AN ADAPTIVE CONTROL STRATEGY OF VSC-HVDC SYSTEMS WITH FAULT-RIDE THROUGH CAPABILITY

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ABSTRACT:

This paper proposes a modified current limit strategy (MCLS) and a frequency hysteresis control (FHC) for improving the disturbance ride-through capability of a VSC-HVDC link supplying passive industrial installations. Since industrial loads are more sensitive to voltage drops than frequency deviations, it's essential to guarantee the stability of voltage during severe faults. The development of the second order resonance control methods includes three steps. First, the main factor that affects the ac voltage in the passive industrial system is analyzed in order to enhance the voltage stability more effectively. Secondly, according to the analytical results, the MCLS is proposed to increase the ac voltage in transient conditions. Thirdly, in order to make the MCLS have a better control result, the FHC is added to the VSC resonance controller with the MCLS, which can also further enhance the ac voltage of the passive system. The simulation tests under metallic single-phase and three-phase faults are done in **MATLAB/SIMULINK**, and the results verify the validity of the control methods.

I. INTRODUCTION

Large passive industrial installations, such as offshore oil platforms, have a substantial power demand and a high power quality requirement [1,2]. With the rapid development of industry, voltage sags have become the most severe problem for the stability of industrial systems [3,4].Industrial installations are much more sensitive to voltage drops as compared with frequency deviations [5,6]. Therefore, in order to improve the fault ride-through capability of passive industrial installations, it is important to guarantee the stability of voltage. With the increased use of voltage source converter based high voltage direct current (VSC-HVDC) transmissions, the VSC-HVDC technology is playing an important role in power systems [7,8]. The VSC-HVDC systems can control the active and reactive power independently [9] and feed power into passive networks [10-13].

Over the last years, a series of research efforts have been made to improve the voltage stability of passive industrial loads. A new VSC controller supplying passive industrial plants is proposed in [6], where the VSC-HVDC uses the ac voltage and frequency controller. The idea of the designed strategy is to give priority to keeping up the ac voltage and slightly decrease the frequency during disturbances. However, as the controller hasn't set the frequency of the passive network in steady-state operation, the system cannot be started reliably and this control strategy may not make passive networks ride through severe faults. In [15], a droop frequency controller of the VSC inverter is developed. The main idea of the controller is to produce a new reference frequency of the VSC output voltage based on the dc voltage performance, whereas the voltage stability of the passive industrial system during severe faults is still poor. A Multi-terminal VSC-HVDC system connecting the main grid, wind farms and offshore oil platforms was studied in [16-18]. Analytical results of this VSC-MTDC system in steady and transient conditions were also presented. An enhanced fault ride-through method for offshore platforms is given in [17]. When faults occur in the offshore oil installations, the control strategy proposed in [17] employs a voltage-dependent limiter, to limit the maximum amount of active power from the offshore VSC. However, the main concern of [17] is the dc voltage, but not the ac voltage of industrial installations. In [19], a nonlinear control strategy aiming to improve the waveform quality of the VSC output voltage was presented, where the ac grid dynamics were not considered.

This paper proposes novel control strategies for a VSC-HVDC link to improve the fault ride–through capability of passive industrial installations. The new VSC controller based on the conventional ac voltage control (CAVC) consists of a modified current limit strategy (MCLS) and a frequency hysteresis control (FHC). The control strategies are designed to enhance the voltage stability of passive industrial systems. Impacts of metallic single-phase and three-phase faults in the sending side of the VSC-HVDC system are simulated and analyzed in MATLAK/SIMULINK to test the proposed approaches.

II . BASIC CONCEPTS OF SYSTEM

A. System Topology

It is depicted in Fig. 1 [15] that the power is delivered from the main grid to the passive industrial system by a VSC-HVDC transmission system. Since induction motors are considered as the dominant load in industrial systems, the analysis of this paper is mainly for induction motors. Variable frequency drives and protective functions are not included in this paper by assuming they are a small part of the passive load [6].

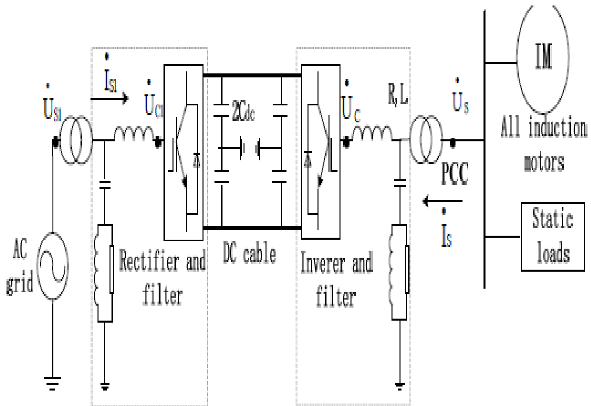

Fig. 1 The topology of the studied system.

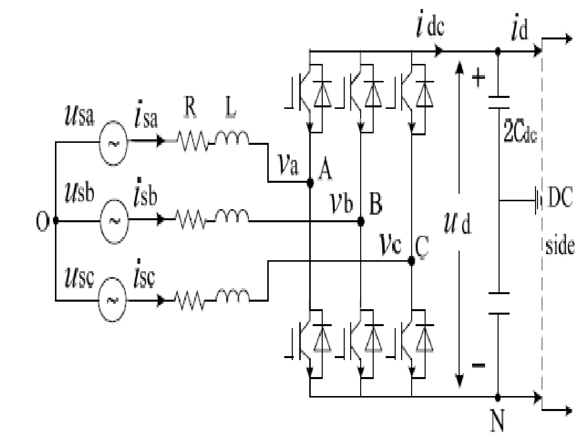

Fig. 2 The basic topology of VSC.

B. Mathematical Model of VSC

The basic topology of the VSC mentioned in [25] is shown in Fig. 2. Three-phase Kirchhoff voltage equations are listed below:

$$\begin{cases} L \cdot di_{sa}/dt + R \cdot i_{sa} = u_{sa} - v_a \\ L \cdot di_{sb}/dt + R \cdot i_{sb} = u_{sa} - v_b \\ L \cdot di_{sc}/dt + R \cdot i_{sc} = u_{sc} - v_c \end{cases} \quad (1)$$

After Park-transformation into *dq*-axis:

$$\begin{cases} L\dfrac{di_{sd}}{dt} = u_{sd} - v_{sd} + \omega L i_{sq} - R i_{sd} \\ L\dfrac{di_{sq}}{dt} = u_{sq} - v_{sq} - \omega L i_{sd} - R i_{sq} \end{cases} \quad (2)$$

C. Overall Control Description of VSC-HVDC

The control of the VSC-HVDC is based on the inner and outer control loop. The main function of the VSC inner control loop is to make *dq*-axis current components (i.e., *isd* and *isq*) follow references generated from the outer control loop. In order to suppress negative sequence currents during unbalanced faults, we set the command references as [28] When a VSC-HVDC system feeds power into a passive network, the outer control loop of the rectifier station operates on the dc voltage control mode and the ac voltage or reactive power control mode. At the grid side, VSC can achieve synchronization with the main grid using the Phase Locked Loop(PLL) [8,10]. The control scheme of the rectifier station [8] is shown in Fig. 3, where *Q* is the reactive power transferred from ac grid to the rectifier station, *Us1* is the amplitude of the voltage of the ac grid (see Fig. 1), *Qref* and *Us1ref* are the reference values of *Q* and *Us1*.

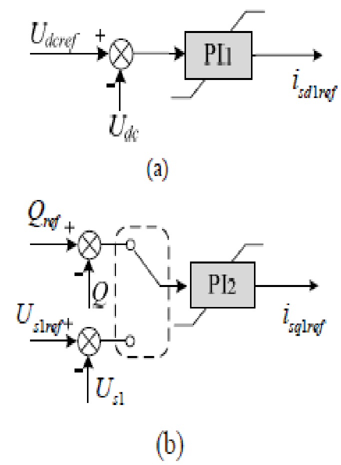

Fig. 3 The outer control loop of the rectifier station. (a) dc voltage control mode. (b) ac voltage or reactive power control mode.

III. ENHANCED CONTROL STRATEGY

In order to enhance the voltage stability of the passive industrial system, this section presents two ride-through methods, which consist of a modified current limit strategy (MCL) and a frequency hysteresis control (FHC). Both of them are based on the conventional ac voltage control (CAVC) adopted by the VSC at the receiving side.

A. Modified Current Limit Strategy

In conventional power systems, the reactive power flow and the ac voltage are closely connected, mainly because of the inductive characteristics of high voltage transmission lines. The change of reactive power in the system may have a large impact on the ac voltage of the power grid [23].

When a VSC-HVDC is supplying passive industrial installations, the rectifier station operates on the dc voltage control mode. In case of faults in the sending side, there is an ac voltage drop in the grid and the current of the VSC rectifier reaches the limit. As a result, the VSC at the grid side is unable to maintain the dc voltage. The variation of the active power may cause the fluctuation of the dc voltage, resulting in a disturbance of the ac voltage at the PCC, since the ac voltage in the passive system is modulated from the dc voltage of the VSC-HVDC [22].

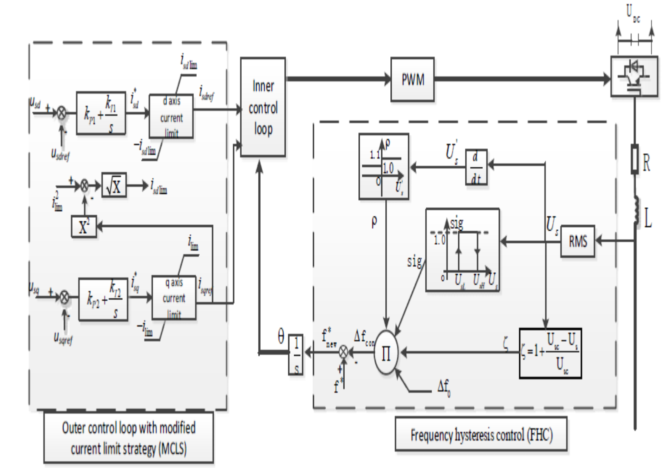

Fig. 4 Block diagram of proposed control method of the VSC-HVDC at the receiving side.

IV. SIMULATION RESULTS

According to the topology in Fig. 1, the paper uses the test system in Matlab/Simulink to verify the validity of the control strategies proposed above. In the simulation, the VSC at the sending side operates on the dc voltage control mode and the reactive power control mode. An ac voltage controller is used on the inverter of the VSC-HVDC system. The parameters of the VSC-HVDC system are shown in Table I in the appendix Simulation results show that in the passive industrial system, when the percent of induction machine loads is higher than 58%, the ac voltage collapse happens earlier than the dc voltage collapse during severe faults. It can be derived that in the case that induction motors account for more than 58% of all passive loads, the proposed control methods are applicable. The control parameters of the FHC are set as U_{sL}=0.85 p.u., U_{sH}=0.95 p.u., U_{sC}=0.7 p.u. andΔf_0=0.5 Hz. Here, the fault time is set as 0.1 s. considering that with the increase of the fault time, a dc voltage collapse may happen and the passive industrial system becomes unstable inevitably [6].

A. Metallic Single-Phase Fault at the Sending Side

Among all AC faults, single-phase ground fault is the most common fault. To test the fault ride-through capability of the control strategies, a single-phase fault is applied to the sending side of the VSC-HVDC at 0.5 s, when the system is under the steady state. After 0.1 s, the fault is cleared. The simulations have been done under different control strategies used on the inverter of the VSC-HVDC system, i.e., the conventional ac voltage control (CAVC), the CAVC with the MCLS and the CAVC with the MCLS and FHC. The simulation results are shown in Figs. 7~8.

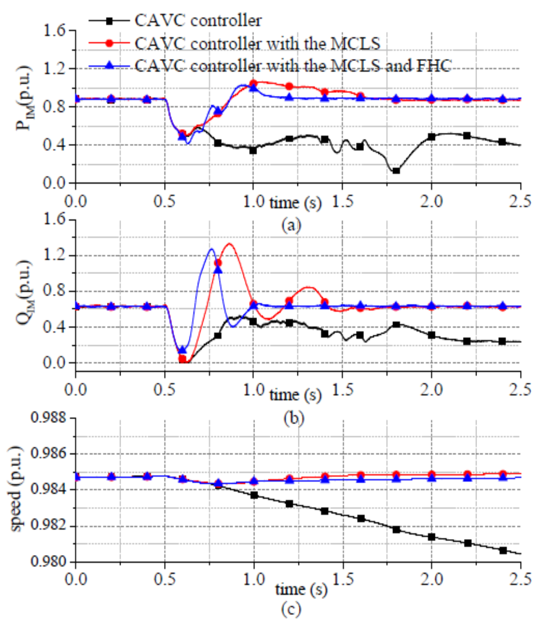

Fig. 8 IM responses of the metallic single-phase fault with different control methods. (a) IM active power. (b) IM reactive power. (c) IM speed.

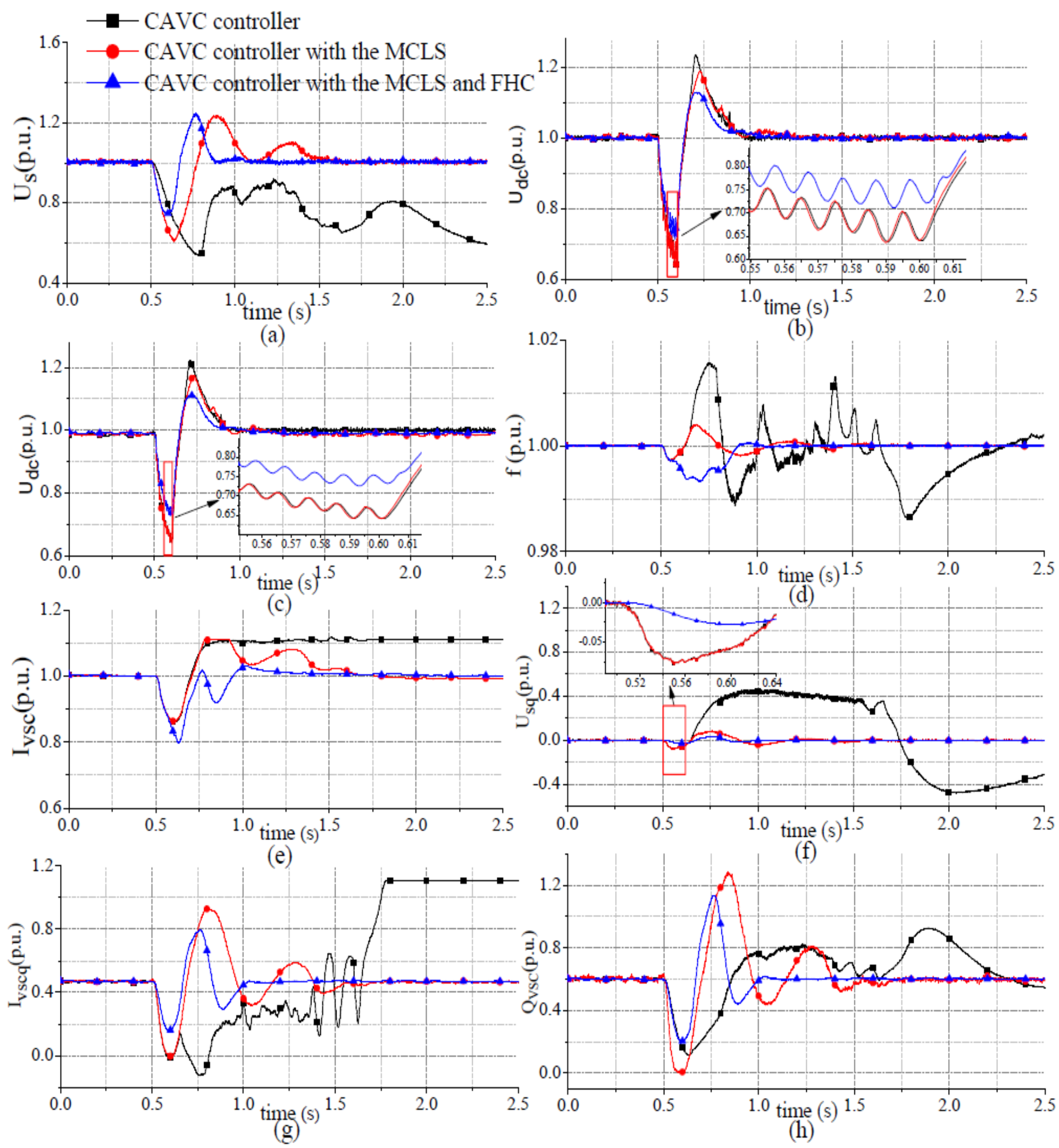

Fig. 7 System responses of the metallic single-phase fault with different control methods. (a) ac voltage at the PCC. (b) dc voltage of the rectifier VSC. (c) dc voltage of the inverter VSC. (d) frequency of the passive system. (e) VSC current. (f) the q axis component of voltage at the PCC. (g) the q axis current component of VSC. (h) reactive power transferred from the VSC inverter.

Fig. 7a clearly shows the effects of the MCLS. When the inverter VSC is under the CAVC controller, the ac voltage at the PCC does not return to its pre-fault level after the fault clearance. While with the MCLS, the PCC voltage can keep stable after the fault. As shown in Fig. 7b~c, during the fault, the delivered active power reduces, which results in the decrease of the dc voltage. There are double frequency oscillations in the dc voltage during the single-phase fault. It could be observed from Fig. 7d that during this ac fault, the frequency of the voltage at the PCC. Fig. 8 gives the IM responses of the single-phase fault. With the MCLS, the induction motor can ride through the ac fault. As shown in Fig. 7d, with the FHC, the frequency at the PCC drops lower as compared with the other controllers. This results in the reduction in the Power.

V. CONCLUSION

This paper aimed at designing control strategies to enhance the voltage stability of the passive industrial installations supplied by the VSC-HVDC. Based on the analytical result that the main factor affecting the ac voltage of the passive system is the reactive power, the control methods that consist of the modified current limit strategy and the frequency hysteresis control are proposed. By analyzing the simulation results, it can be concluded that,

1) When a metallic single-phase fault happens at the sending side of the VSC-HVDC system, the ac voltage in the passive industrial system drops inevitably. When the VSC at the receiving side is under the CAVC controller, the ac voltage does not return to its pre-fault level after the fault clearance. While with the MCLS, the voltage can keep stable after the fault clearance. The voltage stability can be enhanced further when the MCLS and FHC are added to the VSC controller simultaneously.

2) During a metallic three-phase fault, the ac voltage in the passive system cannot keep stable under the VSC controller with the MCLS. While with the FHC, a voltage collapse is avoided, which means that it is feasible to decrease the set frequency of the VSC at the receiving side to ride through severe faults? As it mentioned above, the control strategies proposed in this paper could enhance the voltage stability of the passive industrial installations effectively.

VI. REFERENCES

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