Mechanical structure optimization of energy storage tank group in MEES system

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Abstract. The energy storage component of the MEES system is mechanical elastic energy storage tank group. Whether the mechanical structure design of energy storage tank is reasonable or not directly determines the performance of the whole system. In this paper, the structural design scheme of series linkage energy storage tank group is proposed, which can take into account the energy storage capacity and power demand. Firstly, the structural group of energy storage tank is analyzed. Secondly, the operation mode of energy storage and power generation process of energy storage tank group is described in detail. Finally, the mathematical model of energy storage/generation operation is established, which provides theoretical guidance for the configuration of capacity and power of energy storage tank group.

1. Introduction
The mechanical elastic energy storage (MEES) \cite{1, 2} system is a kind of physical energy storage system proposed in recent years. The energy storage device is mechanical elastic energy storage tank group, and the energy storage form is mechanical elastic potential energy. The energy storage tank group contains a certain number of single energy storage tankers, in which a large number of spiral torsion spring (STS) are packaged and fixed in parallel. The energy storage and power of the energy storage tank group are directly determined by the elastic modulus, length, width and thickness of STS. In order to make the MEES system have more storage power and energy storage capacity, the length, width and thickness of the STS often have a larger value. This will bring a lot of difficulties to the electrical control system of the energy storage system.

(1) In the process of energy storage operation, how to prevent the inversion of energy storage tank group when its reverse moment increases rapidly.

(2) In the process of power generation operation, when STS is in tightening state and the MEES system starting torque is very large, how to adjust speed to avoid system out of control.

(3) With the operation of the power generation process, the torque of the energy storage tank group gradually decreases, and the speed increases gradually under the constant power operation mode. The speed of the energy storage tank group should be in the maximum state when the power generation is completed. At this time, the energy storage system stops running, and STS will react on the wall of the energy storage tank, which will cause great damage to STS and also cause great impact on the energy storage system. Therefore, flexible parking of energy storage system has become a key issue.

It is not only difficult to solve these problems from the perspective of electrical control, but also has high implementation cost. However, from the perspective of mechanical structure optimization of
energy storage tank group combined with the matching electrical control method, it is easy to achieve good results.

2. Characteristics and functions of series linkage energy storage tank group

In the process of energy storage, the MEES system converts electrical energy into mechanical elastic potential energy and stores it in the mechanical elastic energy storage tank group. In the power generation process, the mechanical elastic potential energy is converted into electrical energy for load use. It can be seen that the energy storage tank group is the core component of the MEES system, and its position in the MEES system is shown in the red part of Fig. 1.

3. Mechanical structure design of series linkage energy storage tank group

The mechanical assembly structure of series linkage mechanical elastic energy storage tank group is shown in Fig. 2. Multiple STS are fixed in a single energy storage tank in parallel, and multiple single energy storage tanks are connected in series through the overrunning clutch. The PMSM drive shaft is inserted into the driving end of the overrunning clutch of the first single energy storage tank through the reduction gear tank and electromagnetic brake, the left end cover of the first single energy storage tank extends out of the shaft, inserts into the driving end of the overrunning clutch of the second single energy storage tank to fix, the second single energy storage tank shaft is inserted into the third single energy storage tank, the driving end of overrunning clutch is fixed, and so on, until all the single energy storage tanks of the unit are fixed. After fixed connection, the last single energy storage tank shaft is fixed connected with the electromagnetic brake and PMSG generator shaft through the acceleration gearbox, and the mechanical installation of the series linkage mechanical elastic energy storage unit is completed.

4. Operation mode of series linkage energy storage tank group

4.1. Energy storage operation mode

As shown in Fig. 3, during the operation of energy storage, the PMSM rotor is driven by electric energy to rotate, and which is connected with the driving end of the overrunning clutch of the first energy storage tank. Due to the limit function of the overrunning clutch, the speed of the driven shaft can not be lower than that of the driving shaft. The driven shaft also rotates to screw STS fixed on the mandrel, and the STS in a certain tightening state drives the driving end of the overrunning clutch of the secondary energy storage tank to rotate through the shaft of the energy storage tank, so as to turn the STS of the secondary energy storage tank, and so on, until the last section of the energy storage tank is locked by the electromagnetic brake, the energy will no longer be transmitted out. When the STS in all energy storage tank are tightened, the energy storage process is completed, and the electric energy is converted into elastic potential energy and stored in STS.
4.2. Power generation operation mode

As shown in Fig. 4, during the generating process of the system, the electromagnetic brake releases the shaft of the last energy storage tank, and it starts to rotate under the action of STS torque to drive PMSG to start generating electricity. The driven end of the overrunning clutch of the last energy storage tank disengages from the driving end, and then rotates. The penultimate section of the energy storage tank starts to rotate. However, due to the speed limitation of the overrunning clutch, its speed cannot exceed the driven end of the overrunning clutch of the last energy storage tank, and so on until the first energy storage tank. Since the shaft of the first energy storage tank is always held tightly by the electromagnetic brake on the PMSM side during the power generation process, the energy release is terminated. It can be seen that when multiple energy storage tanks adopt this linkage structure for power generation and operation, once the STS in the last energy storage tank is released, the STS in all other energy storage tanks will be successively driven to release until the energy release signal is transmitted to the first energy storage tank. Once the speed of the last energy storage tank decreases due to driving PMSG to generate electricity, the energy stored in the other energy storage tank will be transmitted. Until all energy storage tanks are released, all the stored mechanical elastic potential energy will be converted into electric energy. Therefore, the series linkage energy storage tank group realizes the storage of mechanical elastic potential energy and the efficient conversion between electrical energy and mechanical elastic potential energy.

5. Advantages of series linkage energy storage tank group

As mentioned above, the advantages of series linkage mechanical elastic energy storage tank group structure are as follows:

1) Multiple single energy storage tanks are connected in series in the linkage energy storage tank group. At the same time, multiple sets of the STS are paralleled in the single energy storage tank, which greatly increases the energy storage capacity and power storage of the energy storage system. This kind of mechanical assembly structure can fix any modular STS in a single energy storage tank, and realize the free configuration of the rated power. The energy storage tank group is equipped with any single energy storage tank to realize the free configuration of energy storage capacity. It is beneficial to the adjustment of operation power and energy storage capacity of the MEES system.
(2) In the process of energy storage of the MEES system. As the overrunning clutch has one-way backstepping function, the energy storage tank group can only rotate in one direction, so the reverse rotation of the energy storage tank will not occur. At the same time, after the electromagnetic brake at PMSM side is activated, the back and forth vibration of the energy storage tank can be avoided, and the flexible shutdown of the system can be realized after the energy storage is completed.

(3) During the power generation operation of the MEES system, the PMSG side brake is opened, and the mechanical elastic potential energy stored in STS is released to drive PMSG to generate electricity. Due to the automatic release function of the master-slave end of the overrunning clutch under a certain speed, the connection between the energy storage tanks becomes flexible. When the elastic potential energy of the single energy storage tank is released, the driven end of the overrunning clutch will automatically separate from the driving end, so that the STS fixed on the mandrel and the tank can rotate together, thus avoiding the damage of the STS.

6. Conclusion
In this paper, a new type of mechanical elastic energy storage tank structure is proposed, which focusing on the self-locking protection function. By using the overrunning clutch to replace the conventional coupling, the operation characteristics of the energy storage tank are optimized, and the flexible braking of the energy storage and power generation process is realized, which provides a good prerequisite for the optimal design of electrical control.

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