Design of Intelligent Commutation Switch System Based on HPLC Carrier Scheme

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Abstract. China's low-voltage transmission lines are mostly three-phase four-wire power supply networks. Due to the large number of single-phase power users which are dispersedly located, there are different levels of three-phase load imbalance problems in most distribution areas. With the improvement of the national economy, the electricity consumption at the grassroots level has increased, and the problem of unbalanced three-phase loads of the low-voltage power grid has become increasingly prominent. The article introduces a product which can handle unbalanced three-phase problems in the low-voltage distribution area. It can quickly and accurately detect the three-phase unbalance problem of the low-voltage distribution system. The three-phase intelligent commutation switch system can adjust the single-phase load without power cut in real time ensuring that the three-phase load in the station is in a relatively balanced state. This product can effectively reduce transformer loss and line loss caused by three-phase load imbalance, and avoid single-phase over-current, terminal low-voltage, etc. It can also prevent numerous safety hazards caused by three-phase unbalance. This paper introduces the harm of three-phase unbalance, the working principle and system of the commutation switch, and the advantages of the HPLC scheme to highlight the intelligence and program advantages of the commutation switch.

1. Introduction
In the medium and low voltage distribution network system, there are a large number of single-phase, asymmetrical, non-linear, and impact loads. Due to the poor design of the early power grid, a large number of single-phase loads are concentrated in one or two phases. These unbalanced loads can cause three-phase imbalance in the power distribution system, resulting in an imbalance of three-phase voltage and current in the power supply system.

Due to uneven load distribution, the natures of the load are also inconsistent, resulting in insufficient reactive power and unbalanced load in the low-voltage power supply system.

2. Definition of three-phase imbalance
First, Three-phase unbalance refers to the inconsistency of three-phase current (or voltage) amplitude in the power system, and the amplitude difference exceeds the prescribed range. The main cause of the three-phase imbalance is the unbalanced three-phase load, which belongs to the fundamental wave load allocation problem.
Article 8.7.4 of The State Grid Corporation Enterprise Standard (Q/GDW519-2010) Rules for Operation of Distribution Networks stipulates that the formula for calculating unbalance degree is as follows: \( \frac{\text{maximum current} - \text{minimum current}}{\text{maximum current}} \times 100\% \).

National Grid Standard: The unbalance of three-phase load should not exceed 15%. For the three-phase transformer with a small amount of single-phase load, and the neutral line current should not exceed 25% of the rated current.

2.1. The harm of three-phase imbalance

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At present, China’s low-voltage power grids generally adopt three-phase four-wire system and the distribution transformer is connected by Yyn0. Because of the large number of single-phase loads and the asynchronous of power consumption, three-phase unbalanced operation of distribution transformers is inevitable. Three-phase voltage or current asymmetry will cause a series of hazards to power generation, transmission, distribution equipment and electrical equipment in the power system.

- increased line loss. When the current passes through the conductor, the resistance of conductor will cause power loss. The line loss increases as the imbalance degree increases.
- increased the active power loss of distribution transformer. The existing 10/0.4kV low-voltage distribution transformers are mostly Y/yn0 connected. When the secondary side load is unbalanced and there is zero sequence current, and the primary side can not flow because there is no neutral lead-out line. When the zero-sequence current is too large resulting in the excessive zero-sequence magnetic current. The excessive drift of neutral point will cause some phase voltage to be too high, which will lead to the saturation of the core and greatly increase the iron loss.
- reducing the output of the distribution transformer. Transformer capacity is designed and manufactured according to three-phase load balance conditions. Its three-phase winding structure and performance are consistent. The rated capacity of each phase is equal, and the maximum allowable output is limited by the rated capacity of each phase. When the three-phase load is unbalanced, its maximum output can only be limited to the rated capacity of the largest phase of the three-phase load, and the relatively affluent capacity of the lighter load can reduce the output of the transformer. The output reduction of the transformer is related to the balance degree. The output reduction increases as the unbalance degree increases. It also affects the utilization of transformer equipment.
- the output power of the motor is affected and the winding temperature is raised. The three-phase voltage asymmetry caused by the three-phase load imbalance will generate a reverse-rotating magnetic field in the stator of the induction motor, and the motor operates under the action of the forward and reverse two-order rotating magnetic fields. Since the positive sequence rotating magnetic field is stronger than the reverse order rotating magnetic field, the motor rotation direction is unchanged. However, since the rotor reverse sequence impedance is small and the reverse sequence current is large, the reverse sequence magnetic field and the reverse sequence current will generate a large braking torque, which will reduce the output power of the motor and increase the temperature of the winding, which jeopardizes the safe operation of the motor.

2.2. Traditional Method to Manage Three-phase Imbalance

2.2.1. Principle overview. Adjust the load by manually changing the line. This is the most common method but requires great manpower input. And it needs to cut off the power and can’t adapt to the change pattern of the load for a long term.
2.2.2. Phase-to-phase capacitance compensation. By connecting parallel capacitors phase to phase and compensating reactive power to the two phases, some active power will be transmitted while compensating reactive power according to Wang’s theorem. The capacitor compensation cost is low, and the system failure does not affect the user's power supply. However, the strength of the active adjustment is small, and it is easy to cause reactive power over-compensation; the single-phase flow can only be used in each case, and the utilization rate of the capacitor is low; the single-phase flow can only be used in each case, and the utilization rate of the capacitor is low; the balance on the distribution side is solved, but the line side is still in an unbalanced state, and the line loss cannot be reduced.

Power electronic type three-phase load can automatic adjusting device. The low-voltage static idle compensation SVG and the active power filter APF detect the unbalanced components, reactive components and harmonic components of the load through the detection technique, and use the inverter technology to generate the unbalanced, reactive, and harmonic components that need to be compensated. It can comprehensively solve problems such as reactive power, harmonics, voltage fluctuations and three-phase load imbalance in the power distribution area. However, this method is costly and can only achieve an approximate balance of the three-phase current of the low-voltage side of the transformer, which is not a real load balance.

3. Introduction to intelligent commutation switch system
The intelligent commutation switch system is a set of products used to control the three-phase unbalance of the low-voltage distribution area. It is suitable for three-phase four-wire 380V/220V low-voltage power distribution system, which can quickly and accurately detect the three-phase unbalance problem of low-voltage power distribution system. Through three-phase intelligent commutation switch system, the single-phase load is adjusted in time without power cut. The three-phase load in the station is in a relatively balanced state. This product can effectively reduce transformer loss and line loss caused by three-phase load imbalance, and suppress single-phase over-current, terminal low-voltage, etc. It can also reduce numerous hazards caused by three-phase unbalance.

The intelligent communication switch system uses the power line carrier to communicate which the intelligent master control switch acts as the host and the commutation switch act as the slave. The communication module uses HPLC carrier module, the main control switch uses an HPLC route carrier module, and the commutation switch uses an HPLC single-phase carrier module for communication.

Advantages of HPLC carrier technology:
- The carrier of HPLC is based on TCP/IP network technology which has been widely verified. It has perfect data protection and verification in link layer and network layer, which is far more better than all kinds of lightweight node organization and relay algorithms.
- High speed carrier communication of HPLC can complete data transmission in a very short time, which can greatly reduce the impact of sudden interference. Even if a communication fails, it can be quickly retransmitted to ensure data reliability.
- Most of the carrier chips of HPLC are based on 32-bit core of high performance and DSP technology, which have advantages in technical level and performance.
- In addition to data encryption in the application layer, high-intensity encryption algorithms such as DES, 3DES and AES are supported by the carrier of HPLC in the link layer, and data communication is of high security.
- Even in the communication distance where narrowband carriers have more advantages, the high-performance modulation methods such as OFDM and perfect relay networking mechanism can fully meet the current application needs of most stations.
- High performance, fast speed and strong expansion capability of carrier communication of HPLC can load many network applications, but its cost is not much higher than that of narrowband carrier, so it has the advantage in cost.
3.1. Consist of system
The system consists of the intelligent commutation terminal (responsible for load monitoring and automatic commutation control) and several commutation switch units (responsible for the operation of load commutation) as shown in fig1. Intelligent commutation terminal monitors the three-phase current of distribution transformer low-voltage outgoing line in real time. If the unbalance degree of three-phase load of distribution transformer low-voltage side exceeds the limit within a certain monitoring period, the intelligent commutation terminal reads the real-time data of current and phase sequence of distribution transformer low-voltage outgoing line and all load branches of commutation switching unit, carries out optimization calculation and sends out optimal commutation control instructions, according to which each commutation switch unit completes the specified commutation process.

![Fig 1. System topology](image)

3.2. System function
- Automatic balancing of three-phase load: monitors three-phase unbalance in real-time and automatically adjusts three-phase load according to unbalance degree. Commutation time is less than 20 msec, without power cut. It will not cause the reset and restart of common electrical appliances, nor will it cause damage to electrical appliances.
- Reduce transformer loss: make the transformer in a symmetrical operation state, effectively reducing transformer loss.
- Reduce line loss: effectively reduce the neutral line current, thereby reducing the neutral line loss and phase line loss.
- Solve the problems of low or over-voltage: Solve the problems of low or over-voltage caused by three-phase unbalance, and avoid burning down electric equipment or affecting the normal operation of electric equipment due to over-voltage.

3.3. System advantages
- Maintenance-free and management-free: no special maintenance and management is required after the system has been put into operation, saving manpower and material resources and improving efficiency.
- Automatic commutation and not need to cut power; automatic commutation, and no manual participation is required; commutation time is less than 20 msec, and will not lead to power interruption.
- Reliable phase-to-phase short-circuit prevention technology; reliable hardware blocking technology to prevent multiple phase sequences from being connected at the same time; multiple software algorithms to intelligently prevent phase-to-phase short circuit.
The switching element does not consume electricity, and the power consumption of the device is small; the permanent magnet relay mechanism is used and operated without voltage; the power consumption of the device is ≤8W.

### 4. Principle of the technology

#### 4.1. Principle of Balance

4.1.1. Principle overview. A main control switch is installed at the beginning of each branch to monitor the three-phase unbalance condition and issue an adjustment command; a commutation switch is installed at the front end of the branch to monitor the load condition of the self-loaded circuit. According to the commutation command issued by the main control switch, the corresponding commutation operation is performed.

4.1.2. Intelligent networking. The commutation switch uses the power carrier to communicate. The main control switch adopts the HPLC routing module, and the commutation switch adopts the HPLC single-phase carrier module, improving the communication efficiency and reliability.

Each master switch is only responsible for communicating with the commutation switch of its same branch. One branch constitutes a subsystem, the master switch acts as the master, and the commutation switch acts as the slave.

For the mode of multi-meter switch common network, the system develops a unique intelligent networking mechanism-preemptive time-sharing communication mechanism, which avoids the conflict and interference of carrier communication between different branches and realizes the function of intelligent networking [9].

#### 4.2. Principle of no-power commutation

The operating principle of non-power-down commutation is to complete the phase sequence switching in a very short time, and the basic basis is as follows:

4.2.1. Action components. The commutation switch uses a permanent magnet relay as the action element. Based on the characteristics of high load capacity, low power consumption, fast moving speed, low loss, reliable operation and low cost of permanent magnet relay, the commutation switch realizes the function of non-power-off commutation, which will not cut off power and ensures the quality of power supply.

There are lots of theoretical investigations and actual tests showing that the 30ms power-down time will not cause the non-load sensitive power equipment to lose power, and the commutation switch commutation time is less than 20ms, which meets the application requirements.

4.2.2. Zero-crossing commutation. To ensure longevity, the commutation switch uses zero-crossing switching technology to minimize damage to the operating components. The zero-crossing cutting technology is based on the principle of “current zero-crossing, voltage zero-crossing input”, which can achieve the extremely small impact and extremely small electric arc.

#### 4.3. Commutation Algorithm Principle.

When the unbalance degree of the branch in the main control switch exceeds the set value, the balancing logic algorithm will be started. The system is based on the balance algorithm principle of mathematical recursive logic: when the unbalance degree of the main control switch surpasses the set value, it will start the balance logic algorithm. Each user's power load is different, and the unbalance degree of each branch is different. Based on the principle of mathematical recursive logic algorithm, the system combines the balance demand with the load size of each commutation switch, carries out logical combination operation, and solves the optimal strategy.
The principle of balancing algorithm based on branch balancing strategy is that after the optimal strategy is calculated by the main control switch in each branch, the commutation switch in the branch will be ordered to perform the corresponding commutation operation, thus realizing the branch balancing. Each branch in the platform reaches three phase equilibrium state, and the three-phase balance of the transformer can be realized.

The main conclusions of this paper are as follows:

- The product basically conforms to the technical principles and requirements to be followed in the design, production and selection of the three-phase load unbalance automatic regulating device (commutation switch type) of the State Grid. Its advantages are: a) realizing three-phase balance based on single-phase load of switching terminal, and solving three-phase unbalance problem from the original cause; b) realizing three-phase balance between distribution transformer and line, effectively reducing line loss; c) not affecting user’s power consumption when switching phase.

- Communication based on the carrier of HPLC has characteristics of high communication performance, fast speed and strong expansion capability. The equipment has been tested in many places, and the effect of three-phase unbalance control is obvious.

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