HVDC Islanding Testing Analysis and Control Parameter Optimization

Wang Jianming [1, a], Zhang Jian [1,b] and Yin Yonghua [1,c]

[1] China Electric Power Research Institute, Haidian District, Beijing 100192, China

[a]wangjm@epri.sgcc.com.cn, [b]jianzhan@epri.sgcc.com.cn, [c]yinyh@epri.sgcc.com.cn

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Abstract. This paper researches HVDC operating characteristics and its sensitive factors of islanding system based on JinSu UHVDC in China. Several factors such as water hammer effect coefficient, parameter of governor, load model, DC frequency controller, power system operation mode and stability control measure has influence to the system stability. To optimize UHVDC control system and ancillary power source parameter, dead area match scheme of control system is proposed as well as reasonable limit step value. The analysis and scheme in this paper is verified by the actual data of JinSu UHVDC islanding testing. The operation control strategy can support precious experience for planning and operation of HVDC projects.

Introduction

There are two operation modes for HVDC transmission line. The common mode is network mode, under which converter stations connect to the main power grid. The other mode is called islanding mode. Islanding mode is an important operation mode for DC system. In this mode, converter stations of DC form independent system with nearby power plants and transmission lines. The independent system switches off connection with main power grid. Because of weak network structure and little short circuit capacity of islanding system, disturbance and faults of DC or AC system will bring great risk to sending system especially HVDC line transmits large capacity power. Transmission capacity of HVDC will be constrained and water resource will be abandoned if islanding system lack of enough stability margin. During the development process of UHVDC(Ultra High Voltage Direct Current) in China, several UHVDC projects are facing the problem that the sending system may change into islanding mode.

Islanding system operation and control of HVDC have been studied by some researchers. In paper[1], islanding system except plants and transmission lines were replaced by an equivalent generator and two different control strategies were proposed for islanding mode operation with electromagnetic transient simulation software.

Paper[2] constructed DC model based on electromagnetic transient simulation software PSCAD/EMTDC, studied frequency characteristic of Hu-Liao HVDC in islanding mode and proposed the control strategy.

In paper [3], a detailed real-time digital simulation closed-loop model of islanding operation is built by Real Time Digital Simulator(RTDS) and control & protection cubicles, by which control traits of DC system in islanding operation were analyzed.

Paper [4], [5] researched the control problem of islanding mode, presented additional control strategy of HVDC and validated it by RTDS.

All of above paper researched the stability characteristics and control strategy of DC islanding mode by electromagnetic transient simulation software such as RTDS and PSCAD/EMTDC. However, electromagnetic analysis cannot consider the influence of bulk system because of limitation of simulation scale.

This paper uses electromechanical transient simulation program PSD-BPA to study HVDC islanding stability as bulk power system can be considered in this program. To reflect the dynamic response feature of HVDC line accurately, a new HVDC model(called DA card)in is adopted in PSD-BPA, which is much closer to actual JinSu UHVDC control protection system. According to simulation analysis and debugging test, HVDC islanding operation feature and sensitive factor is mastered. The control protection optimum scheme is proposed for HVDC transmission line and its matching power source.

Survey of JinSu UHVDC Project

The rate voltage of JinSu UHVDC is ±800 kV and rate capacity is 7,200 MW. JinSu UHVDC project starts at Jinping convertor station and ends at Suzhou convertor station. In 2012 JinSu UHVDC was put into operation while only two generators of match power plant were completed. In normal operation mode, JinSu connects to main grid by YuePu double transmission lines. When YuePu lines are cut off, sending end of JinSu UHVDC will form islanding system. The Power grid structure nearby JinSu UHVDC is shown in Fig.1.

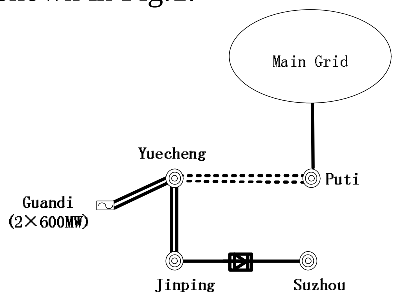

Fig.1. Power grid structure nearby JinSu UHVDC

JinSu UHVDC has set up frequency controller whose transfer function model shows as Fig. 2.

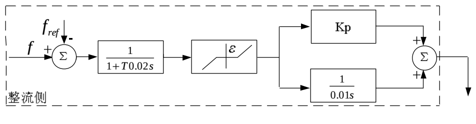

Fig.2. Transfer function model of DC frequency controller

The HVDC calculation model D card in PSD-BPA which is widely used before is prototyped based on Pacific DC in the America. The DM card is prototyped based on CIGRE model and DN card is based on Siemens model. However, the control protection system of JinSu UHVDC approximates ABB model. In order to get more accurate response feature, china electric power research institute has developed new DA card and applied it in the power system analysis.

Reactive power Voltage and Power Angle Stability Characteristic of Islanding System

In islanding system, when DC operates in low power level, the converter will cost little reactive power. Even putting into the fewest AC filters, HVDC system still injects much reactive power into AC power grid. For balance surplus reactive power, several control methods are adopted. For example, JinSu transmits power 500MW with 3 set AC filter and 6 set lv reactor in converter station, while Guandi generators produce nearly zero reactive power. The 500kV bus voltage in islanding system is 541kV around.

Usually power angle stability becomes prominent problem when remote plants are accessed into power system through long distant transmission lines. In islanding system generators connect tightly, so power angle stability will not constrict transmission ability of HVDC.

Frequency Stability Characteristic of Islanding System

The ability of keeping frequency stability is weak for HVDC sending islanding system. If proper stability control measure cannot be adopted, system frequency will collapse. In this paper several disturbances in islanding system are simulated to analyze frequency stability.

Influence of short circuit fault.

AC line fault at sending end. Frequency will be impacted when AC short circuit fault occurs in islanding system and it will recover normal quickly after action of delay protection. Short circuit fault will not cause permanent power unbalance as long as correct delay protection response. For example, when three-phase short circuit fault occurs at Guandi-Yuecheng 500kV AC line and is cleared by relay protection, frequency peak value increases up to 50.52Hz and then recovers normal in the end. The frequency curve shows as Fig.3.

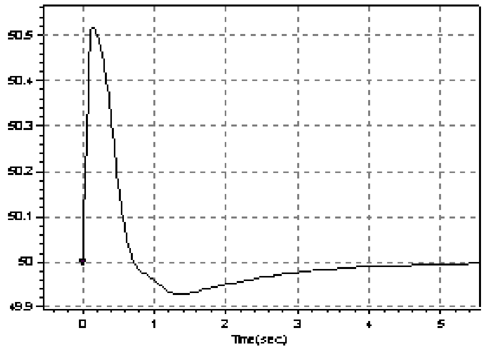

Fig.3. Islanding frequency after AC line fault at sending end

Frequency fluctuation will be less if delay protection acts faster. For same fault, frequency peak value will reduce from 50.52Hz to 50.43Hz in case delay protection acts at 80ms instead 100ms. It is shown in Fig.4. So frequency stability can be improved in case faster delay protection action.

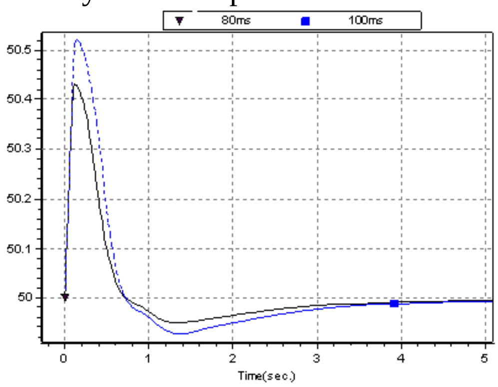

Fig.4. Islanding frequency comparison of different delay protection act time

AC line fault at receiving end. When AC fault occurs at receiving end of HVDC, commutation failure of HVDC will exert an influence to sending islanding system.

In one operation mode, JinSu UHVDC transmits 1800MW, while 4 matching generators are in operation. When 3-phase permanent N-1 fault happens on AC transmission line nearby converter station, commutation failure will occur and UHVDC power will decrease to zero momentarily. With communication failure disappears, DC power will recover to normal level. Because of temporary power unbalance, frequency uprush in islanding system can reach 50.54Hz and stay at dead area edge of DC frequency controller. The curves show as Fig.5 and Fig.6. So faults at receiving end of HVDC need to be considered to analyze frequency stability in islanding operation mode.

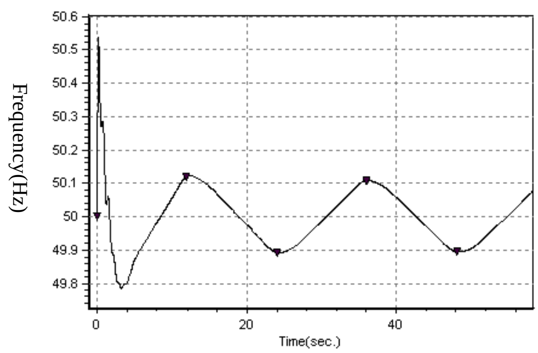

Fig.5. Islanding frequency after AC line fault at receiving end

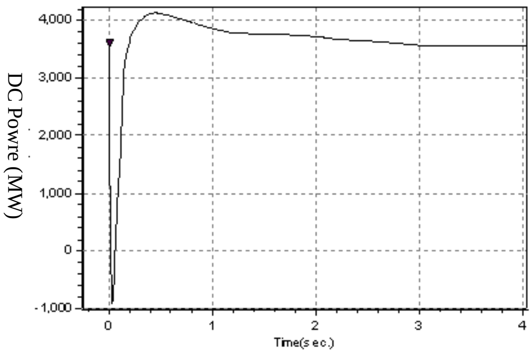

Fig.6. JinSu UHVDC power after AC line fault at receiving end

Influence of unbalance power.

Influence of permanent power unbalance and control measure. When generator is tripped or HVDC bipolar block occurs in islanding system, power balance will be broken down and frequency will oscillate. If quantity of unbalance power is large enough, generator high-frequency protection or low-frequency unloading equipment will act and islanding system will collapse. In order to keep islanding system frequency stability, some control measure should be adopted. The basic principle is that power in islanding system is ought to recover balance as much as possible. There are three typical cases for recovering power balance. First, after generator tripping, HVDC should adjust power according to generator power loss. Second, after HVDC single-polar block, the other polar should increase power quickly. Third, after HVDC bi-polar block, units which have same active outputs is ought to be tripped.

Influence of temporary power unbalance. After generator tripping, the islanding power loss is temporary if HVDC reduces equivalent power quickly and the valley value of islanding frequency is influenced. To avoid load shedding in islanding system, the frequency valley value should be analyzed.

In simulation case, two units in Guandi plant operate on maximum power output condition. Once one unit is tripped with 600MW power loss, JinSu UHVDC will reduce equivalent power in 200ms. The curve shows that the valley value of frequency reaches 49.46Hz and under frequency load shedding device will not act. The frequency curve shows in Fig.7.

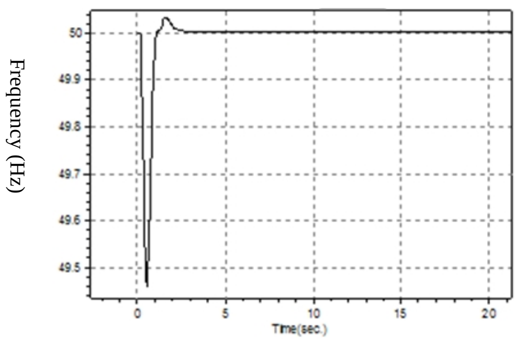

Fig.7. Islanding frequency after generator tripping and control measure

Sensitive factor of islanding frequency stability.

Water hammer effect time constant of hydro turbine. The output of hydro turbine is non-linear, but at given water head and given working condition, its characteristic can be described with linear rigid model as follow:

$$G_w(s) = \frac{1 - T_W s}{1 + 0.5 T_W s} \tag{1}$$

where $G_w(s)$ is output of hydro turbine, T_w is water hammer effect time constant of hydro turbine.

The water hammer effect time constant is determined as

$$T_w = \frac{L U_0}{a_g H_0} \tag{2}$$

where a_g is acceleration of gravity, L is length of aqueduct, U_0 is velocity of water, H_0 is initial water head, T_w is water hammer effect time constant. As output mechanical power of water turbine is affected by both water velocity and water head, T_w changes with generator working condition. Typically, T_w is between 0.5 second and 4 second approximately.

Obviously the stability margin in islanding system is so depressed that T_w is sensitive to generator governor stability. So model and parameter of hydro turbine should be considered more accurately.

For example, the calculation condition of simulation mode is shown in Table I. When link line between islanding area and main grid is cut down and JinSu UHVDC forms islanding system, UHVDC reduces power 100MW quickly. The islanding frequency curves are compared under different parameter T_w in Fig.8. It is shown that islanding frequency is fluctuant when T_w is 3 while islanding frequency is stable when T_w is 1. The fielding data of islanding operation can verify proper T_w to guide the simulation calculation.

Table 1. Calculation Condition of Simulation Mode

JinSu UHVDC power	800[MW]
Guandi plant output	350*2[MW]
link line power from main grid	100[MW]

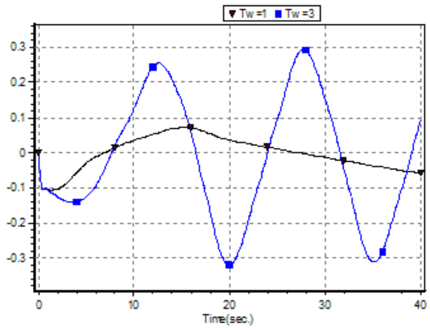

Fig. 8. Islanding frequency when parameter Tw gets different value

PID time constant and difference coefficient B_P of governor. As the extensive application of electro-hydraulic governor system, PID-type governor has been widespread. Its transfer function can be described as follow:

$$G_c(s) = \frac{1}{B_p} \cdot \frac{1+s\frac{K_P}{K_I}+s^2\frac{K_D}{K_I}}{1+s\frac{1}{B_P K_I}} \cdot \frac{1}{1+T_G s} \tag{3}$$

where servo system is described by first order inertia plants, the typical value of time constant T_G is 0.5 second. In addition, K_P, K_D and K_I are proportional, differential and integral coefficient respectively while B_P represents relative regulation coefficient.

The open-loop gain of governor is determined by series correction loop combined with B_P, K_P, K_D and K_I.

The sensitive analysis of coefficient is made to research the parameter influence to governor stability and results are shown in Fig.9-10. It can be concluded that stability margin reduces when B_P, K_D decreases or K_P, K_I increase.

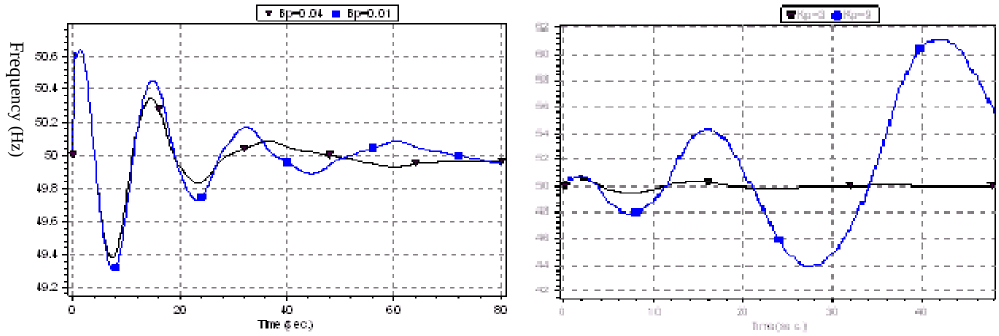

Fig. 9. Sensitive analysis of relative regulation coefficient Bp and proportional, coefficient K_P

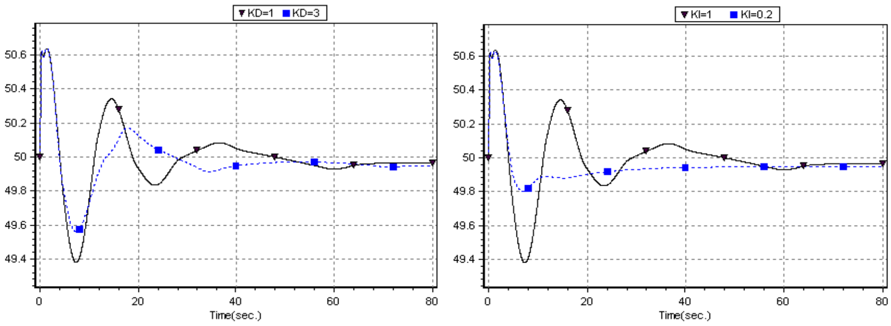

Fig. 10. Sensitive analysis of differential coefficient K_D and integral coefficient K_I

Survey of JinSu UHVDC Project

In first islanding system test, JinSu UHVDC transit 600MW while two units of Guandi plant were on operation. The power of YuePu link line was 160MW from Puti to Yuecheng. After YuePu line was cut off, Yuecheng area with JinSu UHVDC transferred to islanding system.

In islanding system, the power of UHVDC, units and load were matched. However, the frequency of islanding system fluctuated abnormally that fluctuation period was about 14 second and the range reached 0.26Hz. It is showed in Fig.11.

The features of this frequency fluctuation can be concluded as follows: first, abnormal fluctuation appeared after system transition from connection to islanding state. The frequency of fluctuation reached 0.07Hz which was outside the range of low frequency oscillation. Second, amplitude of fluctuation decreased when dead area of DC frequency controller was narrowed. Third, abnormal fluctuation disappeared when primary frequency regulation function of two units exit.

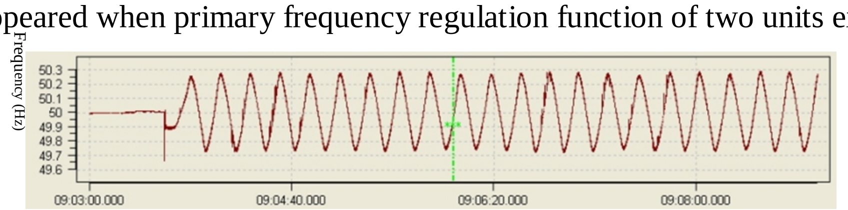

Fig. 11: Frequency fluctuation in first islanding test of JinSu UHVDC

After first islanding test, generator governor and DC frequency controller parameter was adjusted according to test result and simulation analysis. There are three major modifications as follows: first, dead area range of generator is larger than DC frequency controller. Second, amplitude limiting of integration element is decreased greatly to weaken its effect. Third, integration gain coefficient is decreased while parameter B_P is decreased to keep response velocity of governor.

Because DC frequency controller acts before governor, the stability margin of governor increases greatly. In second islanding test, the PMU data curve is showed as figure 8-3. Obviously, the abnormal fluctuation did not appear and frequency was stable. The transient peak value of frequency was 50.17Hz and steady value was 50.04Hz which coincide with simulation results. The actual test data and simulation curve can be shown in Fig.12 and Fig.13 respectively. The second islanding test verified the effectiveness of parameter optimum scheme.

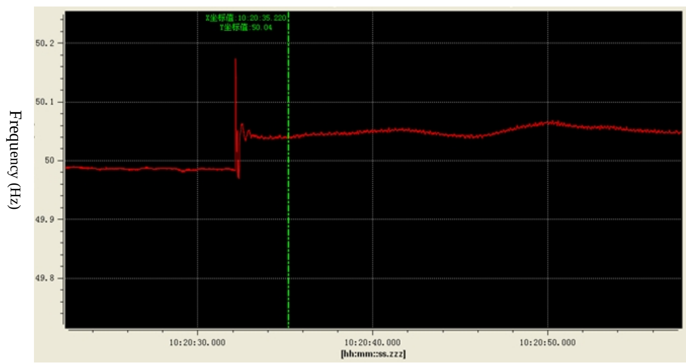

Fig.12. Islanding frequency of second actual test

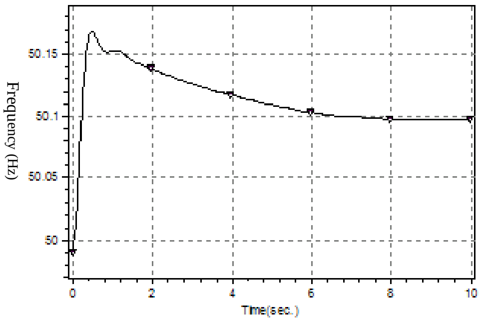

Fig.13. Islanding frequency of simulation calculation on second test mode

Based on JinSu UHVDC, this paper presents stability characteristic and control measure for islanding system operation. As the islanding system is sensitive to disturbance, DC and matching plants should optimize their control systems. To guarantee voltage qualified, enough reactive compensation devices are ought to be installed in convertor station and other nearby stations. Frequency stability is main problem in islanding system. Short circuit fault, generator tripping or DC block fault could cause power unbalance and frequency oscillation. Correct relay protection and DC power fast change function are effective tools to keep islanding system stability.

Water hammer effect time constant of hydro turbine PID time constant and difference coefficient B_P of unit governor is two sensitive factors easily neglected. In first JinSu UHVDC islanding test, sustaining abnormal frequency fluctuation appears. The incompatible parameter of DC frequency controller and unit governor is found the key reason and new optimum control strategy is applied to the islanding system. In second islanding test, the system is stable that shows the validity of simulation analysis and effectiveness of new scheme.

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