Fast Restoration Technique for Distribution Power System with Multi-Terminal DC Links

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Abstract:
A fast power restoration operational scheme and relevant stabilizing control is proposed for distribution power systems with multi-terminal DC network in replacement of the conventional normal open switches. A nine-feeder benchmark distribution power system is established with a four-terminal medium power DC system injected. The proposed power restoration scheme is based on the coordination among distributed control among relays, load switches, voltage source converters and autonomous operation of multi-terminal DC system. A DC stabilizer is proposed with virtual impedance method to damp out potential oscillation caused by constant power load terminals. The proposed system and controls are validated by frequency domain state-space model and time-domain case study with Matlab/Simulink.

1. INTRODUCTION

Background Due to the development in power electronics industry, the capacity and switching speed of Insulated-Gate Bipolar Transistors (IGBTs) have been improved. IGBTs now meet the requirements of high power industry. The switching of IGBTs is controlled by gate voltage, and does not require external circuit to turn off. This advantage makes the IGBTs a suitable choice to regulate ac and dc networks without any complicated turn-off control circuit like the thyristors. Since the dc voltage of IGBTs is controllable via proper switching on gate, and a capacitor is usually parallel connected at the dc side which makes the dc voltage stable, the converter consists of IGBTs is normally known as Voltage-Source Converters (VSC). The VSC discussed in this dissertation normally consists of six IGBTs, which form a three phase ac to dc converter. Since each IGBT has a reverse parallel diode, the current has the capability to flow back and forth between ac and dc side. Therefore, the VSC could either operate as a rectifier or an inverter without any topology change. Proper control algorithms are needed to be designed to make it possible. Renewable energies such as wind, solar and fuel cell require advanced integration technologies. Unlike traditional energy resources such as gas, coal and oil, the output of renewable energies depends on various factors including wind speed, sunlight irradiance and temperature. Hence, power generated from renewable energies is not constant and varies from time to time, which is a big challenge from a power system operator’s view. Moreover, the output of solar and fuel cell energies are normally dc power, which is not compatible with an ac power system.

2. OVERVIEW OF VSC-DC LINK

The development of distributed power generation and advance of electric vehicle (EV) are changing the configuration of the traditional power distribution system. Renewable power, such as wind and solar, are naturally dispersed and compatible for distribution side. Comparing with large renewable generation, which are normally far away from load centre, power produced by distributed generation (DG) is more likely to be consumed locally and there is no need to build up extra high voltage corridor to transmit bulk intermittent power to the load centre. However, mismatch between loads and generations is almost inevitable especially when a distribution substation is feeding both household and industrial load feeders at the same time as both load profiles fairly diverse. Serious mismatch at ‘last mile’ ends of a distribution power system can possibly give rise to severe voltage variations. In some cases, possible overvoltage can reduce their nominal life spans or even damage power equipment, which can be caused by distributed generation power that significantly overweighs local load at the far end from the distribution substation. Such problem is difficult to solve with traditional passive distribution power system. Reactive power control based voltage regulation might play a part to help but with limited performance in a more resistive distribution network. A pre-set renewable generation curtailment scheme may help, however, at a cost of certain amount of renewable energy loss. The potential rising demand from the EV battery charging is also a serious challenge to the conventional distribution network as the charging load can potentially be much larger than traditional household and commercial appliances. With varying charging demand from EV, overloading and consequent contaminated voltage profiles could be the major problems for traditional distribution systems. One possible solution to this problem is to build up centralized charging stations with a predefined energy management scheme and integrate them into the existing power system in a more grid-friendly way. To charge an EV battery array with local renewable generation would be an ideal scenario. To reduce the distribution loss and enhance power supply reliability, the concept of active distribution power system is proposed with load switch spread among certain feeders. Such reconfigurable distribution power system is able to actively redistribute power flow by switching the ties between the feeders, hence the possibility of power flow optimization in terms of distribution losses and voltage profiles. A great variety of smart management methods have been proposed for optimized power flow management based on hard switches. However, the employment of hard tie switches forces the voltages across different feeders to match each other, leading to inflexible power flow control since the real-time power flow is passively determined by the impedance distribution of a certain system configuration.
pattern and the total number of patterns for a certain system is limited. Though radial topology is most commonly used in distribution network for its simplicity feature, ring topology are also widely implemented, with normal open switch (NOS) as loop breaking point, to ensure power supply restoration after a fault. However, the power restoration based on the switching involves NOS control can take minutes to complete. Although the closing of NOS can easily increase system load availability with diverting power dispatching route, it would create a close-loop or even meshed distribution network with reduced fault impedances hence significantly increase fault currents. This could undermine the existing protection and relay system, which is unacceptable so far. To cope with the challenges bought by higher distributed generation (DG) and electric vehicle (EV) penetration to distribution power system, multi-terminal DC networks are proposed in distribution power system level, which is able to enhance voltage profile and load availability, and facilitate more flexible and faster power flow control over emerging distributed generations and charging loads without significant contribution to fault current. A four-terminal DC network is proposed and inserted into a benchmark distribution power system to replace the conventional NOS. An AC–DC coordinating scheme is proposed for power supply restoration to minimize the outage time after a fault on AC feeder. To further take the advantage of the DC link, distributed generation (DG) and charging station are also integrated within the DC network for cost and conversion efficiency concern. One side effect brought about by the multiple-terminal DC network is the dynamics and stability issue. This is due to the fact that, in a multiple-terminal DC system, the terminal impedances of slack terminals are normally well designed and damped while the constant power terminals are not. The terminal impedances of constant power terminal mainly depend on their own static operational (power) point regardless of system stability, which can be undesirable to system dynamics and stability. When all the DC terminals are closely located, which means the line impedances are limited, the undesirable impedances can be possibly accommodated by the slack terminals. However, when there are considerable distribution distances, the slack terminals may not be able to accommodate them from the far ends. As a result, measures have to be taken at the power terminal side. A stabilizing method is also proposed to improve system dynamics from the power terminal side by modifying the large constant power terminal impedances.

It can be directly implemented on accessible terminals by super-imposition over its conventional control; for those inaccessible DC terminals, charging station for instance, a storage-based DC physical stabilizer is proposed to implement the proposed control at the corresponding power terminal. This paper is organized as follows. Overview of VSC-DC Links introduction in section 2 and the system modeling is introduced in section 3. Simulation result in section 4. Case study is then performed in section 5 and finally the conclusion is drawn in section 6.

3. SYSTEM MODELING

To investigate the proposed power distribution system, an original dynamic benchmark system is established, which is shown in fig 3.1 as is shown, the distribution system is based on a single ring topology with an NOS between feeders 8 and 10. Nine feeders are spreading all over the downstream side of the two distribution transformers rated at 200 MW each at 230 kV at the secondary side. The primary sides of the transformers are fed by the main power grid with rated voltage level at 230 kV and the strength of the grid is defined with a short circuit ratio of 10. Loads and DGs are connected to each feeder. Centralized passive load and DG are considered attached to each feeder. Closed-loop current controls are implemented within the DGs, which assumes that all the DGs are well capable to go through AC faults.

Figure 3.1- MATLAB Simulation for VSC DC Link

From figure 3.1, is voltage source converter with DC link. Two voltage source converter (VSCs) are connected to feeders 8 and 10, respectively. A DC charging station and a centralized DC side DG are connected to VSC side via two
DC lines. Both DC charging station and DG has a power rating of 200 MW. Both charging station and DG terminals are also with well-implemented closed loop current control. Figure 3.1 by replacing the NOS with multi-terminal DC Link. An distribution power system with flexible DC link is configured. Two voltage source converters, are connected to feeder 8 and 10, respectively. A DC charging station and a centralized DC side DG are connected to VSC side via two DC line. Both charging station and DG has a power rating of 200 MW. Nine feeders are spreading all over the downstream side of the two power transformers rated at 200 MW each at 230 KV at the secondary side. A DC Charging Station is able to manage its own storage energy and provide temporary power support to the distribution power system. The charging station operates as constant power mode with its current loop control modeled. To deal with the possible instability caused by the undesirable impedance introduced by constant power, a DC stabilizer is proposed at the constant power terminal to neutralize the total equivalent terminal impedance at the constant power terminal side.

4. SIMULATION RESULTS

Figure 4.1 shows a waveform of dc voltage we can seen that a voltage compensation for 1 sec to 1.5 sec time duration.

Figure 4.2 shows that a AC and DC current and Voltage restoration within a 3 sec. T=0, the amplitude of that time ( p.u) VSC start the power DC bus at a ramp rate of 1.8 mw/s and to balance the DC system power. T=0.5 sec, to set the amplitude is 0.8 p.u in this time the voltage and current will be decreased the power also decreased. VSC decrease the import power from feeder at a ramp rate of 1.8 mw/s until it reaches 1.5 mw/s. The AC voltage step (-0.1 pu) is applied at t= 1.5 s during 0.14 s (7 cycles) at station 1. The result show that the active and reactive power deviation from the pre-disturbance is less than 0.09 pu and 0.2 pu respectively. The recovery time is less than 0.3 s and the steady state is reached before next perturbation initiation. The fault is applied at t=3.1 s during 0.12 s (6 cycles) at station 2. For figure 4.3, Station 2 converter controlling DC voltage is first deblocked at t= 0.1 s. then, station 1 controlling active power converter is deblocked at t= 0.3s and power is ramped up slowly to 1 pu. Steady state is reached at approximately t= 1.3 s with DC voltage and power at 1.0 pu (230 KV, 200 MW). Both converters control the reactive power flow to a null value in station 1 and to 20 Mvar (-0.1 pu) into station 2 system. After steady state has been reached, a -0.1 pu step is applied to the reference active power in converter 1 (t=1.5 s) and later a -0.1 pu step is applied to the reference reactive power (t=2.0 s), in station 2, a -0.05 pu step is applied to the DC voltage reference. The dynamic response of the regulators are observed Stabilizing time is approximately 0.3 s, the control design attempts to decouple the active and reactive power responses.

5. CASE STUDY
FAST POWERSUPPLY RESTORATION

The transient overvoltage can be further well capped by dumping resistances if it is above a predefined voltage level. The terminal transient power can therefore be capped regardless of the initial power input. The transient is very short, the total energy is limited. Such amount of energy can be well absorbed by the line impedances and terminal capacitances with limited voltage variation on other terminal. The proposed virtual impedance based stabilizer, connecting AC feeders and charging station can stably provide flexible power dispatch. The fast power restoration after AC fault with large power redistribution over an expanded distribution area. When the upstream connection is open, the feeder supply can be restored by a VSC as long as there is a distribution path between the feeder and the VSC.

6 CONCLUSION

In this paper, it can be concluded that a fast power supply restoration control scheme and corresponding DC stabilization control is proposed for a distribution system with multi-terminal DC network is used the flexible power distribution can be achieved without significant fault current contribution as a direct AC link does.

The proposed stabilization control is able to stabilize the DC system with large constant power load type terminal and ensures a stable operation when providing power support to large AC transients. The proposed control scheme can effectively provide immediate power supply restoration after an AC fault and reconnect the islanding part back to the main grid if the fault is temporary and cleared within reclosing time set.
7. REFERENCES


