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STUDY OF INVERTER, RECTIFIER AND ISLANDING FAULT IN HVDC SYSTEM WITH COMPARISON BETWEEN DIFFERENT CONTROL PROTECTIVE METHODS

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Abstract- In this paper Islanding fault of rectifier and inverter substations are studied in HVDC system both in back to back and long transmission line systems. The effect of system short circuit ratio (SCR), are studied too. To overcome these faults three control action may be effective. System's controller regular action, pulse blocking of faulty converter and rectifier changing operation to inversion mode are three control schemes that studied here. Finally the results compared with each other and with system that has no control action and the best method for each fault are determined. These control-protective schemes are studied in both BB-HVDC and Long transmission line HVDC system. All of these simulations are done using Matlab/Simulink.

Keywords: HVDC System, Islanding Fault, Pulse Blocking, Control.

I. INTRODUCTION

Due to large amount of power demand and its incremental high speed; power system extension in all of the countries would be unavoidable. This matter causes increase in both power producing systems and power transmission systems. HVDC transmission system is one of the most reliable ways of transferring power; therefore, study of its characteristics and behavior during many eventual conditions would be necessary. There are many papers in terms of HVDC fault condition, such as converter's fault, AC or DC system faults, line protection, and other fault detection methods, that indicated in [1, 4, 6, 7, 8, 9, 10, 11]; or about its modeling and control system behavior, [1, 3, 5].

But there are a few studies in the case of converters islanding fault [2], which has studied the islanding phenomena only at inverter substation and just for a back-to-back system. In this paper we study both rectifier and inverter substation islanding in both back-to-back and HVDC system with long transmission lines. All of this study has been done with exact simulating of HVDC system using Matlab- Simulink. Islanding fault occurs when one of the substation's feeding AC systems has suddenly disconnected from Commutation bus-bar. If this fault occurs at rectifier side of a HVDC system, it calls rectifier islanding fault, otherwise, the fault occurs at inverter side, called as inverter islanding fault, Figure 1. Based on the converter in which this fault has occurred, it will have different effects on system's parameters. To study such phenomena, the HVDC System with 500KV DC Voltage, 50 Hz and about 500 MW of power transfer capacity has been selected. For Back to Back (BtB) Type, The nominal series RL branch and for long transmission line system the T type model of transmission line has been chosen. The effect of system's Short Circuit Ratio (SCR) has been studied only at inverter substation.

In [12] a novel approach is presented to model parallel-connected HVAC and BtB VSC HVDC systems. In addition to the state-space representation, a block diagram representation is formed to analyze the system stability characteristics. By this modeling approach, it is possible to analyze the small-signal stability of the system and low-frequency oscillation phenomena with the synchronous machine. In [13] proposed flexible power architecture for an energy generation system which uses a fuel cell stack as main DC energy source.

In this paper, three methods are studied for islanding phenomena. At first the system behavior with no control action are simulated, which is useful to understand the effects of islanding fault and is suitable for comparison case with three controlling methods. The system's controller regular actions are the first methods that are studied, this method is based on HVDC's main control Diagrams (like CC, CV and VDCOL). Pulse blocking of faulty substation's converter are the second method that can be overcome to the fault. Moving rectifier converters to inversion mode are the third method that only is used at inverter islanding fault, which can to deenergizing the transmission line. All of the mentioned methods are studied for back to back HVDC system and long transmission line system. The effects of weak AC connection are also studied in inverter side fault. Lastly the results are compared with each other to determine the best method for each faulty case.

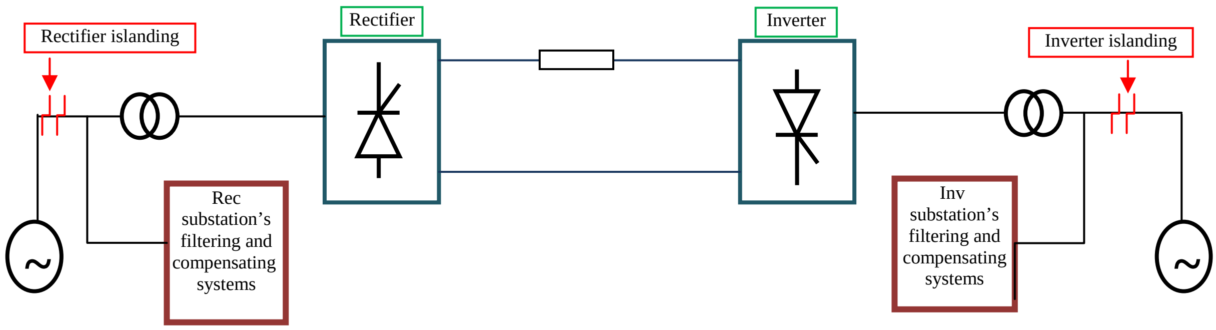

Figure 1. HVDC system islanding fault in rectifier and inverter substations

II. DEFINING THE PROBLEM

The fault occurs at rectifier substation, the amplitude of AC bus voltage will reduce to zero, and after a transient time the power transfer will be blocked. Due to capacitive elements of the rectifier substation such as filters and compensating systems, the voltage of AC bus is reduced to non- zero value and may be oscillated by frequency that differs from bus one. In this system the frequency appeared in 1.8 Hz whose characteristic and FFT analysis have been depicted in Figure 2.

Depending on this bus voltage, both DC line voltage and Current are reduced to values near zero. This matter can cause power transfer to become zero. The low frequencies oscillation could cause malfunction of substation equipments like surge arresters, Filters, transformers and specially measuring and control equipments. This voltage oscillations are became zero after about 30 second which depend on system time response value. Such conditions and results are the same for HVDC system with a long transmission line, but the total response time of the system will be increased.

But if the Inverter substation's SCR be a low value, the situation and results will be differed, in other words, if we have a weak AC Bus at inverter side, the AC bus voltage of Rectifier substation will have both low and high frequency oscillations. If it occurs DC line current will also have such oscillations, see Figure 3, maintaining on system, that is, the rate of their damping is too slow and can cause more ill situation than strong system. In the long line transmission system with weak AC system at Inverter side, the high frequency oscillations disappeared.

If the fault occurs on inverter substation, AC Bus with all of its equipments seems as a single bus power system, and it appears that the voltage and current of inverter's DC side are reduced. Because of existence of many energy storage components in both rectifier and inverter substation like filters, capacitors, reactors, DC line reactor, line capacitor, SVC elements and so on, System parameters will have different characteristics.

Inverter's DC voltage is reduced to zero due to isolation from AC bus, and then DC line current increases to high value depend on DC line resistance and AC systems ESCR. The value of AC bus voltage will be decreased and will have main frequency at 50 Hz, but it contains inevitable value in 250 Hz, Figure 4. This effect may stay on system until the all of the energy storage elements are discharged.

Such condition in inverter AC busbar causes inverter and its substation component is seemed as no inertia generator, which generates active power and consumes reactive power. AC bus voltage after disconnection may appear in different amplitude and frequency due to amount of system storage elements.

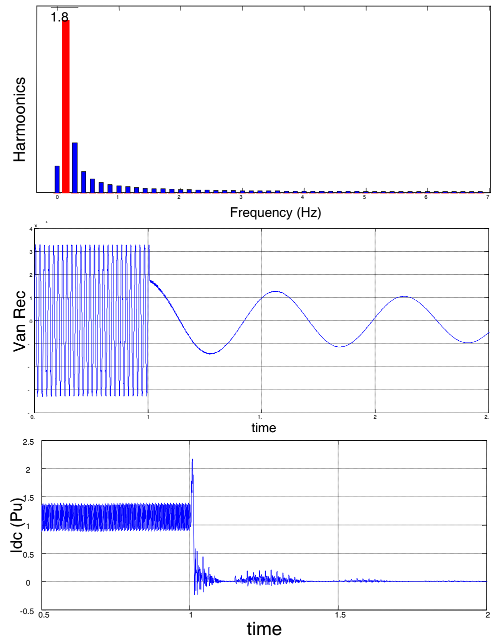

Figure 2. System parameters variations at BB rectifier islanding

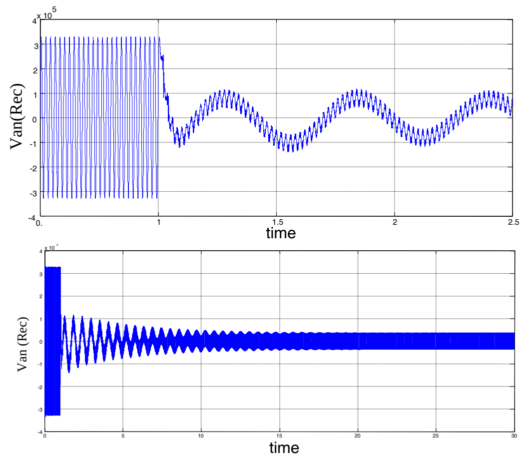

Figure 3. System Parameters variations at BB rectifier islanding with weak AC bus of inverter substation

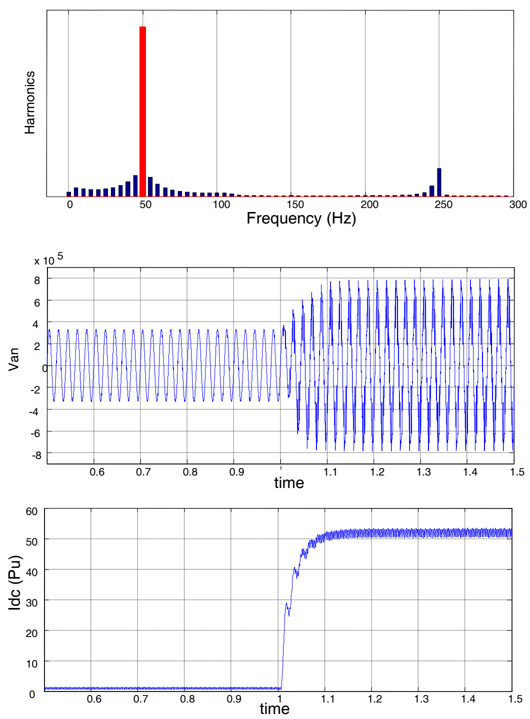

Figure 4. System parameters variations during inverter islanding of BB HVDC system with strong AC Bus of inverter substation

As seen from Figure 4, the values of AC bus voltage increases about 2 times and the DC line current about 50 times. These high values of DC line current and Inverter's AC bus voltage can damage some system's equipments. But with the transmission line consideration Figure 5, the rectifier sides DC current goes to final value (40 times of nominal value), with large amount of oscillations. At the inverter side DC current this procedure acts as a second order system with overshoot. The value of AC bus voltage will be decreased in this case.

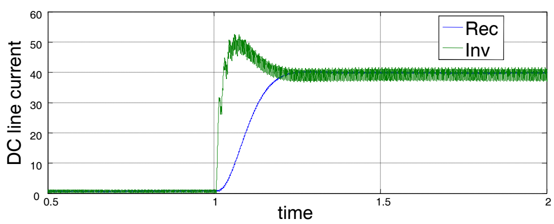

Figure 5. System parameters variations during inverter islanding of long line HVDC system with strong AC bus of inverter substation

Considering weak system, the amplitude and maximum overshoot of DC current will be increased, causing damages to equipments, Figure 6. Unlike previous results in this case AC bus voltage reduced to half of its value.

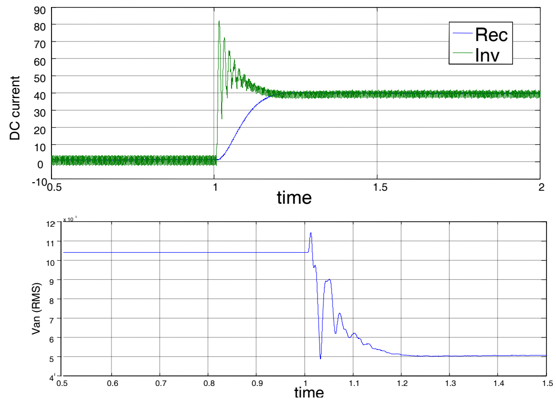

Figure 6. System parameters variations during inverter islanding of long line HVDC system with weak AC bus of inverter substation

III. SYSTEM'S CONTROLLERS ACTON

As a first step toward the design, we mathematically set up the design problem. It is easy to verify that the linear ability condition is guaranteed. Let: HVDC system's controllers are designed to pass the system from most common faults like AC or DC side short circuits, transmission line breaking and so on. The results of controllers' action for inverter islanding fault in BB HVDC system are shown in Figure 7. As DC line current accede to high value (three times of nominal Pu value), constant current controller of rectifier detect a high current fault, therefore increase its firing angle to 120. Because of its designed nature [1], varies firing angle several times to determine if the fault is transient or steady state. Finally in this case controller is faced with steady state one and remains in 120 degree to damp DC current. During this procedure value of DC current attains to low value in almost 0.1 second. Time scheduling of controllers can be adjust by system's main operator.

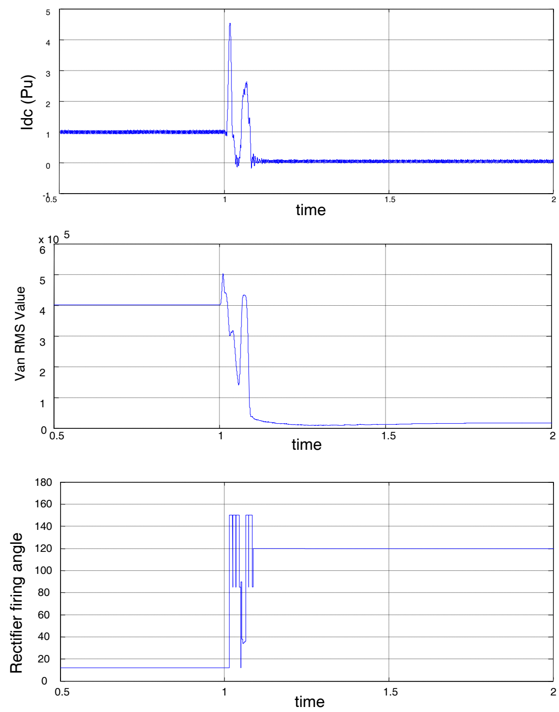

Figure 7. System's controller's action during inverter islanding of BB HVDC system

As it's clear from results, controllers operation to determine transient faults takes some time to decrease the faulty parameters and also cause high values of DC line current in detecting interval. Therefore we discuss about other methods to clear the effect of such fault.

IV. BLOCKING CONVERTERS PULSES

The other method that is studied here is blocking pulses of converter which fault has occurred. It has been assumed that the fault is detected in 0.01 second. For a BB system results are depicted in Figure 8. It is clear that the value of DC current's peak value is worse compared with system that has no control action. For a long line system the situation is the same.

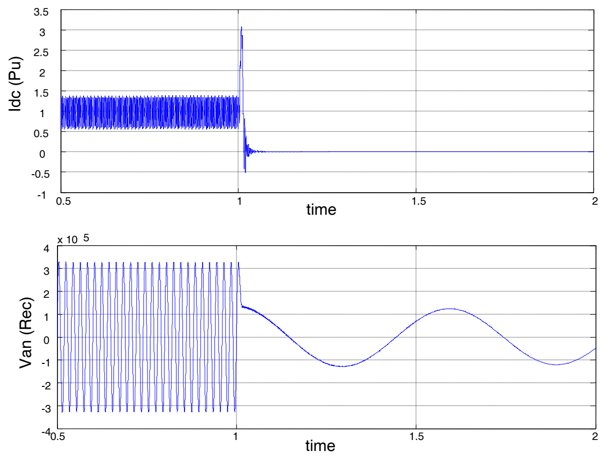

Figure 8. Rectifier pulse blocking during rectifier islanding

If the AC system of inverter substation be a weak one, the results are depicted in Figure 9. It is clear that the AC bus oscillations attain to acceptable value after about 20 seconds. Comparing Figure 3, this case has better results.

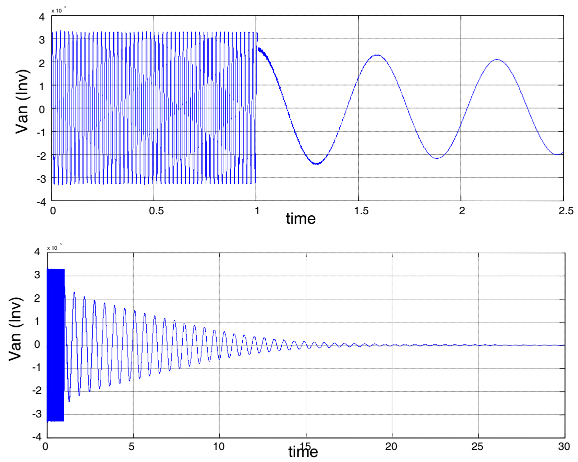

Figure 9. Rectifier pulse blocking during BB rectifier islanding with weak AC system at inverter AC side

Such a control strategy at inverter islanding has good characteristics Figure 10. Both of the DC currents become zero using this method.

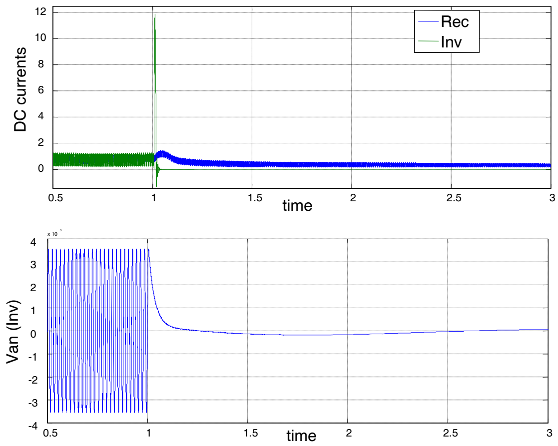

Figure 10. Inverter pulse blocking during inverter long line islanding

But in the weak system the terms will be differed Figure 11. Comparing Figure 6 that there was no control scheme, DC current increase is incredible however its final value is become zero.

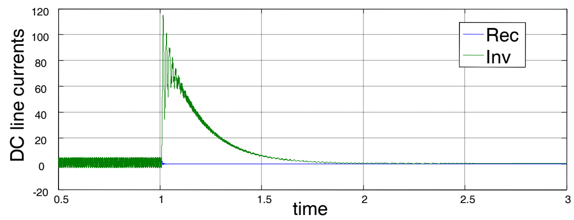

Figure 11. Inverter pulse blocking during inverter long line islanding with weak AC system

If we consider back to back HVDC system, with strong inverter side AC bus and suddenly an islanding fault occurs at inverter substation, the results are depicted in Figure 12. It iss clear that with pulse blocking of inverter substation has better results comparing Figure 4.

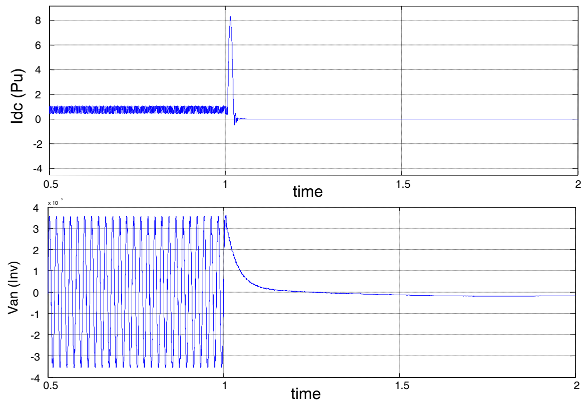

Figure 12. Inverter pulse blocking during BB HVDC system's inverter islanding

V. CHANGING CONVERTER'S OPERATING MODE

This type of strategy is only used in inverter islanding fault. In this method when islanding occurs at inverter substation Rectifier converter goes to inversion mode of operation. This procedure cause discharging of capacitive elements especially in long transmission line systems.

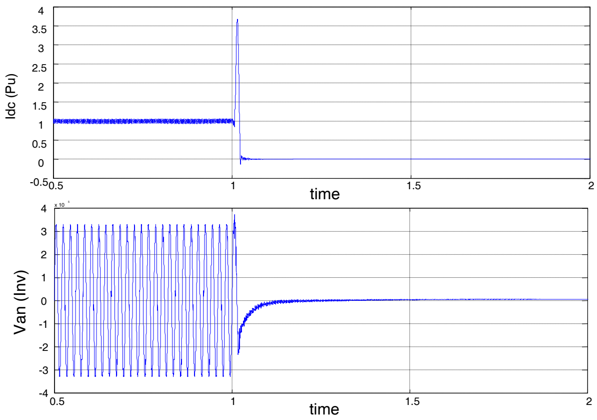

Figure 13. BB Inverter islanding, with rectifier mode changing

When the long transmission lines are considered, Figure 14, it's obvious that DC current and AC bus voltage value are reduced to zero during 2 seconds and DC current's peak value exceeds to 50 times of per unit value.

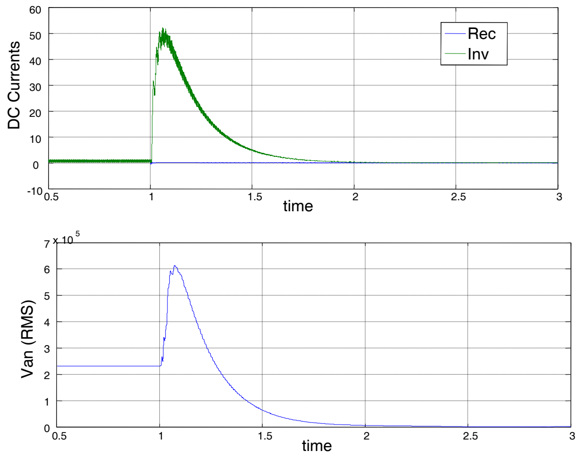

Figure 14. Long line Inverter islanding, rectifier mode changing

For the case with low value of SCR, results are shown in Figure 15. The peak value of inverter's side DC current attains 80 times of per unit value. Comparing with pulse blocking method this strategy has better results. The RMS value of AC bus voltage has better results considering a strong AC system (Figure 14.)

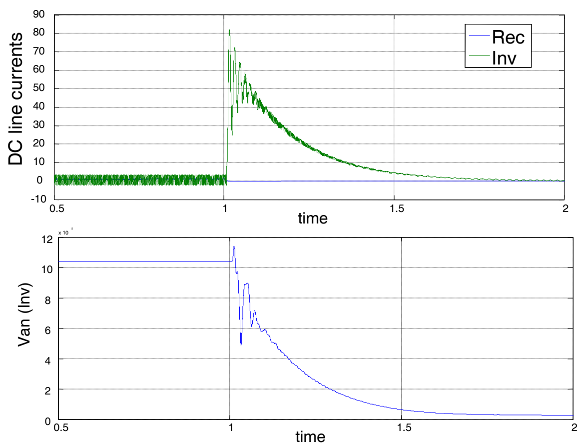

Figure 15. Long transmission line inverter islanding, with rectifier mode changing, in weak AC system

VI. COMPARISON OF RESULTS

As it is shown in the results the rectifier converter's islanding are only studied in back to back HVDC system. If we have strong AC bus we can compare results of Figures 2 and 8. And it is clear that situation with no control action is better comparing their DC currents peak value. For a system with weak impedance condition at inverter AC bus, such a fault (rectifier islanding) has worse condition when there is no control action. Using pulse blocking method the high frequency oscillations are disappeared and the low frequency ones are damped in 20 seconds (Figures 3 and 9). In this study system's main controllers (constant current and constant voltage controllers) are only considered at inverter back to back islanding fault. The reason retains to its large time response. For inverter islanding with back to back system, results have presented in Figures 4, 12 and 13. It's evident that the system with rectifier mode changing (to inverter mode of operation) has better time response and has low amount of DC current's peak value.

For HVDC system with long transmission line existence of line capacitors change the conditions. In this case for inverter islanding fault, both of the rectifier and inverter side DC currents have been increased (Figure 5) but with low steady state value comparing BB system (Figure 4). The control strategies action for such system can be compared using Figures 10 and 14. It is obvious that the response with pulse blocking method has better results comparing with rectifier mode changing.

DC current's peak value does not exceed 12 time of nominal per unit current and also settling time is below 0.1 second, in case which use pulse blocking method. But with rectifier changing mode method the peak value and settling time are 50 times and 1 second that are not comparable with pulse blocking method. These different also exist in AC bus voltage, in case with pulse blocking method there is no increase however with rectifier changing method there is an increase in AC bus voltage value about 3 times of nominal value.

For a weak AC system at inverter AC bus which has long transmission lines, when a fault occurs at inverter substation (Figure 6), system's parameters response changes comparing with strong one (Figure 5). The oscillations in DC line current increase in this case. The controlling methods results can be compared with figures 11 and 15. It is evident that the system with rectifier mode changing has better response than pulse blocking of inverter substations. The value of peak current in firs case (Figure 15) is about 80 times of per unit value but in second one it exceeds 120 times however both of them have same time responses.

VII. CONCLUSIONS

Islanding fault, comparing with other faults of HVDC system (AC short circuits, DC line short circuit, DC line break in and converters miss firing), has low degree of occurrence probability. But it may be also occurred and causes uncompensating damages to substations components, which have high cost. Till now there were no general studies about such conditions.

The phase that cause diverse in this paper comparing other papers about HVDC system's faults is that there were few articles that mentioned to this fault. Therefore this paper may be the start point to other researchers to begin study in this field. As it has pointed in previous section when we face with rectifier islanding fault, if the system SCR has better qualification, it is proper to use no control action and wait until the oscillations damped due to HVDC system time response. But when the inverter AC bus is weak, pulse blocking method has better result.

For inverter islanding if the system is back to back one, the rectifier changing operation to inversion mode has better responses. This method is also proper to use at inverter islanding fault with long transmission line HVDC system when the inverter AC bus is weak. If AC bus has good value of SCR then pulse blocking method has excellent response. The results are shown in Table 1.

Table 1. Faults and system's best action

Fault type	Best action
Rectifier islanding in back to back HVDC sys.	No control
Rectifier islanding in back to back HVDC system with weak AC bus of inverter	Pulse blocking of rectifier converter
Inverter islanding in back to back HVDC system	Changing rectifier operation to inverter mode
Inverter islanding in long transmission line HVDC system	Pulse blocking of inverter converter
Inverter islanding in long transmission line HVDC system with weak AC bus of inverter	Changing rectifier operation to inverter mode

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