

WIDE AREA CONTROL STRATEGY FOR MULTIPLE VSC-BASED DC LINKS INTERCONNECTING DISPERSED WIND FARMS

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ABSTRACT

The paper focuses on a power management scheme in a multi-terminal DC transmission systems for integration of large-scale wind farms spread over a wide area. The proposed power management scheme addresses the reliability concerns in a multi-terminal DC transmission system in case of the most severe fault conditions, such as permanent fault in DC link and open circuit fault at the terminal of the grid-side converter. The primary objective of the proposed scheme is to avoid lost of wind farms power in case permanent faults by providing an alternative path for the power flow through a redundant path. In case of DC faults resistive fault current limiters were used to suppress the current to a reasonable level to enable disconnection of the faulty line. To validate the proposed scheme, a computer model has been built in Matlab-Simulink. Transient and permanent DC link faults are considered in order to demonstrate the effectiveness of the proposed power management scheme.

I. INTRODUCTION

The use of renewable energy resources for electricity generation is increasing worldwide and has become attractive for investors and electrical utilities. Renewable energy sources today are well accepted and considered as a cost effective alternative to satisfy the growing world demand on clean and sustainable source of energy. Wind farms are geographically dispersed over wide areas and growing in number and installed capacity. Therefore, HVDC links are emerging as a suitable option for integrating large wind farms to the grid and for power delivery to customers. On these ground, the large-scale integration of wide-area interconnected wind farms may become a challenge in the near future [1]. It should also be mentioned that technological advancements such as IGBT-based voltage source converter multilevel high voltage DC transmission systems (VSC-HVDC), new control schemes based on PWM strategies are all pushing towards the application of DC links at different voltage levels. Two multi-terminal DC transmission system configurations shown in Fig. 1, have been suggested to collect and transmit power from dispersed wind farms to the grid [2,3]. However, these multi-terminals DC links in Fig. 1, have no redundancy [4]; for example, a permanent open circuit at the terminal of the grid-side converter or occurrence of a permanent DC fault in one of the DC links in Fig 1.a, will lead to lost of one wind farm. Whilst similar faults in the DC link configuration

shown in Fig. 1b, will result in lost of both wind farms as shown in Fig. 1c and 1d. Due to reliability concerns associated with these two topologies, an improved multi-terminal DC link configuration with power management capability is proposed in order to address the security of the supply issues.

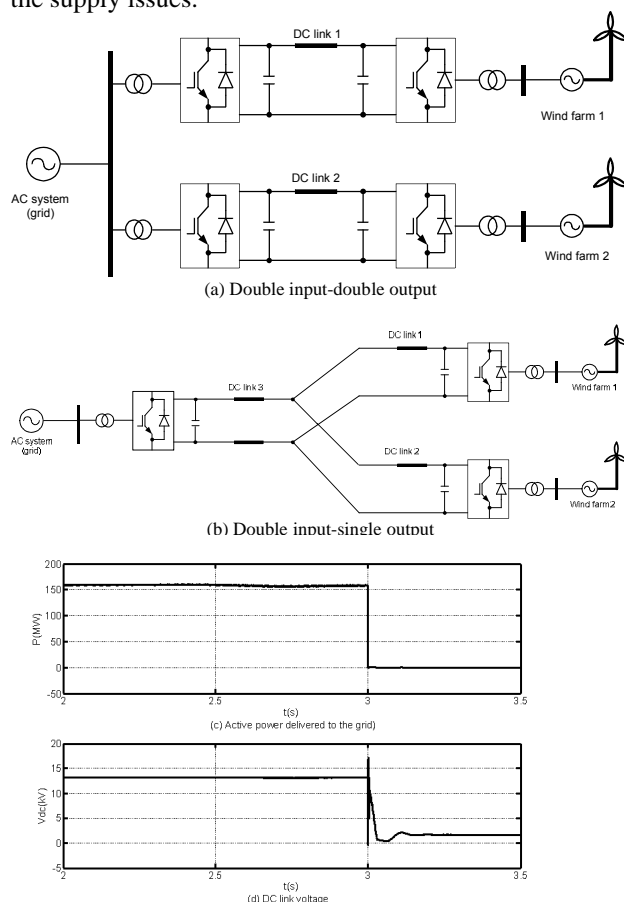


Fig. 1: Multi-terminal DC Link configurations for integration of large wind farms spread over wide area.

II. POWER MANAGEMENT SCHEME IN DC SYSTEMS

There are several advantages of using DC voltage transmission to transfer large amounts of power over wide areas. Some of these advantages are:

- Absence of charging currents and reactive power component in DC systems, enable transmission of power over long distances with minimum losses, mainly copper lose.
- The amounts and directions of power flow in the

system can be controlled, which are unlikely in AC systems.

- The converter stations can be used as static synchronous compensators to regulate voltages in the AC sides.
- It improves system stability significantly due to the decoupling of the AC systems, in other words, fault in one AC system will not affect the rest of the system.

However, DC transmission systems are sensitive to small changes in voltage and vulnerable to DC faults. A fault in one of the DC links may prevent exchange between the AC systems, which may result in system collapse. The proper use of multi-terminal DC transmission systems requires fast protection systems and better power management schemes to be in place in case of contingencies. To address this concern, a power management scheme for multi-terminal DC system is proposed. This scheme aims to sustain the power exchange between the AC systems and reduce the risk of system collapse in case of contingencies. For transient faults in one of the DC links, resistive fault current limiters will be used to increase the effective resistance between the point of fault and the nearest converter station in order to suppress the fault current to reasonable levels that can be handled by converter stations and dc cable or lines. In case of a permanent DC fault in one of the links, the fault current limiters will be used to suppress the current in the faulty link to enable disconnection of the line and the power flow must be redirected through an alternative path. Redirection of power flow to an alternative path may require some converter operating mode to be changed but not necessary all the time.

In case of permanent open circuit faults at the terminals of one of the grid-side converters, that converter must be disconnected and the power generated by the wind farms must be delivered to the grid through the healthy converter. This is possible only, if the total power generated by the wind farms is less than the rating of one converter otherwise some of the power must be spilled out by switching in a resistance at wind farm side. This scenario will not be considered in this paper despite of its importance.

III. CASE STUDY

Fig. 2 shows a DC transmission system with four VSCs (VSC-HVDC). Each station employed three-level neutral point clamped (NPC) converter controlled by using sinusoidal pulse width modulation (SPWM) with a switching frequency of 1.35 kHz. A capacitor voltage balancing method based on DC offset is employed to maintain DC link voltage balanced. Each converter station in Fig. 2 is equipped with DC link voltage controller and active power controller; as a result the operating mode of each station can be switched from DC voltage control to active power control and vice versa accordingly to the system configuration following the

fault clearance. To simplify the model in order to speed up simulation, the wind farms are represented by a voltage source. The wind farms 1 and 2 are set to inject 100 MW each to the system through converter stations 1 and 3. The converters 1 and 3 are operated in active power mode, while converters 2 and 4 in DC voltage control mode in order maintain the DC link of both converters at 200 kV to guarantee zero power flow in auxiliary links in steady state. A DC link fault with duration of three cycles or less is considered as transient fault. When the duration of the DC link fault is more than three cycles the fault is treated as permanent fault, then power must be redirected to a healthy link through auxiliary link 1 to prevent losing power generated by one of the wind farms. Prior to active power redirection, fault current limiters must be used to suppress the fault current in the faulty link to a reasonable level to enable disconnection of the link. In this case, the power delivered to the grid through converters 2 and 4 will be shared equally by default. If the power delivered to the grid needs to be split between converters 2 and 4 based on a specific ratio, the operating mode of converters 1 and 3 must switched to DC voltage control while converters 2 and 4 must be switched to active power control mode; or a DC voltage droop as proposed in [5] can be used to distribute the power between converters 2 and 4.

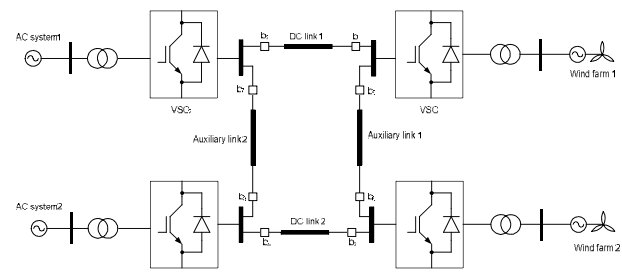


Fig. 2: Topology 1B.- DC Link-wind farm Topology 1 improved with redundancy

IV. SIMULATION RESULTS

In order to demonstrate the effectiveness of the proposed scheme in improving system reliability, the system in Fig. 2 is considered under temporary and permanent DC link faults. The fault current limiters b1 through b6 are modelled by discrete switched resistances rather than nonlinear with maximum resistance of 10 k Ω . Converters VSC₁ through VSC₄ are rated at 200 kV DC and 200 MVA, and located 75 km apart. In temporary DC fault scenario, the system is subjected to solid pole-to-pole fault at the middle of DC link 2 for a period of three cycles (60 ms for 50 Hz). The results obtained from this scenario are presented in Fig. 3.

Fig. 3 show the power flow, DC link voltage and current injected into AC system 1. It can be seen that in steady state the power generated by wind farms 1 and 2 are delivered directly to the AC systems 1 and 2 through DC link 1 and 2 respectively; the auxiliary links do not carry

any power, that means the four terminal system in Fig. 2 are behaving like two independent DC links. The results in Fig. 3f and 3g show that the power flow in the DC link 2 and auxiliary links 1 and 2 is zero during the fault period, due to the suppression of currents in these DC links by fault current limiters. The sharp rises shown in power waveforms demonstrate the sensitivity of the DC system to voltage change and are partly caused by the simplified discrete model of the fault current limiters.

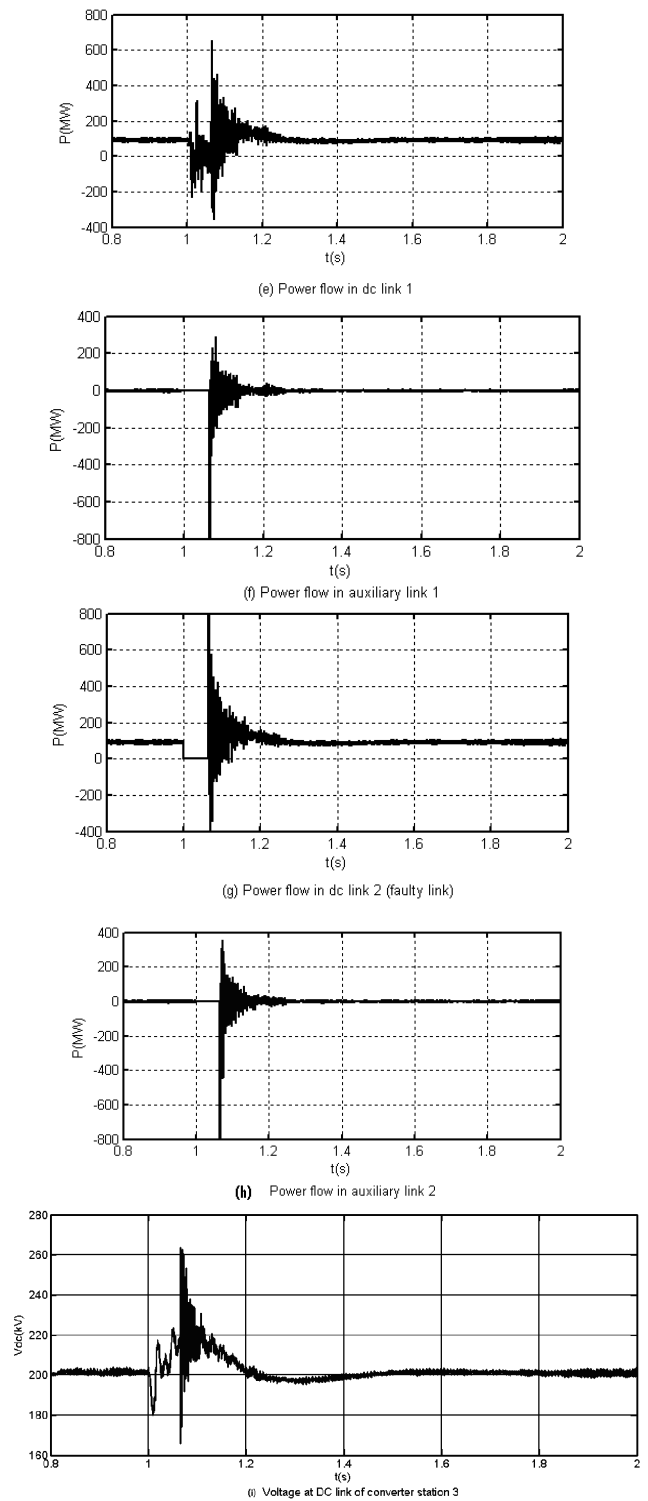
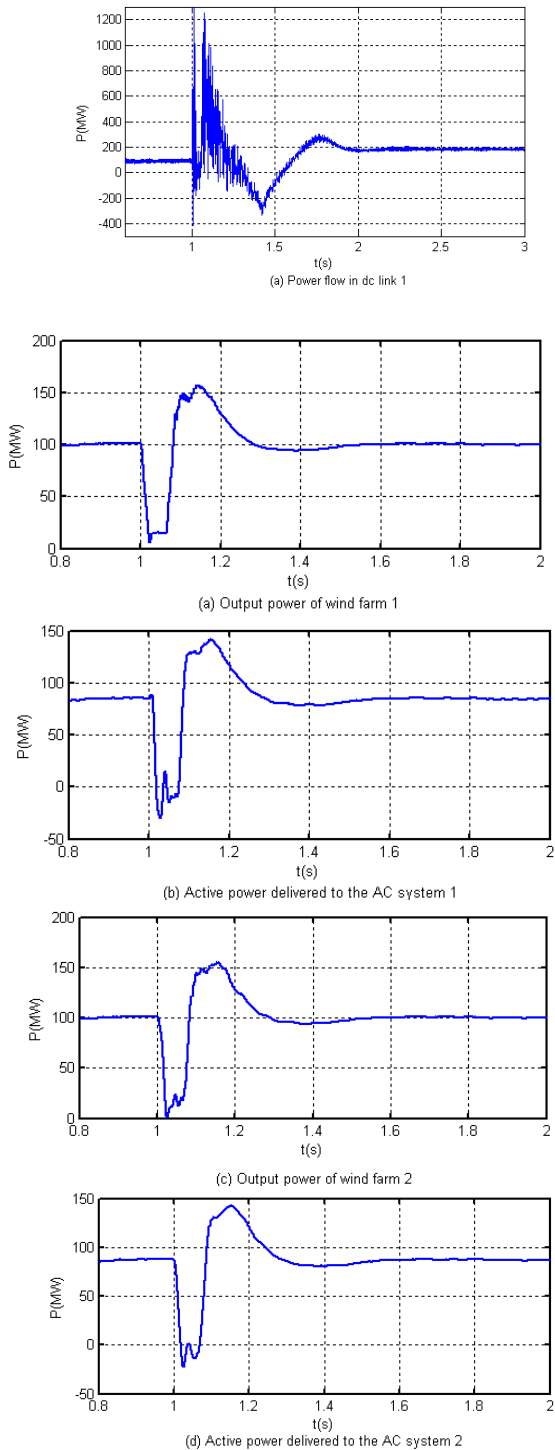


Fig. 3: Power and voltage waveforms when the system is subjected to temporary dc fault at the middle of DC link 2 and the cleared after three cycles.

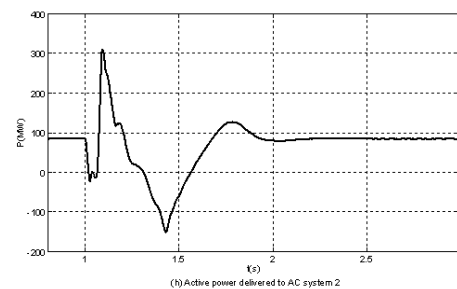
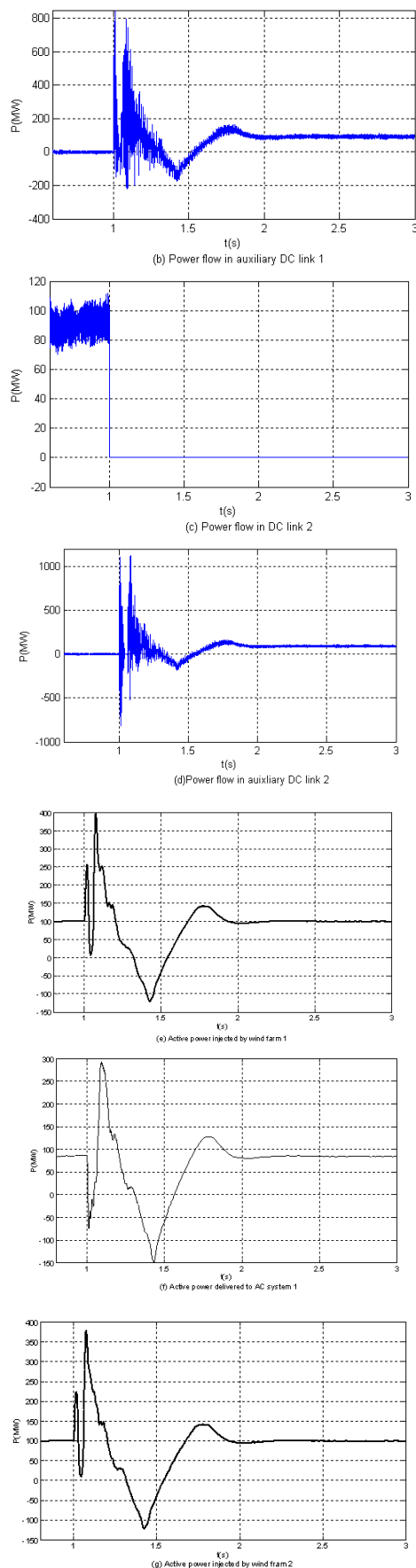


Fig. 4: Power waveforms when the proposed power management scheme is implemented to redirect the power flow when a permanent pole-to-pole fault is occurred at the middle of the dc link 2

Fig. 4 shows mainly the power flow when the system in Fig. 2 is subjected to a permanent DC fault at the middle of DC link 2. It can be noticed that, initially the power flow was through DC link 1 and 2; then the power generated by the wind farm is diverted to DC link 1 through auxiliary link 1 and again to converter station 4 through second auxiliary link 2.

V. CONCLUSIONS

The paper presents a power management scheme which addresses the reliability concern of multi-terminal DC systems. The proposed scheme is demonstrated in a four terminal DC system shown in Fig. 2, its benefits are:

- Improved system stability and reliability.
- The lost power due permanent DC or AC faults is minimal and in some cases it can be avoided.
- It improves fault ride through capability of the wind farms against open circuit at the terminals of the grid side converter, which is unlikely with single HVDC.

VI. REFERENCES

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