RESEARCH ON MECHANICAL ADJUSTMENT FREQUENCY CONTROL TECHNOLOGY OF AC POWER GENERATION SYSTEM

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A new mechanical adjustment frequency method of AC Power Generation and its control technology are proposed in this paper: metal chain Electronic Mechanical Continuously Variable Transmission (EMCVT) is used as the frequency converter of the alternator, and the target of controlling the stable output of the electric frequency is realized by controlling the input speed of the alternator. Based on the introduction of the topology of EMCVT power generation system and its implementation method, the mathematical model of speed ratio control of the governing mechanism of EMCVT is established, and the control theory model of the corresponding speed ratio drive control motor is proposed. By simulating the frequency control experiment of the EMCVT AC power generation system, when the ordinary DC motor is used as the speed ratio control motor, the control power frequency output accuracy can reach 50Hz±1.67%. Constant frequency control is basically realized.

Keywords: AC power frequency control. EMCVT. Speed ratio control model. Drive motor control model.

1. Introduction

Regardless of the type of AC power generation system, the most important condition for using its output power to drive the load object or to connect to the grid (which can be considered that the grid is a lot of load objects that need to be powered) is: the frequency and voltage of the output power of the generator set can be controlled steadily [1-3]. The output voltage of the generator is controlled by its excitation system (AVR), and the frequency of the output power is almost always determined by the rotor speed of the generator set.

The output power fluctuations of the power source of the power generation system in the microgrid increase the difficulty of frequency modulation of the power generation system. The change in the frequency of the power generation system in turn affects the operating state of the source drive unit. All powered access systems require the output shaft of the source engine group to operate

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normally within a defined speed range. After the speed exceeds a certain range, it is necessary to limit the output operation or delay the operation after a certain time to maintain the frequency of the system. Many national grid companies require electric fields to participate in the frequency adjustment of the system by controlling the output power by 3% to 5%.

The traditional method of maintaining the system frequency stability of the generator set is mainly to control the stability of the input speed of the generator set by adjusting the inclination angle of the turbine blade [4,5]. When the input speed of the genset is too high due to excessive load changes, etc., the output power of the electric field is reduced by the method of stopping part of the source motive unit. In many modern power grids, many small generators sets or new energy power generation systems use power conversion systems to achieve frequency control of the output power of the generator set. That is, the power electronic interface (grid-connected inverter) is used to output the power frequency alternating current that meets the load demand or the grid connection condition through the power electronic inverter device and the effective control method [1-5].

In this paper, a new method of power frequency conversion of power system and its control technology are proposed: The Electronic Mechanical Continuously Variable Transmission (EMCVT) and its control technology [6][7] are used to realize the frequency control of the output power of the AC power generation system. Smooth switching between the grid-connected mode and the island-controlled mode can also be achieved by means of the method. With this technology, on the one hand, the problem that the powers in the grid-connected inverter control is difficult to accurately detect and control the delay can be effectively avoided. The power quality when the grid is cut in is improved. Harmonic pollution injected into the grid due to the use of power devices in the inverter is avoided [8]; On the other hand, the use of high frequency, high power, high performance power electronics can be substantially reduced. As a result, the construction cost and operating cost of the microgrid are greatly reduced. The reliability of the operation of the microgrid is improved.

Due to many factors such as structure, performance, material, process and lubrication, most types of mechanical continuously variable transmissions have relatively low transmission torque and high manufacturing cost, so they are rarely used. Although the metal belt (chain) type continuously variable transmission (CVT) has been widely used in automobiles since the early 1990s. However, before the appearance of the metal belt (chain) type EMCVT mentioned in this paper, all the CVT used in automobiles are electro-hydraulic control [8-12]. The electro-hydraulic control mode CVT is not suitable for use in power systems. In the power system, it is necessary to ensure that the shifting cone is always pressurized to achieve power transmission. Hydraulic pumps also need to work uninterrupted.

In the event of a hydraulic pump failure or a leak in the hydraulic piping system, the oil pressure is reduced or lost, causing irreversible damage to the CVT. Obviously, this is not allowed for power systems that require long-term uninterrupted work. No one has previously suggested that this method of mechanical frequency modulation should be due to this technical limitation. Although the EMCVT used in this paper is a friction transmission method, its transmission torque has been developed more and more. At present, it can reach nearly 690Nm and the speed is above 6000 r/min. According to the relevant product sample data, the output power of small and medium-sized generator sets is within the power transmission capability of EMCVT. In general, large generator sets with appropriate speed-up gear sets can also be used with EMCVT. Therefore, EMCVT has a place in the control of the output grid-connected inverter of the microgrid generator set. With the development of CVT technology and the increase of research efforts, the ability of CVT to transmit power will continue to increase [13]. The application space of EMCVT in the output inverter control of microgrid generator sets will also continue to expand.

2. Topology of EMCVT power conversion system and its implementation method

The EMCVT is used as the genset frequency converter, and the frequency of the output power is stabilized by controlling the input speed of the genset.

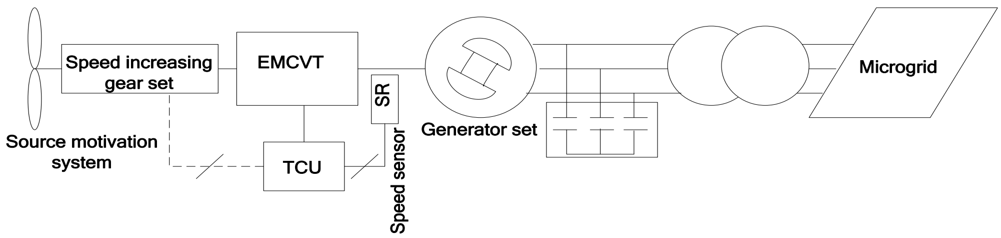

Fig. 1 Topology of a power generation system using EMCVT

The topology of the CVT power generation system is shown in Fig.1. The output of the source motor system is coupled to the upshift gear set. The output shaft of the upshift gear set is connected to the input of the EMCVT. The output of the EMCVT is connected to the input of the generator set via a clutch. The output of the genset is connected to the user load or the public grid via a power frequency transformer. A speed sensor is arranged on the output shaft of the EMCVT or the input shaft of the generator set. The output of the speed sensor is connected to the input of the controller, and the output of the controller is connected to the speed ratio control driver of the EMCVT. Its main functions are:

(1) The speed-up gear set at the front end of the EMCVT is a multi-speed gearbox. The first function is to realize the function of speed increase and reduce torque, and reduce the demand for transmitting torque of EMCVT; the second function is to switch through different transmission gear sets when the working conditions of the source motive are complicated and the output speed changes very much. Achieve different fixed speed ratio output. Ensure the power system needs for EMCVT input speed. Therefore, the frequency conversion control range of the EMCVT is increased; the third function, for output controllable source motives such as diesel (steam) oil generator sets, changes the power of the output power of the generator set by controlling the change of the speed ratio to meet the demand of the user load.

(2) Smooth connection or delayed disconnection of output power is achieved by an external friction clutch of EMCVT [14].

(3) Inverter control and power cut-in control of power generation system using dedicated controller TCU of EMCVT [14]

3. EMCVT control model and frequency conversion control method

Force analysis model of speed governing mechanism. The mechanical structure of EMCVT is shown in Figure 2. The schematic diagram of the EMCVT structure is shown in Figure 3. Mainly consists of the following parts: active moving cone, active fixed cone, drive chain, moving cone, driven fixed cone, disc spring, etc.

(1) When the speed ratio changes from large to small, the force relationship of each component is as follows.

$$\begin{cases} F_{gdlx} + F_{diskR} - m_{zdz} \cdot \alpha_{zdz} = F_{\alpha A} \\ F_{\alpha A} = \gamma \cdot F_{\alpha B} \\ F_{\alpha B} = F_{diskN} + m_{zdz} \cdot \alpha_{zdz} \end{cases} \tag{1}$$

(2) When the speed ratio is changed from small to large, the force relationship of each component is as follows.

$$\begin{cases} F_{gdlx} + F_{diskR} - m_{zdz} \cdot \alpha_{zdz} = F_{aA} \\ F_{aA} = \gamma \cdot F_{aB} \\ F_{aB} = F_{diskN} - m_{cdz} \cdot \alpha_{cdz} \end{cases} \tag{2}$$

Where, F_{gdlx} is the axial force of the nut to the drive shaft. F_{aA}, F_{aB} are the axial thrusts of the metal belt to the main and driven shaft cones respectively. γ is the ratio of the axial force of the metal chain to the main and driven shaft cones. M_t is the torque required for the speed-regulated motor. F_{diskR}, F_{diskN} are the axial spring forces generated by the compression of the main and driven shaft disc springs respectively. m_{zdz}, m_{cdz} are the quality of the main and driven shaft cones respectively. α_{zdz}, α_{cdz} are the accelerations of the main and driven shaft cones respectively.

Speed ratio control model of EMCVT. The transmission ratio of EMCVT is similar to that of belt drive, which is determined by the pitch radius R_{DR} and R_{DN} of the active and driven cones. When the maximum position of the pitch radius of the driving cone is compared with the minimum position of the radius of the driven cone, the transmission ratio is the smallest. On the contrary, the transmission ratio is the largest. The speed ratio model is shown in Equation 3.

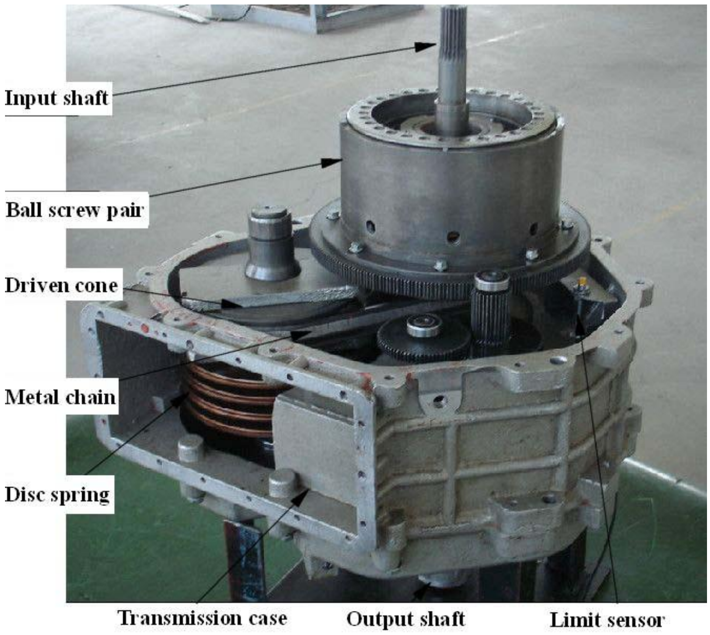

Fig. 2 The mechanical structure of EMCVT

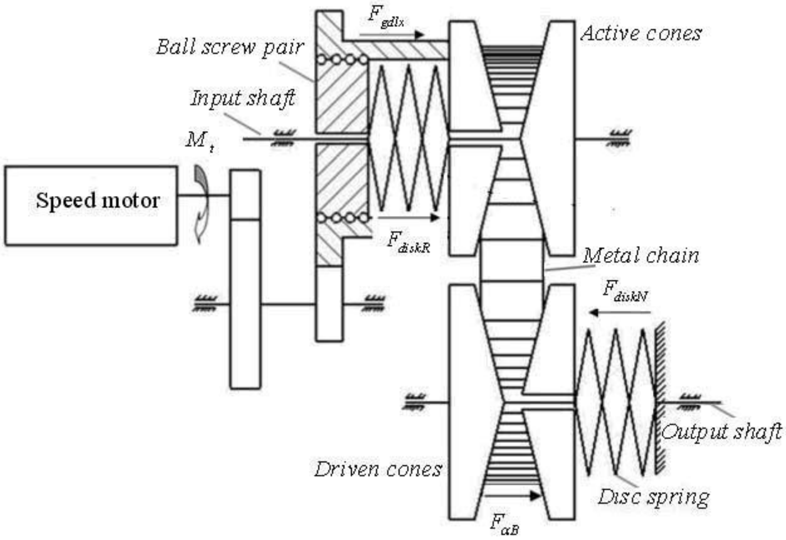

Fig. 3 The schematic diagram of the EMCVT structure

$$i = \frac{R_{DN}}{R_{DR}} \tag{3}$$

The metal chain is a rigid element. Therefore, in the transmission process, the length of the metal chain remains basically the same, and the total length can be regarded as a fixed value.

$$L = (\pi + 2\phi) R_{DR} + (\pi - 2\phi) R_{DN} + 2d\cos\phi \tag{4}$$

Where, $\phi \approx \sin\phi = \frac{(R_{DN} - R_{DR})}{d}$, d is the center distance of the two transmission shafts. From equations (3) and (4), the approximate formula for calculating the speed ratio and the drive wheel radius is:

$$i = (-B + \sqrt{B^2 - 4AC}) / 2A \tag{5}$$

Where, $A = R_{DR} / d$; $B = \pi - 2R_{DR} / d$; $C = \pi + R_{DR} / d + 2d / R_{DR} - L / R_{DR}$. The relationship between the transmission ratio i and the axial displacement X_p of the moving cone on the driving cone is [7]

$$i = \frac{R_{DNMAX} - \frac{X_p}{2\tan\varphi}}{R_{DRMIN} + \frac{X_p}{2\tan\varphi}} \tag{6}$$

Where: R_{DNMAX} is the maximum working radius of the driven cone. R_{DRMIN} is the minimum working radius of the driving cone. φ is pulley's cone angle(cone disc with straight generatrix). X_p can be regarded as the positional parameter of the driving cone. X_p is inversely proportional to the transmission ratio i.

Speed ratio motor control model. In the speed regulation process, the speed-regulating motor accelerates the rotation, and the speed-regulating load needs to overcome the load due to the moment of inertia of the relevant components of the entire speed-regulating mechanism under the accelerated motion.

$$M_d = J \cdot \dot{\omega}$$

Where $\dot{\omega}$ is the angular acceleration of the speed-regulating motor shaft; J is the total equivalent moment of inertia of the output shaft end of the speed-regulating motor.

During the speed regulation process, the speed regulating motor is always in the acceleration operation, and the speed adjustment process from the maximum transmission ratio to the minimum transmission ratio (or from the minimum transmission ratio to the maximum transmission ratio) takes time t_0.

(1) During this process, the active axial cone and the driven axial cone are accelerated from a standstill to the extreme position. The relationship between the active shaft cone and the driven shaft cone is:

$$\begin{cases} \frac{1}{2}\alpha_{zdz} \cdot t^2 = s_{1MAX} \\ \frac{1}{2}\alpha_{cdz} \cdot t^2 = s_{2MAX} \end{cases} \tag{7}$$

Where: s_{1MAX} and s_{2MAX} are the maximum displacements of the main and driven shaft cones respectively; α_{zdz} and α_{cdz} are the accelerations of the main and driven shaft cones respectively.

(2) During this process, the movement of the rolling screw speed nut is the same as that of the active shaft cone. The acceleration of the speed adjusting nut is also α_{zdz}, and the engagement of the rolling screw drive screw and the nut converts the rotary motion into a linear motion. By analyzing the motion of the rolling helix, it can be concluded that:

$$\dot{\omega}_{gdlm} = \frac{\alpha_{zdz} \cdot 2\pi}{nP_h} \tag{8}$$

Among them: the angular velocity and angular acceleration of the rolling nut of the rolling screw are ω_{gdlm}, $\dot{\omega}_{gdlm}$. The lead of the rolling helix is P_h.

(3) During this process, the speed regulating motor shaft transmits motion through the primary reduction gear. Through analysis, the angular acceleration of the adjustable motor shaft can be obtained:

$$\dot{\omega} = \dot{\omega}_{gdlm} i_1 i_2 i_3 \tag{9}$$

Among them: the transmission ratio of the first and second reduction gears are i_1 and i_2 respectively. The gear ratio of the gear to the timing nut is i_3. So there is

$$\dot{\omega}_{gdlm} = \frac{4\pi \cdot s_{1MAX}}{P_h \cdot t^2} \cdot i_1 i_2 i_3 \tag{10}$$

4. Mechanical frequency conversion control experiment

A motor is used as the power source input, and a gearbox with a gear ratio of 1:4 is used as the speed increase box. That is: connect the original output end of the gearbox to the motor shaft; connect the original input end of the gearbox to the EMCVT input shaft, as shown in Fig.4. The frequency converter is used to control the output shaft speed of the motor to make any change between 300r/min and 1500r/min. At the same time, the output speed of the EMCVT output shaft is detected.

The speed ratio of EMCVT used is between 2.4 and 0.5. When the output shaft speed of the motor is 300r/min, the speed of the input shaft of the EMCVT is 1200r/min after the speed increase of the speed increase box. When the output shaft speed of the motor is at 1500r/min, the speed of the input shaft of the EMCVT reaches 6000r/min after the speed increase of the speed increase box. In the experiment, regardless of the change of the speed of the EMCVT input shaft between 1500r/min and 6000r/min, the output shaft speed is always maintained within the range of 3000±50r/min. If EMCVT is used as the alternator input, the power output accuracy of the alternator can be guaranteed to reach 50Hz±1.67%. It is proved that the topology of the power generation system using EMCVT can guarantee the constant frequency output of the generator set.

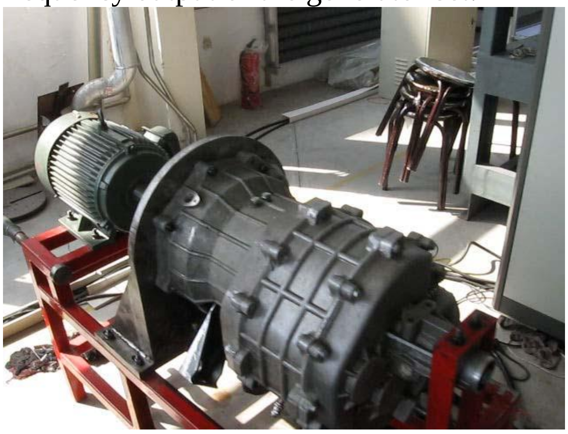

Fig.4. Experimental site of mechanical frequency conversion control

5. Conclusion

Through the above analysis, the following conclusions can be drawn: If EMCVT is used as the controllable input terminal of the alternator; harmonic pollution-free and high-efficiency power transmission can be realized. The control power frequency output accuracy can reach 50Hz±1.67%. Basically, constant frequency control can be realized.

Because the current experiment is only a principle experiment. The speed ratio control motor used only uses an ordinary DC motor, so the power frequency output control accuracy is low. If the servo-controlled motor can be used with the appropriate control strategy, the control accuracy will be greatly improved.

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