Research of Process Immunity Time of Boiler Coal Feeding system in thermal power plant and Solution to Voltage Sags

Li WANG
Golden Cooperate Co., Ltd – China
wangli@gc-bank.com

Xuezhong ZHU
NUAA – China
zxz@nuaa.edu.cn

Huaying ZHANG, Yuming ZHAO, Zhengguo ZHU
Shenzhen Power Supply Co. Ltd – China
zhyszpower@163.com

Mingtian FAN
CEPRI – China
mtfan@epri.sgcc.com.cn

Zixuan ZHENG
Sichuan University – China
zhengzixuan1990@126.com

ABSTRACT

The shutdown of the thermal power plant caused by voltage sags has occurred several times in the whole country. In order to ensure the continuity of power generation during voltage sag, research on process immunity time (PIT) of the boiler coal feeding system is carried out, sensitive equipments in the process which affected by voltage sags and corresponding process parameters are listed, and PIT values and the most sensitive equipment which is coal feeder are obtained. The under-voltage trip of inverter during voltage sag is the real cause of coal feeder shutdown. According to the characteristics of inverter's AC-DC-AC structure and combining power electronics technology Low Voltage Ride Through (LVRT) systems are researched and developed based on DC support technology which take batteries as energy source. And through BOOST DC/DC converter, the LVRT system outputs a constant DC voltage, supporting inverter's DC bus. Experimental data and field applications show that the LVRT system can ensure the normal operation of inverter during voltage sag which ensures the safe and stable operation of the boiler coal feeding system and the continuity of the power generation process.

Key Words: Process Immunity Time, Voltage Sags, Inverter, DC Support Technology, Low Voltage Ride Through

INTRODUCTION

On January 2, 2011, CT of phase A of switch 5053 in line 1 in a 500kV substation of Northeast China Power Grid failed, resulting in 500 kV bus grounding. From the fault recorder, phase voltage Ua of 500kV bus dropped from 535kV to 16.8kV, voltage of transformer of each thermal power unit was decreased, phase voltage Ua of 6kV bus of #4 thermal power unit dropped to 65% of rated value, all coal feeder inverters running on #4 unit tripped for low voltage protection, leading to boiler furnace fire protection (Main Fuel Trip, MFT) act and resulting in the trip of #4 unit, bringing serious influence to the safe and stable operation of power grid. Several similar accidents had happened later.

The shutdown of the thermal power plant caused by voltage sags has occurred in the whole country, which not only brings serious economic losses to the thermal power plant, but also threatens the safety and stability of the power system.

In order to ensure the continuity of power generation during voltage sag, it is necessary to carry out the research on process immunity time (PIT) of the boiler coal feeding system to find out the basic reason for shutdown of power plant. On the one hand, we can know clearly the PIT values of each sub-process and corresponding equipment sensitivity level. On the other hand, it can guide users to take optimal measure of voltage sag for process recovery, so as to ensure continuous process of boiler system and continuity of power generation.

VOLTAGE SAGS

According to IEEE [1], voltage sag is defined as: an rms variation with a magnitude between 10% and 90% between 0.5 cycle and one minute. The definition of IEC for voltage sags is different from IEEE in the magnitude of voltage sag. According to IEC, voltage sag is an rms variation with a magnitude between 10% and 90% between 0.5 cycle and one minute. The instantaneous voltage waveforms of voltage sags is shown in Fig.1, it includes two important features which are magnitude or depth of voltage sags and duration of voltage sags.

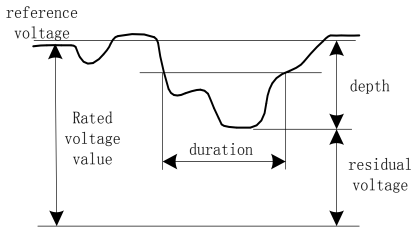


Fig1. instantaneous voltage waveforms of voltage sags

When the voltage effective value reduces to close to zero and continued for some time, it is known as short interruption. There is no strict distinction between

voltage sags and short interruptions in this paper, and solutions to them are similar.
In thermal power plant, voltage sags is called low voltage ride through (LVRT).

PROCESS IMMUNITY TIME

The concept of PIT, short for process immunity time, was proposed by C4.110, a joint working group by CIGRE, CIRED and UIE, during the period of 2006-2010.PIT was defined as the longest time that the industrial process can keep continuous normal working in power outages or sags, and can be used to evaluate sag immunity of industrial process [2], as shown in figure 2. In this figure, P_{nom} refers to the rated value of process parameters, P_{limit} refers to the limit value that can be accepted, t_1 refers to the moment of sag occurrence, △ t is the process response delay, t_2 is the time process parameters go beyond P_{limit}. Process parameters are the physical state indices that each sub process equipment impacts on the whole process, including water temperature, oil pressure, flow valve, and so on; PIT is the constructional standard for sag immunity of industrial process. In Figure 2, P_{nom} and P_{limit} are definited for a given process, determined by structure, components and operation characteristics; △ t depends on the process of design and investment, t_2 depends on the acceptable performance, which is to judge whether the process parameter is acceptable.

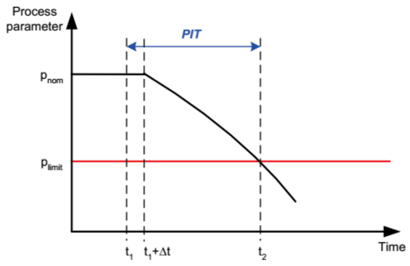


Fig. 2 process immunity time curve

When the sag duration Ta<△T, process and consequence state L1 is completely normal; sag duration △t<Tb<PIT, process and consequence state L2 is automatic recovery; when the sag duration Tc>PIT, process and consequence state L3 needs artificial restoration, as shown in figure 3.

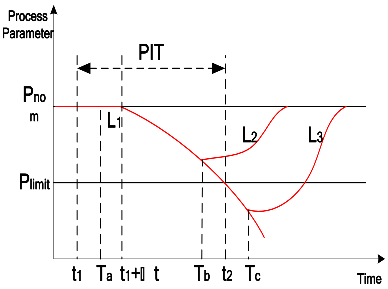


Fig. 3 state estimation based on process immune time

The shorter the PIT is, the lower immunity of the process has, so the higher quality of power supply is required, as shown in figure 4.

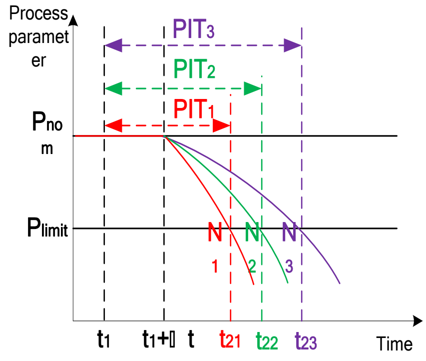


Fig. 4 different PIT of sub process

PIT OF BOILER COAL FEEDING SYSTEM

According to the thermal power plant shutdown event records and protection records, the boiler coal feeding system is the main part to cause thermal power unit tripping, so it is reasonable to assessment the immunity of industrial process against voltage sags of boiler coal feeding system.

PIT assessment steps

1) Generate a list of all devices within the process. The list must be as complete as possible, as process interruptions are often caused by equipment whose impact on the process is not always fully understood.
2) Split up the process in sub-processes or levels. The number of levels required depends on the complexity of the process. The lowest level contains individual equipment.
3) Identify involved equipment and corresponding process parameters.
4) For each "equipment–parameter" combination, the PIT is determined by considering a supply interruption to only that device.
5) Once all PIT values are determined, a ranking of the most critical equipment can be made. This ranking can be done for each defined level within the process.

PIT of boiler coal feeding system

Through the technical communication with the electrical engineer, process engineer and instrument engineer of a thermal power plant, the equipment list related to the process of boiler coal feeding system and the corresponding process parameters are shown in table 1. The process parameter of coal feeder is coal feeding amount, and the process parameters of air preheater, induced draft fan and the air blower is air flow. According to the process and the protection action time, the PIT values of each sub process are shown in Table 1. Based on the PIT values, the priorities of equipments are sorted, it can be seen coal feeder is the most critical equipment.

Table 1 Equipment list and PIT values for a boiler coal feeding process

Level 1	Level 2	Process parameter	PIT	Priority	Action
Coal feeding					
	Coal feeder	Coal feeding amount	1s	1	MFT acts
	Air preheater	Air flow	15s	3	MFT acts
	Induced draft fan	Air flow	9s	2	MFT acts
	Air blower	Air flow	9s	2	MFT acts

According to the results of Table 1, the PIT curve of the boiler coal feeding process is shown in Figure 5, the PIT of coal feeder is the shortest, which means its process immunity is the lowest. So first of all, it is necessary to avoid the shutdown of coal feeder to ensure its non-stop running during voltage sag.

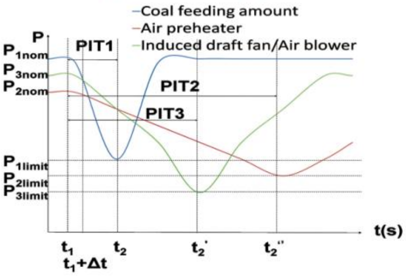


Fig. 5 PIT curve of boiler coal feeding system

With the development of power electronic technology and improvement of industrial automation, the inverter is widely used for its excellent speed adjusting performance and obvious energy saving effect. At present, most coal feeder use inverter drive technology, inverter trips during the voltage sag is the real reason for the shutdown of coal feeder.

The root cause of the unplanned shutdown of thermal power plant is made clearly, inverter trips for under-voltage protection, coal feeder shutdown, MFT acts for coal feeder stop signal interlock, and then the power plant shut down. Therefore, improving the low voltage ride through ability of inverter can avoid the unplanned shutdown of thermal power plant.

ANALYSIS OF INFLUENCE FACTORS OF VOLTAGE SAG ON INVERTER

With mature technology and stable work ability, AC-DC-AC converter has a significant share of the current inverter market. The typical AC-DC-AC inverter topology is shown in Figure 6, the inverter is mainly composed of two modules, namely rectifier module and inverter module. Three phase alternating current will be converted into direct current by diode rectifier circuit, and stored in the capacitor of the DC link; the inverter module is mainly composed of controllable three phase inverter bridge, which can invert the direct current stored in the capacitor into variable frequency alternating current. In the figure, U_{in} and i_{in} are industrial frequency voltage and current, i_d is the current after rectifier module, i_C is the charge and discharge current of the capacitor, U_d is the voltage of the capacitor, u_{out} and i_{out} are the final output voltage and current.

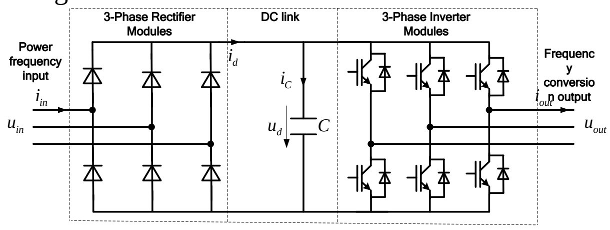


Fig. 6 schematic diagram of inverter topology

The voltage of the DC link capacitor meets the following formula

$$u_d = ku_{in} \qquad k \in [2.34, 2.45] \qquad (1)$$

Among them, K is the voltage conversion coefficient, and is related with the inverter load size. K takes the maximum value of 2.45 in the case of the converter no-load operation, and the value of DC voltage reaches the maximum. DC voltage gradually decreased with the increase of load.

The inverter module mainly uses PWM technology to invert DC voltage into AC voltage, and the frequency and amplitude of the output alternating current are determined by the carrier frequency and amplitude control of PWM. When the carrier amplitude is constant, the output voltage of the amplitude is proportional to the DC voltage，namely proportional to the input AC voltage.

The DC voltage and the output voltage will decrease with the decrease of input voltage. For the most common asynchronous motor load, when the output voltage u_{out} is reduced, the rotor may be locked with large current, which is possible to burn the semiconductor devices in the inverter. Therefore, the inverter will usually detect DC voltage. An order to stop the inverter will be given when the DC voltage is lower than the threshold u_{th}.

Assuming that the capacity of DC link capacitance of the inverter is C, the storage energy of the capacitor is shown as the following formula:

$$Q = \frac{1}{2} C u_d^2 \qquad (2)$$

When the input voltage of the inverter sags, the DC voltage will decrease gradually because of the support of the capacitor. Assuming that the load power of the inverter is Pout, the voltage is restored again as the following formula:

$$\frac{1}{2} C u_d^2 - \frac{1}{2} C u_{d-sag}^2 = P_{out} t_d \qquad (3)$$

In the formula, U_d is the normal DC voltage, $u_{d\text{-}sag}$ is the DC voltage after the sag, and t_d is the time of DC voltage dropping.

The inverter voltage protection principle shows that if the voltage value and duration of voltage sag reach to certain values, the inverter will stop working. Assuming that the voltage sag duration threshold is t_{th}, when the voltage sags meet the following formula, the inverter stops.

$$\begin{cases} u_{d-sag} \le u_{th} \\ t_{sag} \ge t_{th} \end{cases} \quad (4)$$

In the above formula, the expression of t_{th} is as the following formula:

$$t_{th} = \frac{C}{2P_{out}}\left[u_d^2 - u_{th}^2\right] \quad (5)$$

In a conclusion, when the input voltage of the inverter conforms to the following formula, the inverter can continue to work normally:

$$\begin{cases} u_{sag} \ge \dfrac{u_{th}}{k} \\ t_{sag} \le \dfrac{C}{2P_{out}}\left[\left(ku_{in}\right)^2 - u_{th}^2\right] \end{cases} \quad (6)$$

From the above we can see that the tolerance of the inverter is affected by the capacitance capacity, the load size and the setting threshold voltage.

SOLUTION TO VOLTAGE SAG BASED ON DC SUPPORT TECHNOLOGY

According to inverter's AC-DC-AC structure it is reasonable to solve the problem from the DC link by providing DC voltage for the inverter's DC bus. That is called DC support technology, namely providing voltage support for the inverter's DC bus during voltage sags so as to ensure the normal work of the inverter (DC/AC) part to output stable AC voltage, so the motor will not stop working [3].

Working principle

Low Voltage Ride Through (LVRT) system based on DC Support Technology uses batteries [4] as energy source, as shown in Fig.7. The output of LVRT system connects to inverter's DC bus.

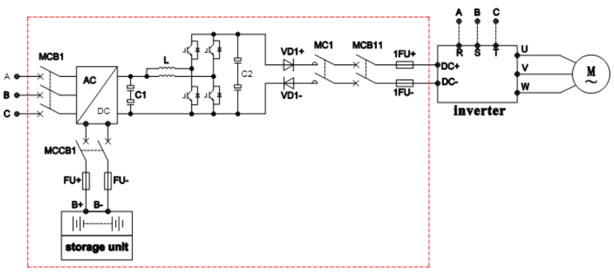


Fig.7 working principle of LVRT system

When AC voltage is normal, LVRT system is in standby mode, the inverter supplies by the power grid. When voltage sag happens, LVRT system turns automatically into work by detecting the changes of AC voltage. That is, LVRT system outputs stable DC 500V (protected inverter of AC 380V) or 1000V (protected inverter of AC 690V) to support the inverter DC bus so as to ensure its uninterrupted work. When the power grid recoveries from voltage sags LVRT system quits running automatically, as shown in Fig.8.

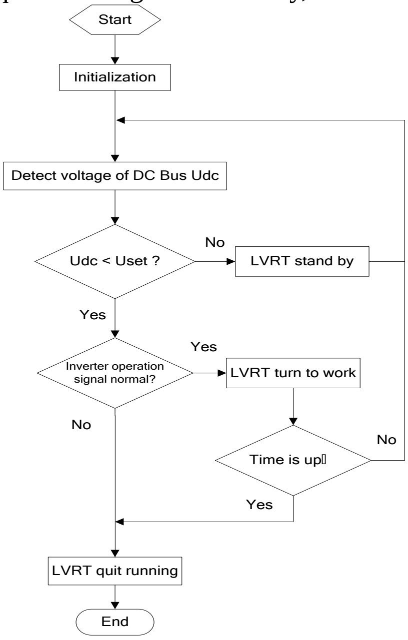


Fig. 8 working flow of LVRT system

Core module of LVRT system

The core part of LVRT system is VSP module which adopts BOOST topology, as shown in Fig.9. It is made of input capacitor C1, inductor L1, a switch tube Q1, diodes D1 and output capacitor C2. The circuit has two working states, charge and discharge state. When Q1 is on (t_{on}), current of L1 (iL) increases linearly to store energy in the inductor, diode D1 bear reverse voltage and cut-off, capacitor C2 provides energy to load R. When Q1 is off (t_{off}), current of L1 cannot change immediately, so it produces reverse voltage, the inductor voltage and input voltage superposes to make D1 conduct, the inductor releases energy to charge C2 and supplies for the load at the same time together with input source, so the circuit realizes stepping up the input voltage.

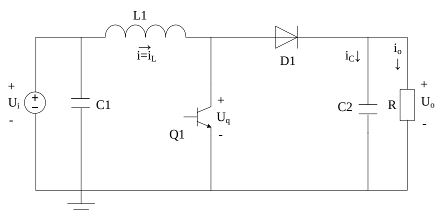


Fig.9 Schematic diagram of VSP module

System control logic

Two aspects should be considered in the management of low voltage ride through of thermal power plant, one is to make auxiliary safely get through the voltage sag so as to avoid the unplanned shutdown for MFT acts when inverter trips, the other is if the MFT acts, auxiliary machine must stop immediately to prevent the explosion of furnace, that is the inverter must stop at the same time. So MFT interlock must be considered in order to ensure the safe out of running of the LVRT system.

In addition, the system needs to collect coal feeder operation signal, inverter operation signal and protection action signal. When coal feeder operation signal is normal and inverter is in operation without protective action, contactor of LVRT system is connected with the inverter DC bus. Otherwise the contactor disconnects with the DC bus to isolate from the inverter. Combined with MFT interlock, coal feeder operation signal, inverter operation signal, LVRT system logic control is as shown in Figure 10, as long as one of the signals losses or abnormal, the contactor releases and LVRT system quits running.

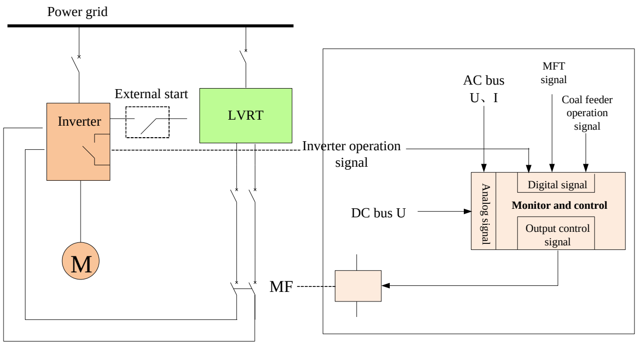


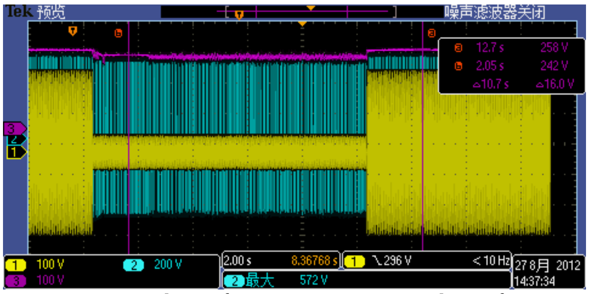
Fig. 10 logic control of LVRT system

Case study

A power plant with a total of four 220T/h coal-fired boilers, each furnace is configured of 8 coal feeders which are driven by SIEMENS 420 inverter. According to user's requirements, the LVRT system is used to solve voltage sag.

Fig.11 Field application of LVRT system

The coal feeder system equipped with LVRT system was tested. The application effect when AC input voltage (CH1) drop to 20% is as shown in Fig.12 from which we can see that with the support of LVRT system, the DC bus voltage of inverter (CH3) is DC484V (Probe attenuation rate is 2) so as to output stable AC voltage (CH2) to ensure the coal feeder in continuous operation during voltage sags.



CH1: AC input voltage of inverter CH2: output voltage of inverter
CH3: DC bus voltage of inverter

Fig. 12 waveforms of LVRT system in field application

CONCLUSION

Voltage sags is an inevitable phenomenon in the operation of power grid which will cause unplanned shutdown of thermal power plant. According to PIT result, coal feeder is the most critical equipment with the lowest immunity due to its inverter trips during voltage sag. Considered the AC-DC-AC characteristics of inverter and power electronic technology, LVRT system based on DC support technology is designed. Experimental data and field applications show that the LVRT system meets the requirements of voltage sag protection to ensure uninterrupted operation of coal feeder driven by inverter, so as to ensure the safe and stable operation of the boiler coal feeding system and the continuity of the power generation process.

REFERENCES

[1] Robert M. Grow, Thomas Prevost, Steve M. Mills, Judith Gorman. ANSI/IEEE 1159-2009, *IEEE Recommended Practice for Monitoring Electric Power Quality[S]*: The Institute of Electrical and Electronics Engineers, Inc, 2009,2.

[2] Math Bollen, Mark Stephens, SaSa Djokic, etc. *Voltage Dip Immunity of Equipment and Installations, CIGRE/CIRED/UIE Joint Working Group C4.110*, 2010.

[3] Wenbo Chen, Mingtian Fan, Zhonghua Mei, Zhang Bao. Research on Voltage Sag Protection system based on DC Support Technology, *CIRED 2015*.

[4] Wenbo Chen, 2012, A kind of voltage sag protection equipment used for DC load [P], China, 2012203798452.