Engine Generator Torque Estimation Technique Using Mechanical System-Electrical Power System Coupled Analysis

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Shaft systems of engine generators have been designed conventionally by analyzing the generated torque of the engine body and the load torque of the generator individually, mainly for the steady state. However to deal with the increase in regeneration energy and the instability of the electrical power system in recent years, transient analysis and evaluation of the power system are taking on increasing importance. This paper reports on technology to estimate torque under transient conditions of the power system and upon the occurrence of an accident using coupled analysis of the mechanical system and the electrical power system of an engine generator.

1. Introduction

In the past, the shaft system of an engine generator was designed by analyzing the generated torque of the engine body and the load torque of the generator individually, and designed mainly for the steady state. In the design process of a shaft system, the torsional vibration from the engine body to the generator is calculated to confirm that there is no resonance point in the operation range, and static strength and lifespan evaluation are performed based on the steady load torque and the maximum load torque.

However, in recent years, there are an increasing number of small-scale systems that introduce large amounts of regeneration energy. In addition, load fluctuations and behaviors that affect electrical power systems as seen in developing countries have been increasing. The number of system accidents occurring in developing countries is much larger than that in Japan. Therefore, evaluation under transient conditions and upon the occurrence of accidents is also required.

In this report, in order to estimate the torque generated on the engine shaft under transient conditions and upon the occurrence of accidents, which is the basis data of the shaft system evaluation, engine shaft torque estimation technology using mechanical system-electrical power system coupled analysis through simulation is presented.

2. Overview of mechanical system-electrical power system coupled simulation

2.1 Target product

The target products are engine generators manufactured by Mitsubishi Heavy Industries Engine & Turbocharger, Ltd., which has a lineup ranging from 180 kW to 15.4 MW. The fuel is diesel oil or gas. The power supply voltage ranges from a low voltage of 200 VAC to a high voltage of 11 kVAC, and the power supply frequency is 50 or 60 Hz. In Japan and developed countries, the need for gas engine generators is high, but in developing countries, there are many areas where the gas supply infrastructure is not well established and the demand for diesel engine generators remains strong. In developing countries, the introduction of regeneration energy has also been increasing, and such a largely fluctuating power source is connected to a weak system in some cases, making systematic disturbances likely to occur.

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This paper reports on the examination results for a 7.5 to 10 MW class, 18-cylinder diesel engine generator aimed for use overseas.

2.2 Overview of simulation analysis model

In conventional engine generator simulation, as shown in **Figure 1**, the inertia of the engine and the inertia of the generator are integrated into the generator model, and the fluctuation of the voltage and frequency is obtained using the engine output as the input, or conversely, using the torque generated by the generator as the input, to simulate the dynamic characteristics of the engine.

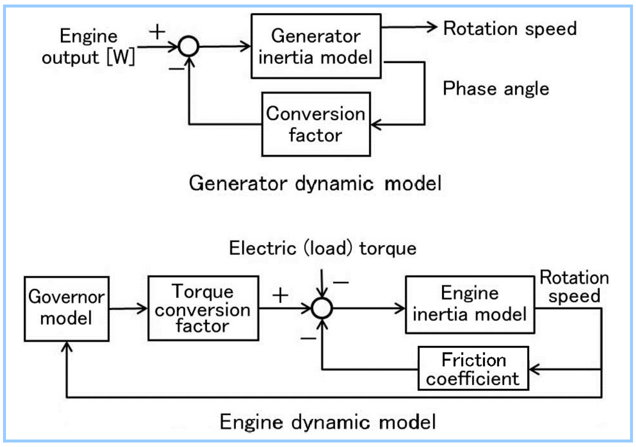

Figure 1 Overview of general simulation model

In the simulation presented here, the torque generated in the electric system is applied as the load torque of the engine at any given time to obtain the dynamic characteristics of the engine. **Figure 2** presents the overview of the mechanical system-electrical power system coupled simulation model.

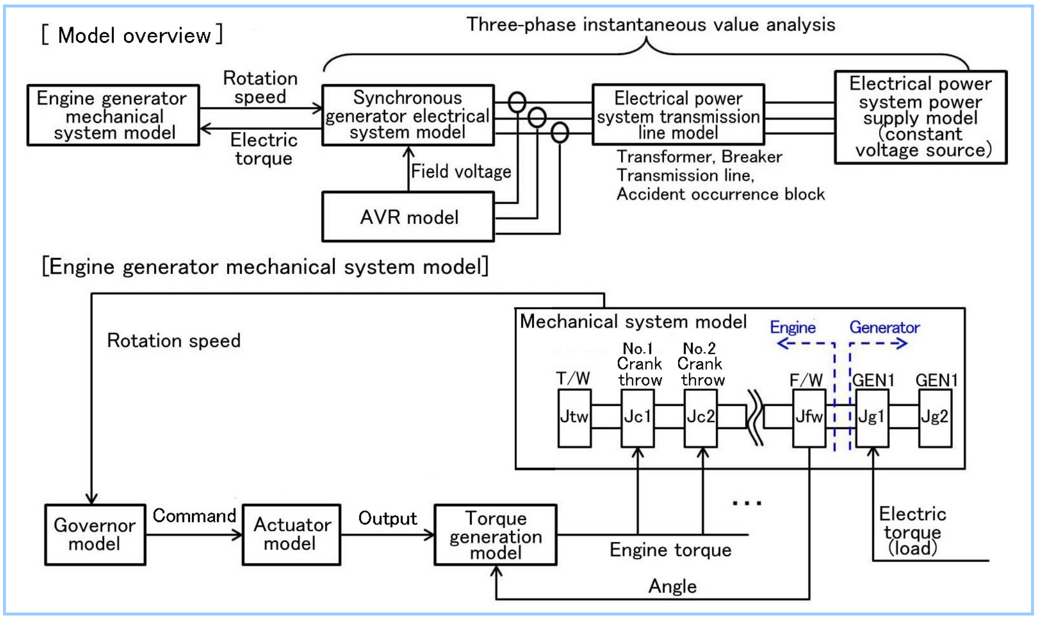

Figure 2 Overview of mechanical system-electrical power system coupled simulation model

The mechanical system models of the engine body and the generator consist of a spring-mass system and consider the torque generated by each cylinder due to explosion, the absolute damping of the engine (proportional to the angular velocity of the engine), and the relative damping (proportional to the difference between the angular velocities at the front and back of the target crank). The governor that adjusts the rotation speed and the output, as well as the actuator that supplies the fuel, are modeled, and not only the influence of the response of the control system, but also the engine shaft torque of the mechanical system can be calculated. The input from the electrical power system to the mechanical system is the input of the electric torque obtained by the generator model.

The electrical power system model of the generator adopts a synchronous generator model, using general generator parameters such as the transient reactance, transient time constant, etc. In addition, an AVR (automatic voltage regulator) for voltage control is also incorporated in the model. In order to keep the engine shaft rotation speed and the generator shaft rotation speed the same, this model uses the engine rotation speed as an input to the generator model.

The generator model and the electrical power system model are connected via a circuit breaker and a transformer, and the electrical power system model consists of a constant voltage source, a transmission line and a power load as an infinite bus. In general, design condition data such as back impedance, etc., can be obtained, but in many cases, it is difficult to obtain detailed transmission line parameters. However, since the transmission line distance could be obtained for this case, the transmission line parameters are determined by using the published resistance and reactance value per distance of a similar transmission line.

In the simulation study, by intentionally changing the parameters of the constant voltage source model of the bus, generating bus frequency fluctuation and causing an accident such as a short circuit (three-phase short circuit or line-to-line short circuit), etc., in the middle of the transmission line, a change is imposed to the bus to obtain the torque applied to the shaft of the engine generator.

MATLAB/Simulink SimPowerSystems[1] is used as the analysis tool.

3. Results of simulation

3.1 Model validation

As a verification of the model, the results of a line-to-line short-circuit (two-phase short circuit) generated at the generator output terminal are given in **Figure 3**. The instantaneous current change was about 10 times the rated current. This is roughly in agreement with the typical literature value[2] of a line short circuit and indicates that the model was reasonable. In addition, it was found that the instantaneous engine shaft torque generated at this time was about 7.5 times the rated torque. Based on this model and on-site record data, the event that occurred at the site and the engine shaft torque were estimated. The results are provided in the next section.

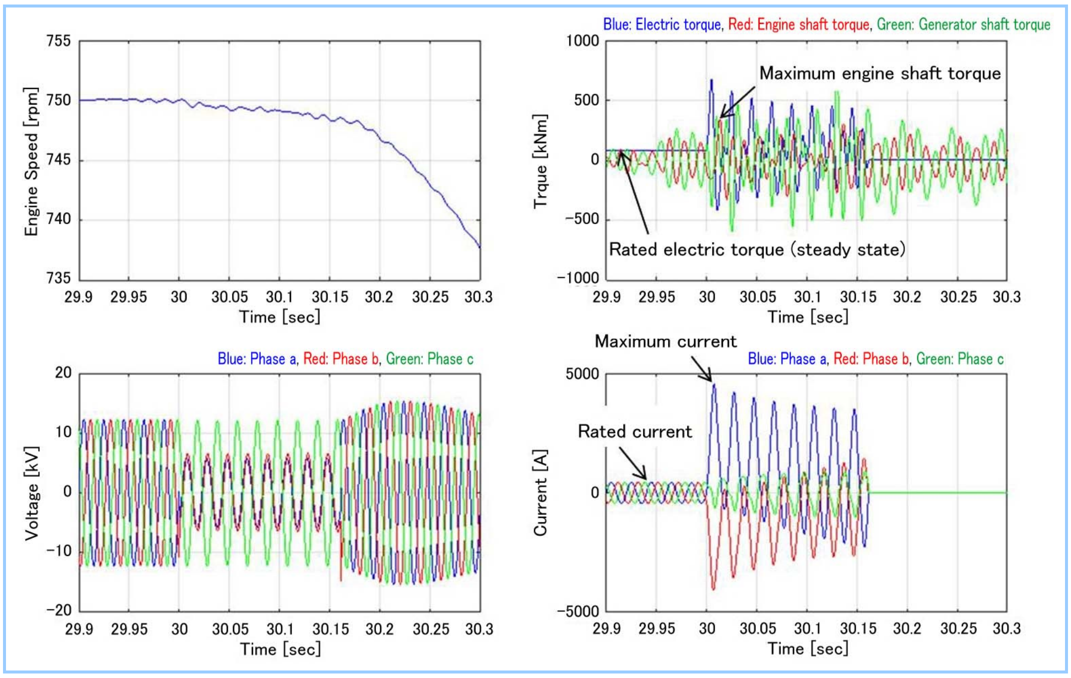

Figure 3 Verification of simulation model (line-to-line short circuit)

3.2 Case study

In the actual plant, the electrical power system is not redundant, and there are many system accidents, resulting in frequent power outages. An electrical power system accident also has a major influence on the engine generator supplying the electrical power, which is one cause of engine trouble. In this simulation analysis, a form of an accident occurring in the electrical power system of the site was estimated and reproduced in the simulation on the basis of the record data (three-phase voltage), and the electrical torque and the mechanical torque in that state were obtained.

As an example of the simulation, first, **Figure 4** illustrates the three-phase voltage of the generator output terminal at the time when a line short circuit occurs in the bus system of the site. When confirming the change in the voltage, it is considered that a high-resistance three-phase short circuit accident has occurred because the three-phase voltage is in the same phase and at the same potential and the voltage is not 0 V.

Figure 5 makes a comparison between the on-site record data and the results of reproducing the data in the simulation. In the simulation, the parameters of the accident occurrence model are adjusted so that the voltage fluctuation in the simulation coincides with the actual voltage fluctuation based on the measured accident data of the line short circuit, and the calculation is performed while switching the parameters for each accident continuation time. For this reason, there is a slight difference in the accident parameter switching section. However, as a whole, the simulation reproduces the line short-circuit phenomenon of the actual equipment.

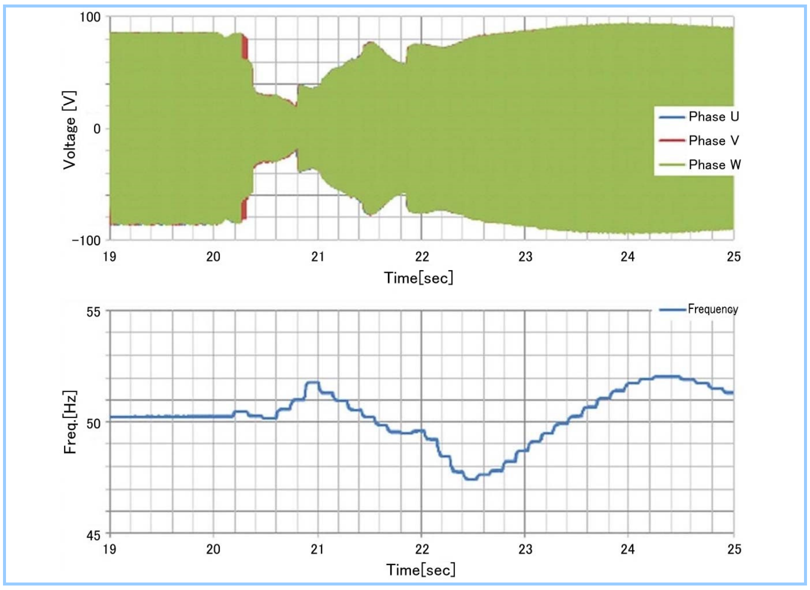

Figure 4 On-site record data of accident (three-phase voltage)

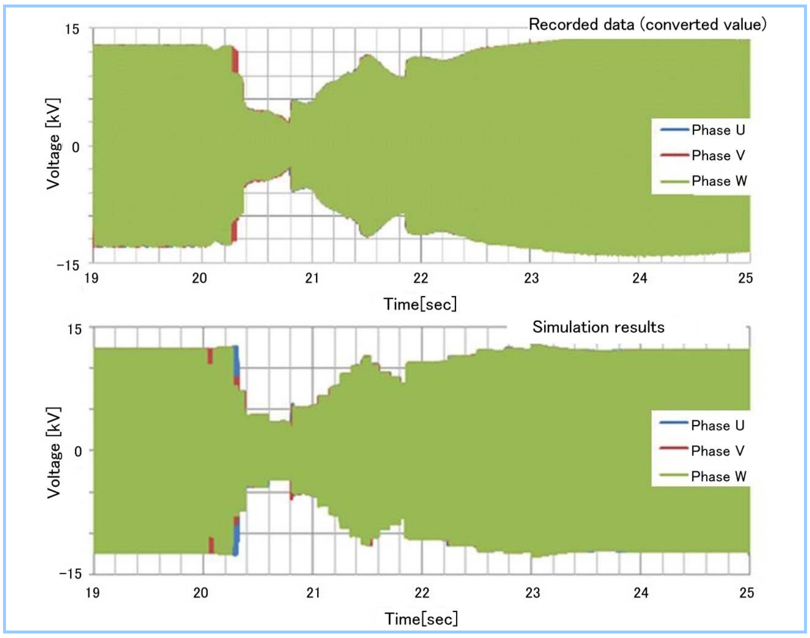

Figure 5 Comparison between on-site record data and simulation results (three-phase voltage)

Figure 6 and **Figure 7** present the changes in the electric torque, generator shaft torque and engine shaft torque in this state. With respect to the generator shaft and engine shaft torque, the instantaneous change, the influence of the response delay of the mechanical system and the control system, as well as the amplification situation of the torque caused by the resonance point, are indicated. Instantaneously, a torque about 4 times the steady torque is generated.

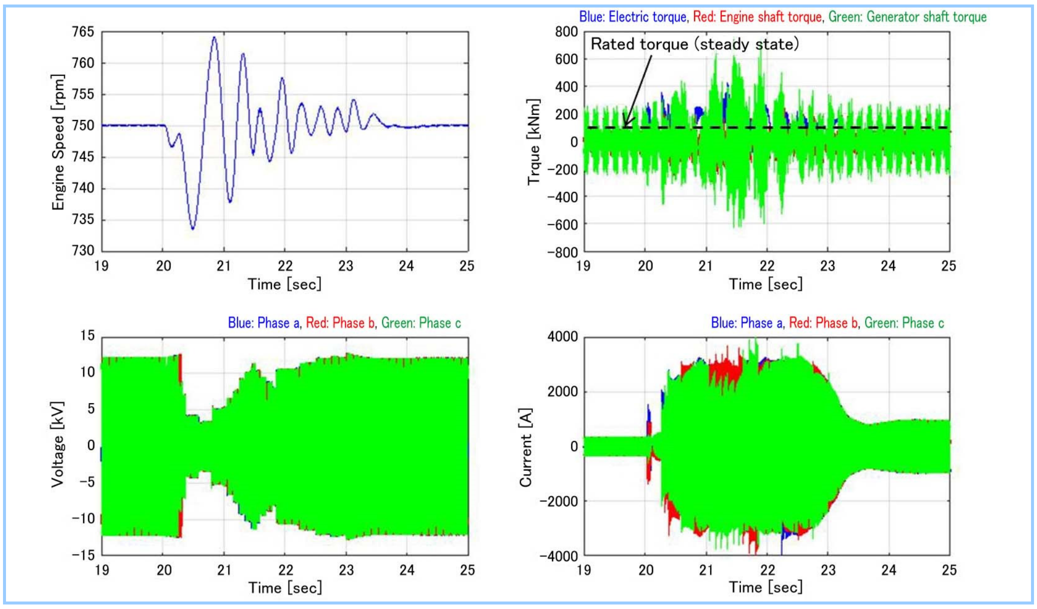

Figure 6 Torque estimated using simulation

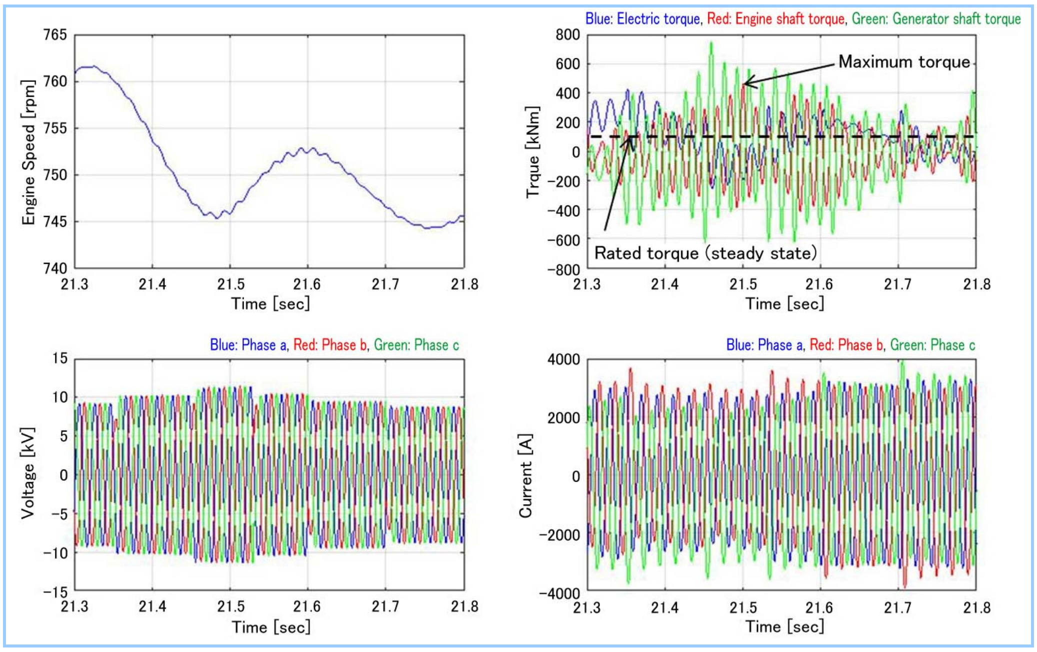

Figure 7 Torque estimated using simulation (magnified view)

4. Conclusion

By using mechanical system-electrical power system coupled simulation, the estimation of engine generator shaft torque in a transient state was made possible. The torque presented as an example here is the torsion torque and the generator shaft torque at the flywheel connecting the engine and the generator, but by modeling the engine generator in further detail and by coupled analysis of the power system, it is also possible to evaluate the torque of more detailed parts inside the engine. Moreover, since this is simulation of the transient state, it can be applied to the tuning of the control system and the transient areas can also be quantitatively evaluated from both the mechanical system and control system. Based on the simulation model, we will estimate the causes of fluctuation events in an electrical power system and quantitatively evaluate the influence on the engine generator, and strive to further improve product reliability.

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