Optimum Control of Shipboard Turbine Generator Predicted Operation Based on Neural Network

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Abstract. Turbine generator is advantageous on durability and reliability for shipboard power station. Limited by power transmission characteristic, the adjustment process may not have enough effectiveness and preciseness while changing working conditions. Based on turbine generator PID speed control model, the optimization of passive adjustment from signal perspective is designed, and control technique for predicted operation with neural network is proposed. According to the result of simulation test, the optimized control can help shortening the regulation time and suppressing speed oscillation.

1. Introduction

With the development of shipboard power grid, capacity and quantity of electric load on ship keep increased, which requires for enhanced ability for shipboard power grid stable operation in the process of sudden load change. In comparison with diesel generators, turbine generators exceed in operational safety, stability and manufacturing costs in condition of heavy load or even overload, which makes it widely used in megawatt shipboard power grid. Complex power transmission process and large time constants in boiler, hydraulic actuator and turbine may be harmful to power grid frequency stability, so it is necessary to research on control signal optimization method in order to improve the adjustment process. Abundant results have been obtained in control method research on the basis of power feedback principle [1], but this method cannot completely eliminate the fluctuation of turbine valve and speed.

Referenced by relevant experimental experience, the speed control model for shipboard turbine generator is built with PSCAD software. On the basis of traditional PID control technique, compensation strategy by using load power information is proposed, and control parameters are optimized with neural network. The result of simulation indicates that, optimized control achieves the desired effect.

2. Control principle

2.1. Power station structure model

Commonly speaking, turbine is usually controlled by its valve, which can directly change steam flow and affect torque balance, maintain machine speed as well as frequency of grid. Limited by cabin structure, shipboard turbine generator usually adopts single cylinder design, with several pressure
stages inside. Turbine and generator is connected by the same main shaft, and turbine valve is controlled by digital electro-hydraulic governor (DEH). The structure model is shown in figure 1. In the process of speed adjustment, the speed control signal generates an oil pressure signal through an electro-hydraulic servo valve, and the oil pressure signal changes pressure oil level of hydraulic actuator, which can change turbine valve position at last. For steam turbines that do not contain reheat system, a linear relationship exists between turbine valve positions, steam flow rate and output power unless steam conditions deviate greatly from rated values [2]. In order to lay emphasis on the optimization of speed control method, the transmission structure of turbine generator is not studied in depth in this paper [3]. Meanwhile, only fixed load is used for testing in this paper.

![Figure 1. Block diagram of turbine generator structure.](image1)

Models are established with PSCAD software, where DEH servo structure consists of several processes including speed control and limit blocks. Gas turbine mainly shows gas expansion and volume delay characteristic, which can be expressed by series of delay and inertia process, as shown respectively in part 1 and part 2 of figure 2.

![Figure 2. Block diagram of DEH and turbine process.](image2)

The IEEE generator fifth-order model is used to describe electro-magnetic transient process while power grid disturbance takes place. The exciter is expressed by the sum of forward integration, self shunt excitation and saturated negative feedback processes, which is shown in figure 3(1). The PID control signal is calculated by proportion, integration and differentiation processes of speed deviation, and the result is applied for speed control and excitation control, as shown in figure 3(2).
2.2. Control method with accurate knowledge on power

Because of several nonlinear transfer processes between controllable components and speed variations, together with time delay in signal measurement, computation and transmission, speed fluctuation around the equilibrium point may always exist in the process of adjustment controlled by PID feedback method. Traditionally, regulation performance can be improved by optimizing PID parameters, designing parallel control [4], or applying nonlinear control method [5]. But as long as feedback variables are used, reciprocation in regulation process of turbine valve cannot be completely eliminated.

Speed adjustment is mainly achieved by valve control. If the information of load changing can be obtained in the initial stage of regulation, the equilibrium point of valve can be determined, and machine speed can be stabilized without second swing by additional control on base of traditional PID method. Changing of main steam parameters is not considered in this paper, and this assumption can meet engineering requirements in most cases.

In the experiment of a 20MW turbine generator speed regulation using static load, speed waveform after manual valve control is recorded below. As seen in figure 4, speed reciprocation is eliminated, but the overshoot can still be optimized by adjusting moment of control. The optimal moment is influenced by several factors, such as inertia of machine unit and amount of load changing. In order to provide quick response, neural network is applied.

2.3. Parameter optimization method

In order to shorten the accommodation time and reduce the overshoot, the optimization of parameters aiming at the additional control method presented above mainly includes two aspects. One, with accurate knowledge of power, the moment of control can be optimized. If the moment is too early or too late, speed recovery will be slow or the overshoot will be relatively larger, which is shown in figure 5 (1) (2) below. Second, with information of power changing unknown, equilibrium valve position needs to be determined before optimizing control moment.
The speed adjustment of turbine generator includes complex nonlinear process. However, considering the machine characteristics such as inertia and delay as well as PID parameters of control system generally remain unchanged during normal operating, a definite corresponding relationship exists between the first swing characteristic and the changing amount of load (shown in figure 6). As the speed drop correlates with the changing amount of load positively, the equilibrium point can be calculated, and proper control can be implemented in the latter part of the first swing process.

With the fact that accurate determination of characteristics of turbine generator still needs further research [6], the model and procedure of regulation system are relatively obscure. Neural network technique can adapt to this situation well [7]. In the process of predicted additional control by using neural network, input signal includes steady speed before the first swing $V_1$, minimum speed of the first swing $V_2$, and output signal includes target valve position $f$ together with the moment of control $t$. Among them, position $f$ is a function of $V_1$ and $V_2$, and moment $t$ can be expressed as the sum of the moment of minimum speed $T_0$ and the time deviation $\Delta t$.

After simulation using output signal $f$ and $t$, the steady time of speed can be evaluated, and optimization process can be done by repeating simulation until the steady time reaches the numerical convergence. The validity of this method is influenced by the number of training samples and the accuracy of simulation model. In theory, this additional control strategy can meet the regulation needs from no-load to full load, and increasing accuracy can undoubtedly make the conclusion more instructive [8].

3. Simulation test
In the simulation test, fixed load with 0.9 power factor is used. At moment of 20s, load is increased by 45% of full load. At the moment of 30s, machine speed is almost stable, and the PID signal takes over valve control again. Waveforms under two different conditions, with or without additional control, are shown in figure 7 (1) (2) below.
As shown in figure 7, after sudden load change, machine speed increases rapidly after initial drop. Without additional control, machine will keep accelerating and exceeding rated speed, and its reciprocating characteristic is consistent with the pattern of valve change. At 42s of simulation, rotation speed is stabilized. By contrast, when additional control is applied, turbine valve is fixed to the target position 0.763 at 22.37s of simulation, and speed is stabilized by the moment of 26s. According to the result, the effect of additional control method is consistent with expectation.

4. Conclusion
On base of traditional PID speed regulation of turbine generator together with manual valve control experiment, operation point prediction control method using neural network is proposed. Facing sudden changes of load, this method can predict equilibrium point from first swing characteristic, and search for optimal moment of control. The simulation result indicates that, this strategy can effectively reduce the adjusting time, and is advantageous for stable operation of shipboard power system.

Practically, motor load occupies a large proportion of power system on ship, relationship between working condition and valve position can be much more complicated than static load, which may request for further research. As neural network method needs more computing resources than traditional ones, its real-time application will be continuously improved with development of hardware technology.

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