Parallel operation simulation of medium voltage diesel emergency power supply vehicles

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Abstract—The large-scale emergency load demand improves the requirements of distribution network for emergency power capacity, and the working condition of multi-engine parallel operation of medium voltage diesel emergency power supply vehicles also arises. In order to solve the difficulty of parallel simulation of medium voltage diesel emergency power supply vehicles, this paper establishes the simulation model of medium voltage diesel emergency power supply vehicles by analyzing the mathematical models of internal components. According to the parameter conditions of parallel operation, the parallel controller is designed. Finally, the multi-engine parallel system model of medium voltage diesel emergency power supply vehicles is built by using Matlab / Simulink, and the parallel operation simulation of medium voltage diesel generator vehicles is completed.

1. Introduction
With the explosive growth of power consumption, the social demand for power supply guarantee capacity of distribution network is increasing[1]. In case of permanent failure of distribution network, important power loads such as data center and hospital need to use emergency power supply to maintain power supply, to ensure the safety and stability of production and life[2-3].

At present, the emergency power supply in distribution network generally adopts the diesel generator or high-power energy storage. Medium voltage diesel emergency power supply vehicles have the advantages of high power, convenient movement and flexible power supply, which can provide emergency power supply in case of power failure to reduce power failure time and improve power supply guarantee capacity of power grid. It has become an important choice of emergency power supply for distribution network[4-5].

With the large-scale emergency load demand improves the requirements of distribution network for emergency power capacity, and the working condition of multi-engine parallel operation of medium voltage diesel emergency power supply vehicles also arises. In order to solve the difficult problem of parallel simulation of medium voltage diesel emergency power supply vehicles, this paper mainly introduces the modeling method of medium voltage diesel emergency power supply vehicles, and designs the parallel controller. The electromagnetic transient simulation model of the parallel system of two diesel emergency power supply vehicles is built by Matlab / Simulink, and the parallel operation characteristics of medium voltage diesel generator trams are determined by simulation test.

2. Model Building Method of Medium Voltage Diesel Emergency Power Supply Vehicle
The medium voltage diesel emergency power supply vehicle is composed of diesel engine, synchronous generator, governor, excitation controller, electrical and mechanical sensors. When
conducting electromagnetic transient simulation modeling, it is necessary to theoretically analyze the control modes of diesel engine, synchronous generator, governor and excitation controller.

2.1. Diesel engine model
The input of diesel engine control is the expected speed, expected power and actual speed of diesel generator, and the output is the mechanical power of diesel engine. The dotted box in Fig.1 is the module structure block diagram of diesel engine in Matlab / Simulink.

![Fig.1 Block diagram of diesel generator](image)

In Fig.1, the actual speed and expected speed input by the diesel engine are unit values. Given the reference speed and reference power of the diesel engine, the speed and power of the diesel engine are compared to control the output torque of the diesel engine. The diesel engine contains two transfer functions:

\[
TF1 = \frac{1 + T_4 s}{1 + T_5 s},
\]
\[
TF2 = \frac{1}{1 + T_6 s}
\]

\[
\begin{align*}
V_d &= -i_d R_s - \omega \psi_q + \frac{d\psi_d}{dt} \\
V_q &= -i_q R_q - \omega \psi_d + \frac{d\psi_q}{dt} \\
V_0 &= -i_0 R_0 + \frac{d\psi_0}{dt} \\
V_{fd} &= \frac{d\psi_{fd}}{dt} + R_{fd} i_{fd} \\
0 &= \frac{d\psi_{kd}}{dt} + R_{kd} i_{kd} \\
0 &= \frac{d\psi_{kq1}}{dt} + R_{kq1} i_{kq1} \\
0 &= \frac{d\psi_{kq2}}{dt} + R_{kq2} i_{kq2}
\end{align*}
\]

Where T4, T5 and T6 are time constants with values of 0.25, 0.009 and 0.0384 respectively.

2.2. Synchronous generator model
The seventh order state equation of synchronous generator is shown in equation (3). Where, subscripts "d, q and 0" respectively represent d-axis, q-axis and 0-axis components; \(V_d, V_q\) and \(V_0\) represent stator voltage; \(V_{fd}\) represents rotor voltage; \(i_d, i_q\) and \(i_0\) represent stator current; \(\psi_d, \psi_q\) and \(\psi_0\) represent stator flux component; \(\omega\) represents rotational speed; \(\psi_{fd}, \psi_{kd}, \psi_{kq1}\) and \(\psi_{kq2}\) represent rotor flux component; \(i_{fd}, i_{kd}, i_{kq1}\) and \(i_{kq2}\) represent rotor current component; \(R_s\) represents armature resistance; \(R_0\) represents...
0-axis resistance; \( R_{d1}, R_{d2}, R_{kq1} \) and \( R_{kq2} \) represent rotor resistance. When building the simulation model, Simulink's own module "synchronous machine Pu standard" can be used.

### 2.3. Governor and its control model

The governor is an important part of the automatic regulation of the diesel engine. The part outside the dotted box in Fig.1 is the control module of the diesel engine governor, including a transfer function, a gain part, an integrator and a delay link. The transfer function is:

\[
TF = \frac{T_1 s + 1}{T_2 s^2 + T_3 s + 1}
\]

The time constants \( T_1, T_2 \) and \( T_3 \) are set to 0.01, 0.02 and 0.2 respectively, the gain \( K \) is 0.5, the initial value of torque in the integrator is 0.52, and the torque is limited between 0 and 1.1.

![Block diagram of diesel generator exciter](Fig.2)

#### 2.4. Exciter and its control model

The generator exciter adopts IEEE DC1A exciter model, without load compensator and DC commutator exciter with controlled magnetic field with continuous acting voltage regulator, which adopts self excitation mode. Fig.2 is the module block diagram of the excitation part of the diesel generator in Simulink.

The transfer function used in the lead lag compensation link is:

\[
H(s) = \frac{1 + T_1 s}{1 + T_2 s}
\]

Fig.3 is the block diagram of the control part of the exciter of the diesel generator. The diesel generator can realize four control modes: leading power factor control, lagging power factor control,
3. Parallel Controller Model

The parallel controller needs to detect and judge the voltage difference, frequency difference and phase difference of the parallel unit, and send a signal to adjust and control the parallel unit when the synchronization conditions are not met. Therefore, the parallel controller used in this paper includes the following parts: electrical quantity calculation module, voltage synchronization condition detection and control module, frequency synchronization condition detection and control module, phase angle synchronization condition detection module, synchronization signal output module and power tracking control module.

![Electrical quantity calculation module](image1.png)

![Voltage synchronization condition detection and control module](image2.png)

The structure of electrical quantity calculation module is shown in Fig.4. The unit values of line voltage ($U_1$, $U_2$), active power ($P_1$, $P_2$) and reactive power ($Q_1$, $Q_2$) at the output port of the two medium voltage generator trams are solved by calculating the frequency and phase angle of the three-phase voltage signal and combined with the three-phase current real-time signal.

The structure of voltage synchronization condition detection and control module is shown in Fig.5. It judges whether the absolute value of the voltage difference is less than the allowable voltage error, and the allowable error is the set value $\Delta U$ (take the unit value of 0.1pu). When the conditions are not met, the excitation voltage adjustment value is controlled by PID, and the logic signal "1" is output when the conditions are met.

The structure of frequency synchronization condition detection and control module is shown in Fig.6. It judges whether the absolute value of the frequency difference is less than the allowable frequency error, and the allowable error is the set value $\Delta f$ (take 0.4hz). When the conditions are not
met, the speed adjustment value is controlled by PID, and the logic signal "1" is output when the conditions are met.

![Fig.6 Frequency synchronization condition detection and control module](image)

The structure of phase angle synchronization condition detection module is shown in Fig.7 It judges whether the absolute value of phase angle difference is less than the allowable frequency error, and the allowable error is the set value $\Delta \theta$ (taken as $8^\circ$, converted into radians, i.e. $0.13963$), when the conditions are met, the logic signal "1" is output.

![Fig.7 Phase angle synchronization condition detection module](image)

The structure of synchronization completion signal output module is shown in Figure 8. The input port includes voltage synchronization signal, frequency synchronization signal and phase synchronization signal. When the above three signals reach the high level at the same time, the logic gate output signal triggers the sampling holder and outputs the logic signal "1" to the circuit breaker 2 to connect the units to be paralleled to the network and complete the parallel operation of the units to be paralleled.

![Fig.8 Synchronization signal output module](image)
The structure of power tracking control module is shown in Figure 9. When the synchronization is not completed, the unit value of active power detected at the output ports of medium voltage generator vehicle 1 and medium voltage generator vehicle 2 is output to complete the power tracking when the parallel operation is not completed. When the synchronization is completed, calculate the total active power shared by the two units, and then calculate the active power value and output control value of the two units according to the rated capacity, to complete the power distribution and power tracking control of parallel operation.

Fig. 9 Power tracking control module

4. Operation Simulation of Parallel System of Two Medium Voltage Diesel Emergency Power Supply Vehicles
As shown in Figure 10, medium voltage diesel emergency power supply vehicle 1 (V1) and medium voltage diesel emergency power supply vehicle 2 (V2) are selected for parallel test of two machines in this section.

Fig. 10 simulation diagram of parallel operation of two medium voltage diesel emergency power supply vehicles
Fig. 11 Parameter variation diagram of V1 and V2
V1 is the operating unit and V2 is the unit to be paralleled. The parameters of the two medium voltage diesel emergency power supply vehicles are the same: \( P_n = 1 \text{MW} \), \( U_n = 10.5 \text{kV} \), \( f_n = 50 \text{Hz} \), \( x_d = x_d'' = 2.016 \), \( x_d' = 0.242 \), \( x_d''' = 0.191 \), \( x_q = 0.188 \), \( T_d = 1.486 \text{s} \), \( T_d'' = 0.053 \text{s} \), \( T_q'' = 0.1 \text{s} \), \( R_s = 0.01 \), \( H = 1.5 \text{s} \), \( p = 2 \). The initial values of voltage and speed of V1 and V2 are set to the rated value “1”, in which the voltage and speed of medium voltage of V2 are controlled by the parallel controller after synchronization. Circuit breaker 1 (always open) and circuit breaker 2 (controlled by parallel controller) are the main switches of V1 and V2 respectively. Load 1 is set as \( P = 400 \text{KW} \), \( Q = 300 \text{kvar} \), \( \cos \phi = 0.8 \) (1/2 of the unit capacity). The synchronization start time is set to 20s.

The parameter changes of the two medium voltage diesel emergency power supply vehicles are shown in Figure 11. Before 20s, V1 started without load and operated stably with load 1. V2 started without load, and the voltage amplitude and frequency of the two units were stable around 1pu. The synchronization starts at 20s, the parallel controller is put into operation, and the parameters of V2 are adjusted synchronously. After about 1.4s adjustment, the synchronization completion signal of parallel controller is set to high level, and the parallel circuit breaker of V2 is closed, so that V2 is put into operation. When V2 enters the system the voltage amplitude and frequency fluctuate to a certain extent because the parameters of the two units are not completely consistent. After about 9s of load transfer, load distribution, speed regulation and voltage regulation, V1 and V2 start synchronous and stable parallel operation.

5. Conclusion

In this paper, the modeling method of multi-engine parallel system of medium voltage diesel emergency power supply vehicles is proposed, and the simulation test is carried out. The simulation results show that there is a gap in voltage amplitude, frequency and phase angle before multi-engine parallel operation of medium voltage diesel emergency power supply vehicles. After synchronous control by parallel controller, all conditions meet the synchronization requirements. When the unit to be operated is put into operation, there is no large parameter fluctuation, and after control according to power distribution, each unit can share the load according to the rated capacity. Therefore, the parallel operation simulation principle of medium voltage diesel emergency power supply vehicles in this paper is correct and meets the expectations.

References

[1] Wang X, Yang C, Huang M, et al. (2018) Multi-objective optimization of a gas turbine-based CCHP combined with solar and compressed air energy storage system. Energy Conversion & Management, 164(MAY):93-101.
[2] Zhang, Z.C., Qin, Y., Gu, C.H. and Xu, Z.B., (2018) Research on operating performances of 500 kVA flywheel energy storage UPS power supply vehicle. Movable Power Station&Vehicle, vol. 3, pp. 25–29.
[3] Zhang, Z.C., Qin, Y., Gu, C.H. and Xu, Z.B. (2019) Research on operating performances of 300 kVA zero switching time of UPS emergency power supply vehicle. Electrical Technology, vol. 1, pp. 7–10.
[4] Qin, Y., Gu, C.H., Zhang, Z.C. and Xu, Z.B. (2019) Research on performance state of 500 kW diesel electric emergency generator vehicle,”Electrical Age, vol. 4, pp. 55–58.
[5] Gallo M, Costabile C, Sorrentino M, et al. (2020) Development and application of a comprehensive model-based methodology for fault mitigation of fuel cell powered systems. Applied Energy, 279:115698.