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Supervision system for leading phase of multi-generators based on LabVIEW and fractional order controller

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ABSTRACT

A supervision control system and its operational principle for leading phase operation of multi-generators are presented in this paper. The principle of leading phase operation of generator is discussed firstly. Then the software of LabVIEW is introduced briefly. The application of fractional order controller for the supervision control system of leading phase operation of multi-generators is given. The system is comprises of Beidou satellite system module, power angle measurement and calculation module, parameter identification module, interface conversion module, display module, etc. The clock signal of the system is generated by Beidou satellite navigation system. Then, the design of supervision control system based on LabVIEW is given. Based on the LabVIEW platform, the running state and convenient management of leading phase operation of multi-generators are achieved. If a generator exceeds the limit value, the reactive power is adjusted immediately by the corresponding monitoring unit, until the appropriate range is obtained. The supervision control system is safe and reliable, and with relatively high precision.

KEYWORDS

Leading phase operation of multi-generators; Supervision system; LabVIEW; Fractional order controller.

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INTRODUCTION

With the rapid development of power system scale, the higher requirements for monitoring and control of the security and stability of power system is more and more urgent. According to the wide area of power system, the large number of equipments, and the rapid variables change, the information acquisition for running states of key points must rely on the same, high precision reference time. So the safe, reliable, high precision clock synchronization time has become a basic requirement of modern power grid and the future smart grid operation[1].

The currently phasor measurement unit is mainly based on the global positioning system (GPS) for synchronizing reference. Its reliability is dependent on GPS availability and accuracy. For the security and stability control of power system, GPS signal has some shortages, such the poor short-term stability and anti-interference performance, and so on[2-4]. At present, several global satellite navigation and positioning systems are widely applied, such as the GPS system in American, the Galileo system of Europe, the GLONASS system in Russian, and the Beidou satellite navigation system in China. The Beidou navigation system is now applied in some power systems in China[5-6].

Due to the LabVIEW’s graphical programming characteristics, LabVIEW has been used in more and more areas of monitoring. Along with the LabVIEW software’s features gradually increased, the scope of application is gradual extended. Its performance is also more powerful. Therefore, a monitoring system based on LabVIEW for leading phase operation of multi-generators is presented in this paper. At present, the research on monitoring and control technology of generator system is mainly for the integer order system model, and those methods have certain limitations. The existing control system takes the control object as integer order system. But the existing systems in reality are all more or less fractional order[7]. Therefore by use of fractional order, the description of the system will be more accurate, and be more close to the actual situation of the system. In this paper, the LabVIEW is used for the supervision and control of leading phase operation of multi-generators. And the controller is design based on fractional order theory.

The rest of the paper is organized as follows. The basic principle of leading phase operation of generator is presented. Then the brief introduction of LabVIEW is given. The control strategy of fractional order theory is proposed, and the operational principle of the supervision system based on LabVIEW and fractional order controller is discussed. Finally, the paper is completed with a conclusion.

PRINCIPLE OF LEADING PHASE OPERATION OF GENERATOR

Figure 1 is the phasor diagram of lagging and leading phase operation of generator. As shown in Figure 1, the generator G is connected with infinite power system S. The terminal voltage U_G is constant. E_q is the generator potential. I is the stator current. φ is the power factor angle. I_f is the excitation current. X_d is the synchronous reactance. δ is the generator power angle[8-10].

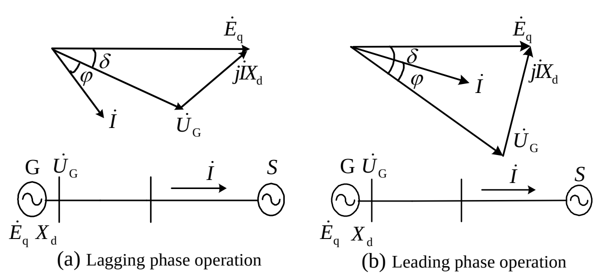

Figure 1 : Phasor diagram of lagging and leading phase operation of generator

When I_f is increasing, E_q is also increasing. I produces a magnetic armature reaction. And now I lag in U_G. At the same time, φ also changes. Generator generates active power P and reactive power Q. At the moment, generator is in the state of lagging phase operation, as shown in Figure 1(a). Conversely, the generator is in the state of leading phase operation, as shown in Figure 1(b).

BRIEF INTRODUCTION OF LABVIEW

Virtual instrument is one of the most representative graphical software. America National Instruments NI firstly puts forward the concept of virtual instrument. Virtual instrument makes the original concept of traditional instrument and complete subversion, and change the user to improve the fact that not according to their own needs. The hardware and the function are more virtual. And the software is the core of virtual instruments. It is the combination of computer technology and virtual instrument. LabVIEW is one of the most important software of virtual instrument. Figure 2 is the block diagram of configuration for virtual instrument system. Figure 3 is the software architecture of virtual instrument.

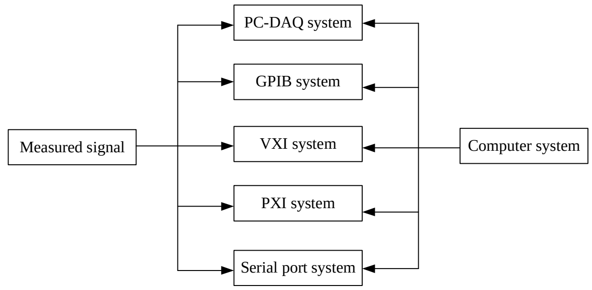

Figure 2 : Block diagramof configuration for virtual instrument system

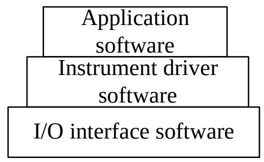

Figure 3 : Software architecture of virtual instrument

FRACTIONAL ORDER CONTROL THEORY

In this paper, the fractional order $PI^{\lambda}D^{u}$ is used in the supervision system for leading phase of multi-generators. By choosing appropriate parameters, the control effect can obtain ideal effects.

Figure 4 is the schematic diagram of controller based on fractional order calculus. Similar to the integer order PID controller, the transfer function of fractional order $PI^{\lambda}D^{u}$ controller is given by

$$G(s) = K_p + K_i s^{-\lambda} + K_d s^{\mu} \quad 0 < \lambda \le 1, 0 < \mu \le 1 \qquad \textbf{(1)}$$

Where, Kp is the proportional gain. Ki is the integral coefficient. Kd is the differential coefficient. λ the integral order. *u* is the differential order.

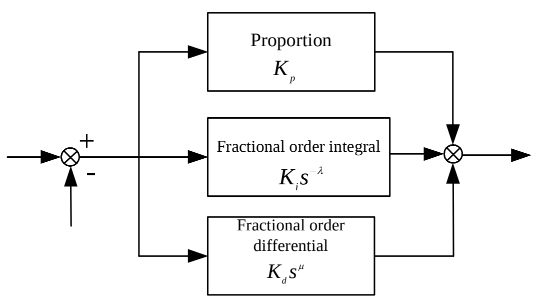

Figure 4 : Schematic diagram of controller based on fractional order calculus

By equation (1), when $\lambda = 0$, $\mu = 0$, $G(s) = K_p$ is the integer order of P - controller. When $\lambda = 0, \mu = 1$, $G(s) = K_p + K_d s$ is the integer order of PD - controller. When $\lambda = 1, \mu = 0$, $G(s) = K_p + K_i s^{-1}$, and G(s) is the integer order of PI - controller.

When $\lambda = 1, \mu = 1$, $G(s) = K_p + K_i s^{-1} + K_d s$, and G(s) is the integer order of PID - controller. Compared with traditional integer order PID controller, the fractional order $PI^{\lambda}D^{u}$ controller has two more variables of any real number of λ、μ. If $0 < \lambda \le 1, 0 < \mu \le 1$, the controller order of λ and μ can be any value from 0 to 1, which makes the adjustment range of controller is wide, and can obtain better accuracy.

OPERATIONAL PRINCIPLE OF THE SUPERVISION SYSTEM BASED ON LABVIEW

Figure 5 is the working principle diagram of the supervision control system. The system is comprises of Beidou satellite system module, power angle measurement and calculation module, parameter identification module, interface conversion module, display module, etc. In Figure 5, the G represents generator. PT represents potential transformer. *X* represents system connection reactance. K_i and X_i represent the ratio and impedance of *i*th step-up transformer of power plant, respectively. i

= 1, 2, …, N. N is the total number of power station generators. $\dot{U}$ is the terminal voltage of generator. $\dot{U}_T$ is the high side voltage of step-up transformer. $\dot{U}_S$ is the high bus voltage of receiving system[6]. Beidou satellite system is the basic part of the whole monitoring system. The clock signal is provided by the Beidou satellite signal receiver.

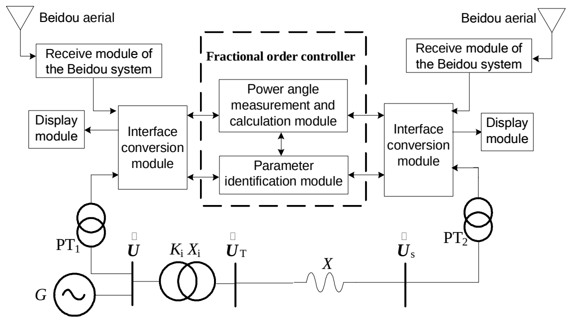

Figure 5 : Working principle diagram of the supervision control system

Figure 6 is the system software overall structural diagram. As shown in Figure 6, the main menu of the supervision system is consists of system help, software information, time display, power angle setting, data acquisition, excitation control, and so on.

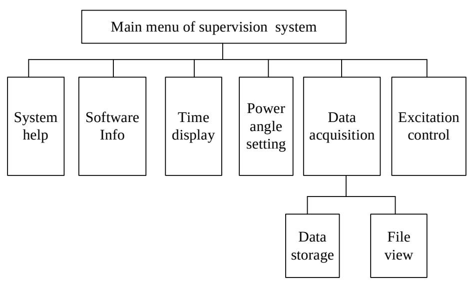

Figure : 6 Overall structural diagram of system software

Figure 7 is the system software flow chart. As shown in Figure 7, the system initialization consists three parts, the main panel event structure, the time module operation and the system main cycle.

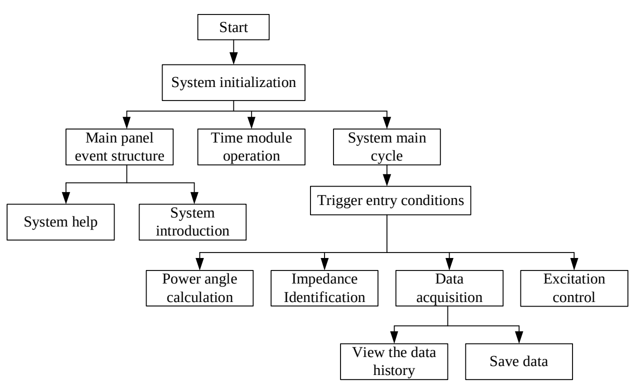

Figure : 7 System software flow chart

In this paper, the RS-232 module is used to achieve the communication between lower place machine and super place machine. Figure 8 is the schematic diagram of serial communication of RS-232 module.

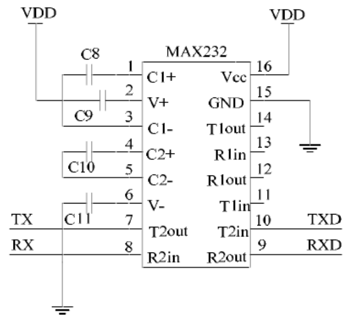

Figure 8 : Schematic diagram of serial communication

Power angle measurement and calculation module is connected with interface conversion module and parameter identification module. The power angle δ_1 between synchronous generator and the system is calculated by the measured voltage *U*, active power *P*, reactive power *Q* and excitation current $\boldsymbol{I}_{f0}$. Then, according to the identified system connection reactance *X*, reactance of the step-up transformer, the power angle δ and the system static stability margin are calculated.

With the non salient pole synchronous generator as an example, the per-unit system is used for each value. θ is the power factor angle. I is the stator current. $\boldsymbol{I}_{f\delta}$ is the equivalent excitation current of compound air-gap. $\boldsymbol{I}_{fa}$ is demagnetization current of armature reaction. $\boldsymbol{I}_{f0}$ is no-load excitation current. $\boldsymbol{E}_{\delta}$ is electric potential of air gap. θ_1 is the angle between $\dot{\boldsymbol{U}}$ and $\dot{\boldsymbol{E}}_{\delta}$. θ_2 is the angle between $\dot{\boldsymbol{E}}_0$ and $\dot{\boldsymbol{E}}_{\delta}$. θ_3 is the angle between $\dot{\boldsymbol{I}}_{f\delta}$ and $\dot{\boldsymbol{I}}_{f0}$.
The solving steps are as follows[6]:

(1) First, I and θ are calculated by P, Q and U of generator, and the $P = UI\cos\theta$ and $Q = UI\sin\theta$. The OA is calculated by air-gap line of no-load characteristic and IX_{δ}.

(2) The OB is calculated by short circuit characteristic curve and *I*.

(3) The demagnetization current of armature reaction is calculated by $\boldsymbol{I}_{fa}$ =OB-OA.

(4) θ_1 is obtained by $\dot{\boldsymbol{E}}_{\delta} = \mathrm{j}\dot{\boldsymbol{I}}X_{\delta} + \dot{\boldsymbol{U}}$.

(5) $\dot{\boldsymbol{I}}_{f\delta}$ is perpendicular to $\dot{\boldsymbol{E}}_{\delta}$. The angle between $\dot{\boldsymbol{I}}_{f\delta}$ and $\dot{\boldsymbol{I}}_{fa}$ is definite.

(6) The triangle is consists of $\dot{\boldsymbol{I}}_{f\delta}$, $\dot{\boldsymbol{I}}_{fa}$ and $\dot{\boldsymbol{I}}_{f0}$. The $\dot{\boldsymbol{I}}_{fa}$ and $\dot{\boldsymbol{I}}_{f0}$ are known. The angle between $\dot{\boldsymbol{I}}_{fa}$ and $\dot{\boldsymbol{I}}_{f\delta}$ is known. Then, the triangle is the only definite. θ_3 is calculated.

(7) $\theta_2 = \theta_3$, $\delta_1 = \theta_1 + \theta_2 = \theta_3 + \theta_1$. Then the power angle δ of generator is obtained.

CONCLUSION

The presented supervision control system for leading phase operation of multi-generators based on LabVIEW has the following characteristics: safe and reliable, relatively high accuracy, and convenient practical application. The design of fractional order controller for the presented supervision control system is an important research direction for further work.

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