the effectiveness of device are two subjects in the same test task. Accordingly, the verification test platform must have the functions of system simulation and closed-loop access actual devices.

Refer to the technical papers about protection test field of SPS, paper [2] shows a kind of closed-loop test platform for examining differential protection device based on Hypersim real-time digital simulator, and paper [3] uses PSCAD/EMTDC (a non real-time numerical simulation software) to study a fault location method. The mentions in the two papers do not meet the functional requirements of the platform described in this paper, because the former is only for single device test and the latter does not have any physical effect.

China Ship Development and Design Center (CSDDC) have developed a digital-physical hybrid simulation platform for verifying the protect settings, which includes checking the coordination of design settings and testing the accuracy of device trip action. This paper describes the setup principle and hardware composition of the platform that based on eMEGAsim real-time digital simulator, introduces connection and interface of each part, and confirms its availability by an application test.

2. Digital-Physical Hybrid Simulation

2.1. Simulation Mechanism of Hybrid Modeling

The understructure of digital-physical hybrid simulation is to utilize the physical effect of real-time digital simulator. Physical essence of real-time digital simulator is a super computer, belongs to faint power signal system. Its core bases on electromagnetic transient calculation software for solving the differential equation (mathematical model) of the system equivalent circuit in real time. With A/D and D/A conversion, the real-time digital simulator input quantities from physical external as the equation's "source variables", also output equation's "solution variables" to the outside physical world.

Because the digital simulation model is a virtual equivalent of mathematical abstraction, the digital model method can be used in simulating all kinds of complex networks without increasing the hardware cost. Nevertheless, the digital simulator has a limitation that it can only interface with the actual objects as fairly weak power as signal system, not able to connect directly any physical electric device. That means necessary interface equipments are indispensable for balancing the power difference between digital simulator and physical device.

2.2. Composition of Hybrid Simulation Platform

The structural features of the ring SPS determine that its fault has the following different characteristics from terrestrial power systems:

- Fault has a serious impact on the voltage and frequency of the whole power grid.
- Relatively lower rated voltage and higher fault current directly affect the normal operation of generators and other loads.
- More nonlinear loads are sensitive to power supply interruption or power quality change, and the nonlinear ingredients of fault current high.
- Fast fault impact, easily lead to the subsequent other failures.

In view of above fault characteristics, the hybrid simulation platform must have the below basic properties:

- The digital model of SPS needs enough scale to ensure the accurate simulation of dynamic behavior of the every subsystem.
- Generator modeling requires detailed models (including excitation and governor model).
- All digital-physical interface (including A/D, D/A, signal power match etc.) must be linear equipments to avoid nonlinear distortion of signal transmission.
- For all closed loop interface equipments, the total time delay of signal transmission cannot be greater than a discrete time step of the digital simulator.

Due to the particularity of SPS, at present protection design the three-segment protection based on current-time principle has been a regular settings scheme which trip setting is divided into instantaneous, short delay and long delay, future more advanced differential and adaptive protection are developing [4] [5]. Obviously, each segment of current setting and time setting of each protection device in ring structure grid affects the entire system safety operation and reliable power supply. Especially, the coordinate performance between every action settings directly determines the selectivity of fault trip.

As a tested object, the protection device usually divides sensing part and executing part in accordance with its structure. The sensing part receives the physical variable from the secondary side of current/voltage transformer, while the executing part sends trip logic order in response to settings. Easy to extrapolate that the tested protection device, also known as relay, inputs analog signal (current or voltage) and outputs switch signal.

A hybrid simulation platform based on digital-physical closed-loop has the structure as shown in **Figure 1**.

As shown in **Figure 1**, the tested protection device (for example, relay or breaker) has an equivalent model in eMEGAsim SPS digital model. The simulated current of this model acts on the actual tested device by power amplifier, and the action signal of the device is fed back into eMEGAsim to control the action of the digital model.

3. Digital-Physical Interface and Closed-Loop Test

3.1. Analog Interface

Refer to **Figure 1**, analog outputs (D/A) of eMEGAsim SPS digital model use OP-DAQM-DA-16A converter module in which every channel offer full range

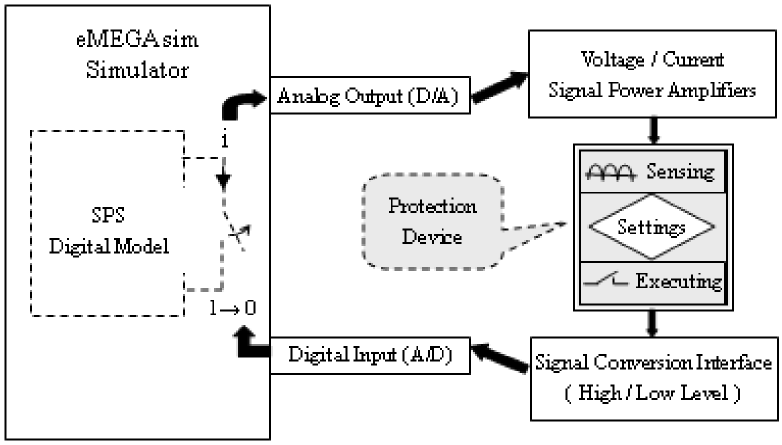

Figure 1. Structure of hybrid simulation platform.

of voltage analog programmability by software from 500 mV to 16 V with 16 bits resolution. The module can drive 16 analog channels at 35 mA output simultaneously.

Signal power amplifiers are the most critical interface equipment because their outputs are physical equivalent to the secondary side of the actual transformers (mainly current transformers CT). As for whether the secondary side of the CT used in access to release of circuit breakers of SPS is voltage or current, usually voltage for Air Circuit Breaker (ACB) and current for Molded Case Circuit Breaker (MCCB).

Define abbreviations and acronyms the first time they are used in the text, even after they have been defined in the abstract. Abbreviations such as IEEE, SI, MKS, CGS, sc, dc, and rms do not have to be defined. Do not use abbreviations in the title or heads unless they are unavoidable.

3.2. Logic Interface

In the eMEGAsim SPS digital model, the equivalent component model of actual tested protection device is controlled by 0/1 logic signal from digital input (0-Open, 1-Close). The digital inputs (A/D) use HCPL-2631 optical-coupling triode module which 12 V high level corresponding to digital input "1" and 0 V low level to "0". The protection device's action signal (relay contact or breaker auxiliary contact) is converted to high/low level by means of signal conversion interface. The interface circuit is shown in **Figure 2**.

3.3. Application Example

Large SPS ring structure grid usually consists of two power stations and each station contains two generators [6]. Without loss of representation, the topological structure of SPS considering the typical load branches is shown in **Figure 3**, which is also an equivalent circuit framework for eMEGAsim digital simulation modeling.

In **Figure 3**, K1-K11 and S1-S3 are the equivalent models of the tested device's executing part (relay, ACB, or MCCB) in eMEGAsim. Respectively simulate

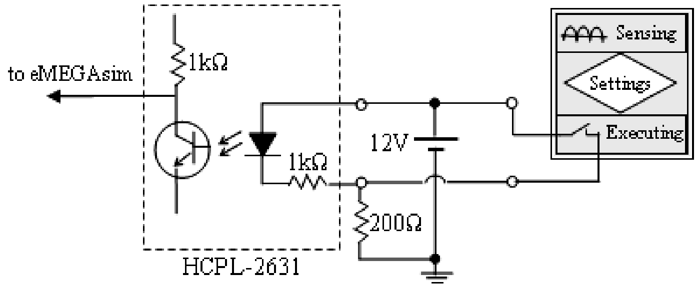

Figure 2. Action signal of device convert to digital input of eMEGA-sim.

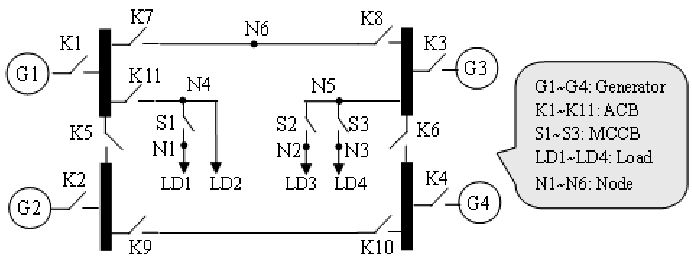

Figure 3. Typical SPS digital model diagram for protection settings test.

fault (overload or short circuit) at node N1-N6, can verify all settings and their coordinate of the lower/upper distribution board, the bus protection and the power switchboard. In this application, the three-segment protection settings of tested devices is verified, and the expected results are obtained.

4. Conclusion

The digital-physical hybrid simulation platform makes full use of the experimental safety and flexibility of the eMEGAsim digital model in simulating of fault behavior. Structure of the platform, digital-analog interface and closed-loop test method are described in this paper. The test results for actual SPS devices show that the platform can effectively verify the correctness and coordination of the protection settings.

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