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A protection scheme for MMC-MVDC Grid based on the characteristics of voltage traveling waves

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***Abstract*—Fast and reliable protection scheme is the key to ensure the safe operation of flexible DC grid. A longitudinal backup protection method based on the characteristics of traveling wave is proposed. The arrival simultaneity of forward and backward traveling waves under forward and backward DC faults, and the characteristics of the traveling waves are analyzed. The direction criterion is formed by using the characteristic that the backward traveling wave and the front traveling wave arrive at the same time. If the judgment results of the protection at both ends are forward faults, it can be determined as an internal fault. The protection at both ends only needs to transmit direction signal to form the longitudinal protection. Simulation results show that the protection scheme can accurately distinguish internal and external faults, and has a good performance to overcome transition resistance.**

I. INTRODUCTION

With the widespread penetration of distributed new energy such as wind power and photoelectric and various DC loads, traditional AC systems cannot meet the needs of future energy structure. Flexible DC system based on MMC has the advantages of flexible control, large power supply radius, high power quality, narrow line corridor, etc., which make it become the development trend of future power grid, and also one of the hot topics studied by scholars in recent years. However, when a fault occurs in DC system, the fault current rises rapidly, which poses a great threat to the power electronic devices. Therefore, DC fault detection and isolation is of great significance to ensure the reliability and stability of the whole system.

This paper analyzes the fault characteristics of MMC-MVDC system, and the waveform characteristics of forward and backward traveling waves under the situations of forward faults. The criterion based on the amplitude of the backward voltage traveling wave and change rate of the forward voltage traveling waves is proposed. The simulation results show that the protection scheme is feasible and has a good ability to withstand fault resistance.

II. CHARACTERISTICS OF FAULT TRAVELING WAVES

In this paper, a four-terminal flexible DC system as shown in Fig. 1 is selected as the research object. In order to limit the fault current, current-limiting reactors are installed at both ends of the line, which form the boundary of the protection area. The measuring device and the protective device are installed inside the boundary reactor. This paper takes line1 as an example for analysis.

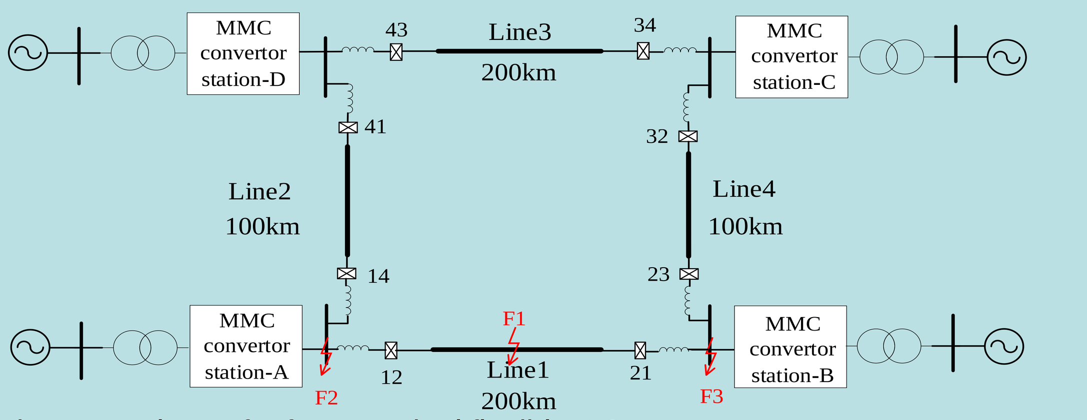
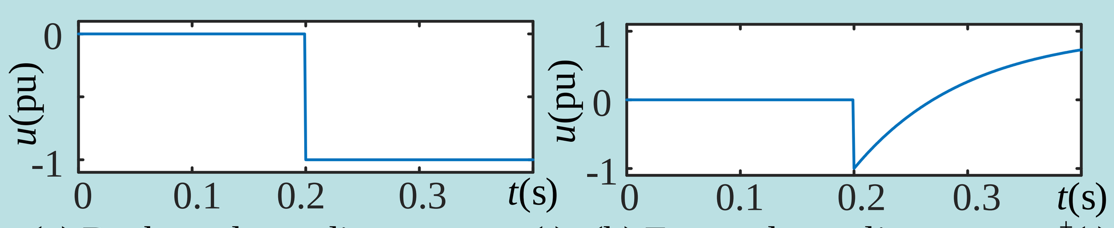


Fig.1. Topology of a four-terminal flexible DC system.

After analysis, when the fault traveling wave arrives at the detection device, the fault backward traveling wave is a negative step signal, and the forward traveling wave rises immediately after the sudden drop. This feature can be directly used as a protection criterion.



(a) Backward traveling wave $u_2^-(t)$ (b) Forward traveling wave $u_2^+(t)$

Fig.2. Schematic diagram of forward fault traveling wave.

III. PROTECTION SCHEME

a) Signal Acquisition and Mode Conversion.

The protective device monitors the voltage and current of the system in real time, and calculate the mode component. Then extract the fault component. The calculation method of fault component is

$$\begin{cases} \Delta u_1 = u_{1sample} - u_{1load} \\ \Delta i_1 = i_{1sample} - i_{1load} \end{cases}$$

where Δu_1 and Δi_1 is the fault component of voltage and current, $u_{1sample}$ and $i_{1sample}$ are the line mode component of the voltage and current sampling value, u_{1load} and i_{1load} are the line mode component of the voltage and current load value.

b) Pick up and Timing

Judge whether the line-mode voltage exceeds the starting threshold, if

$$\Delta u_1 < u_{1SET}$$

where u_{1SET} is the threshold, the protection is picked up.

c) Internal-external Discrimination

Judge whether the local end meets the protection criterion within a specified time t_{SET}, and send the logical signal of the result to the contralateral protection, and receive the signal sent by the contralateral protective device. t_{SET} is a time setting value. First, calculate the forward and inverse traveling waves

$$\begin{cases} u_{1f} = \Delta u_1 + Z_{C1}\Delta i_1 \\ u_{1b} = \Delta u_1 - Z_{C1}\Delta i_1 \end{cases}$$

Then calculate the derivative of forward traveling wave

$$du_{1f} = \left(u_{1f}(n) - u_{1f}(n-1)\right) \times f_s$$

If the values satisfy the inequalities

$$du_{1f} > D_{SET}$$

$$u_{1b} < u_{backSET}$$

for three consecutive sampling time, it is judged as a forward fault, and sent the logical signal of RES_SEND=1 to the opposite side protective device, otherwise the logical signal RES_SEND=0. If the criterion does not satisfy within a specified period of time t_{SET}, the protective device will return.

Judge whether the protection actions or not. If the logical signal R satisfies

$$R = RES\_SEND \cap RES\_RECV = 1$$

the protection action.

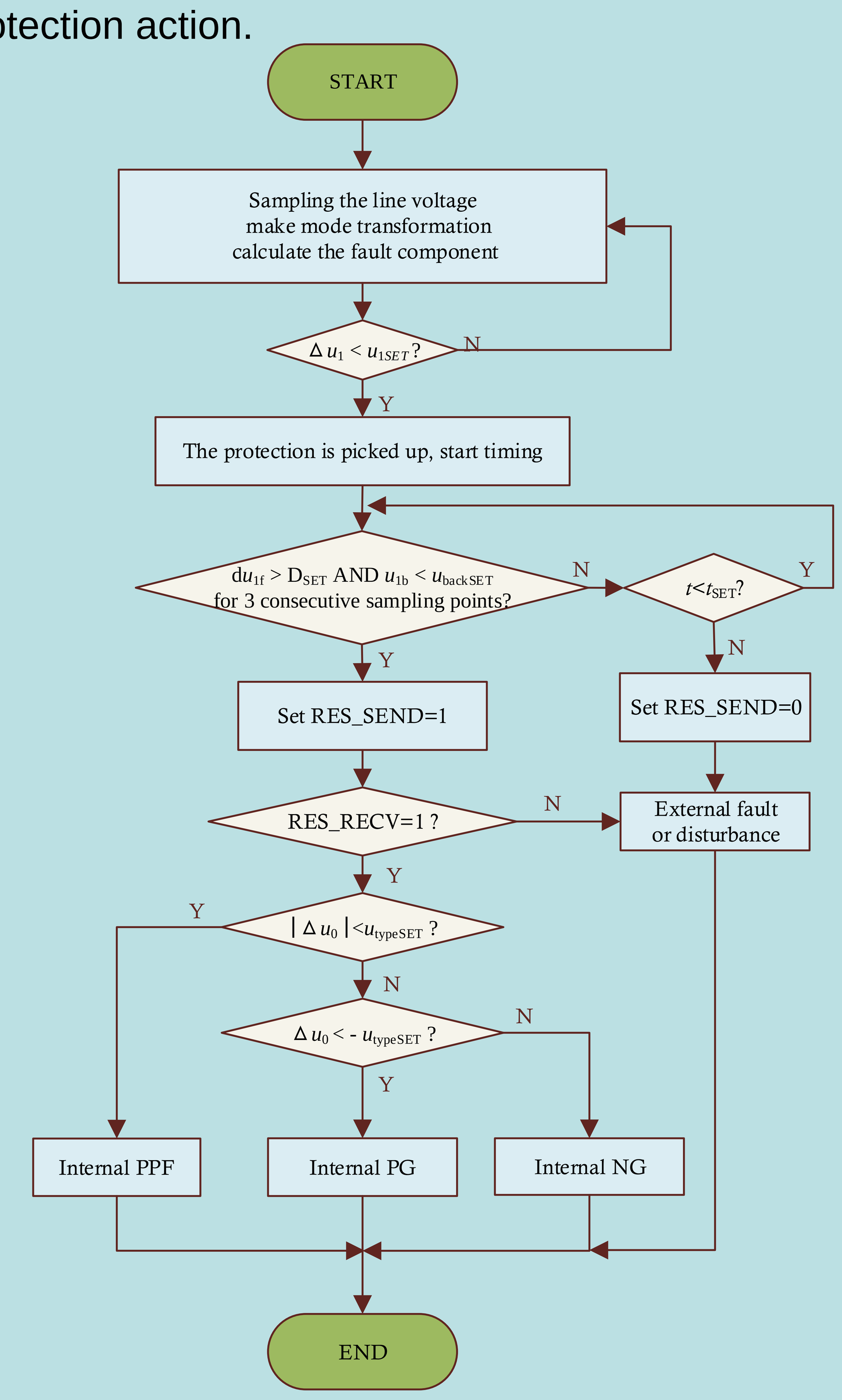


Fig.4. Flow chart of the protection scheme..

IV. CASE STUDY

A four-terminal MVDC network is built as shown in Fig. 1. The rated voltage is ±200kV. Line 1 and line 3 are 200km in length, and line 2 and line 4 are 100km. The boundary reactor is 100mH. The sampling frequency is 100kHz.

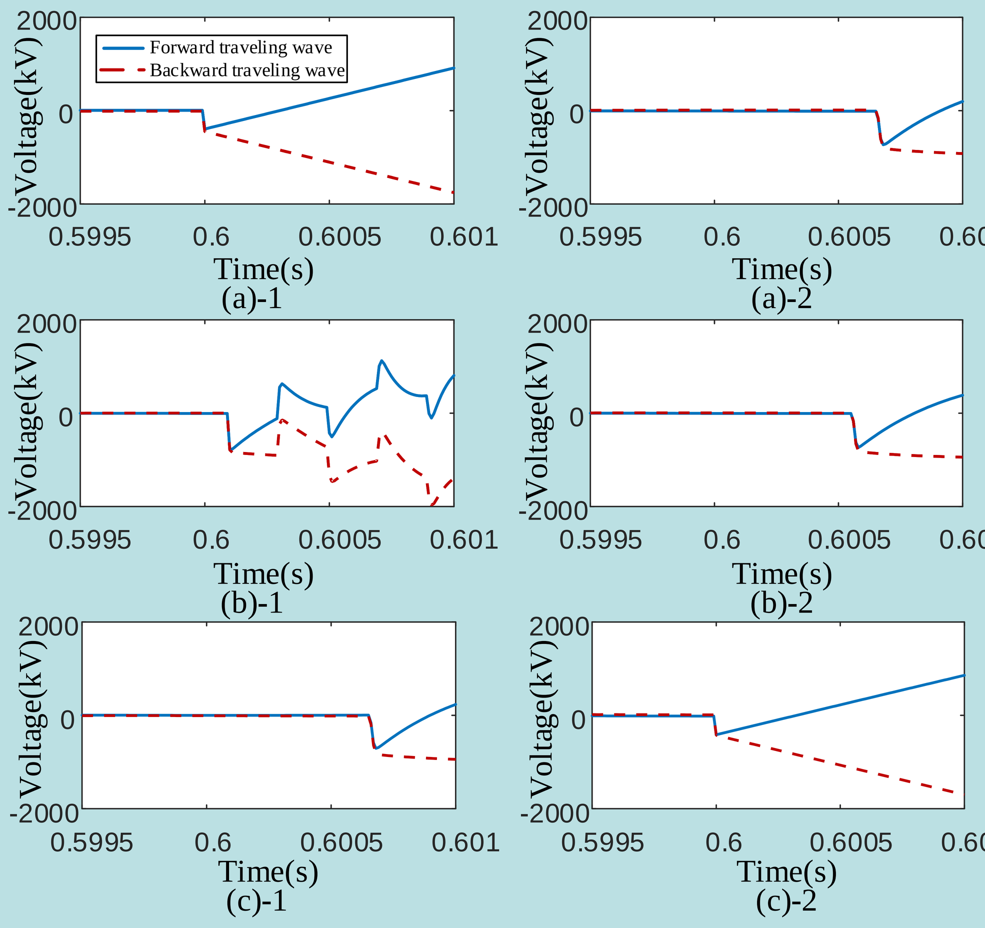


Fig.4. Forward and backward traveling waves under PP faults occur at F1, (a)PPF at 0km, (b) PPF at 30km, (c) PPF at 200km , "-1" represent the relay12 while "-2" represent the relay21

F1, F2 and F3 are simulated and verified as shown in Fig. 4 and Fig. 5. Among them, F1 selects three fault cases: 0km, 30km, and 200km from the converter station A. The faults occur at 0.6s, and the data of 1 ms after the fault is selected for analysis, which contains a lot of transient information.

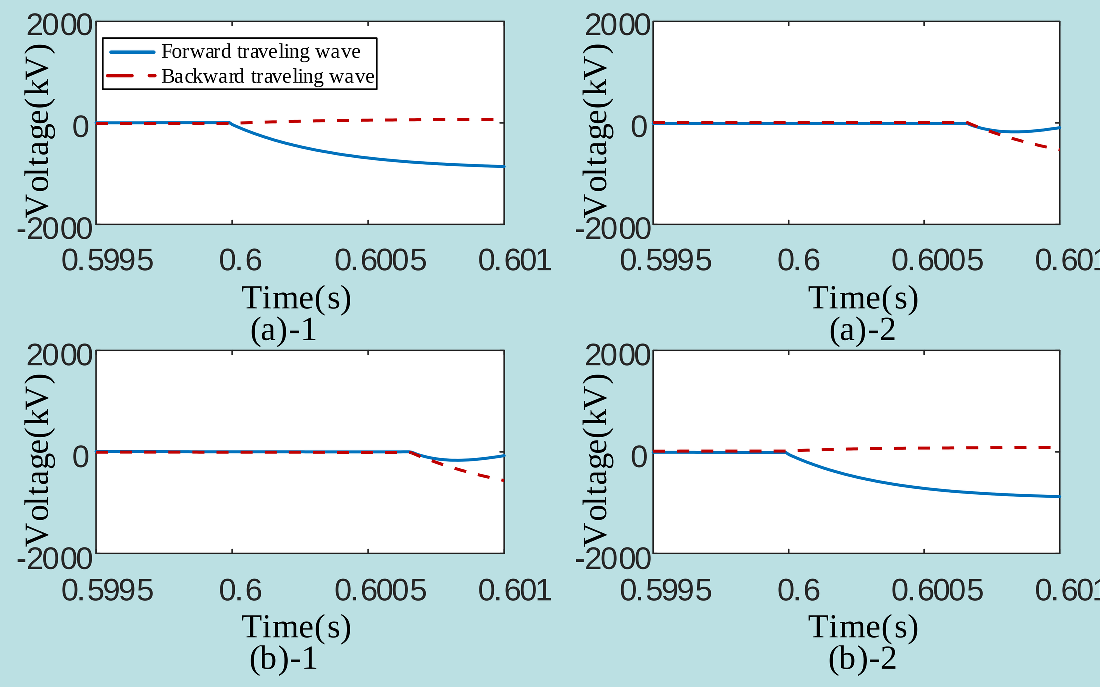


Fig.5. Forward and backward traveling waves under external PP faults, (a)PPF at F2, (b) PPF at F3, "-1" represent the relay12 while "-2" represent the relay21

The PG fault simulation tests are carried out for the above fault points. The graphs of traveling waves for internal faults and external faults are shown in Fig. 6 and Fig. 7. The waveform diagram under internal fault only shows the fault situation at 0km and 30km. It is easy to find that the waveform characteristics are very similar to it under PP fault, but the amplitude is smaller. In the case of NG fault, the characteristic of the traveling wave is similar to that of positive ground fault, and the amplitude and rate of change are also similar.

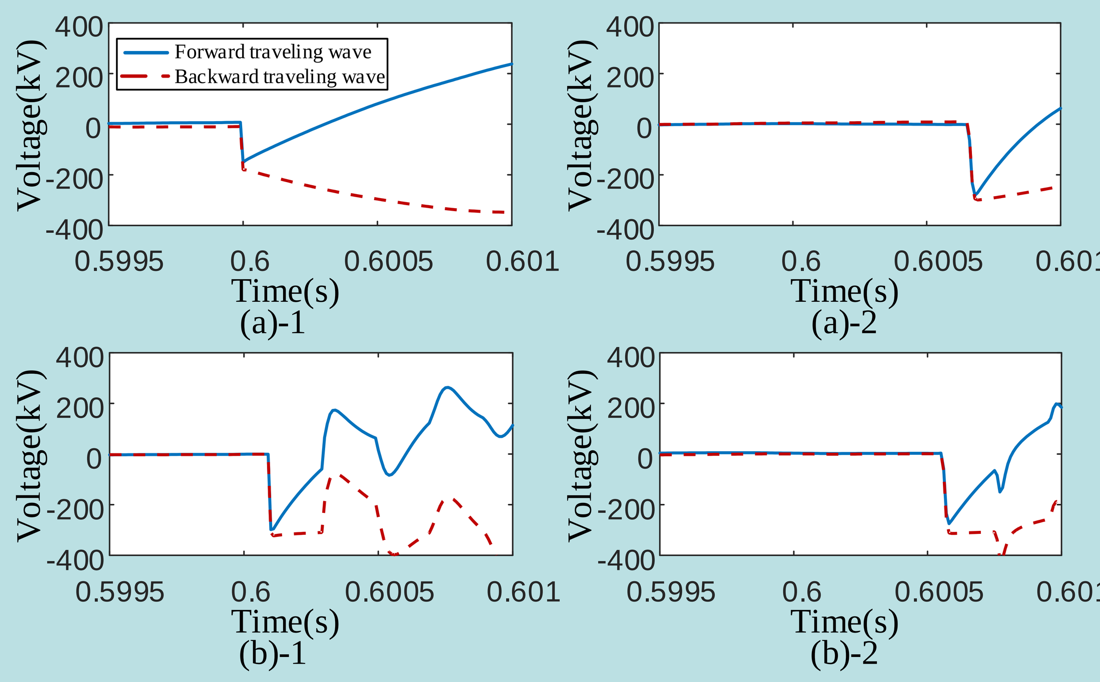


Fig.6. Forward and backward traveling waves under PG faults occur at F1, (a)PPF at 0km, (b) PPF at 30km, "-1" represent the relay12 while "-2" represent the relay21

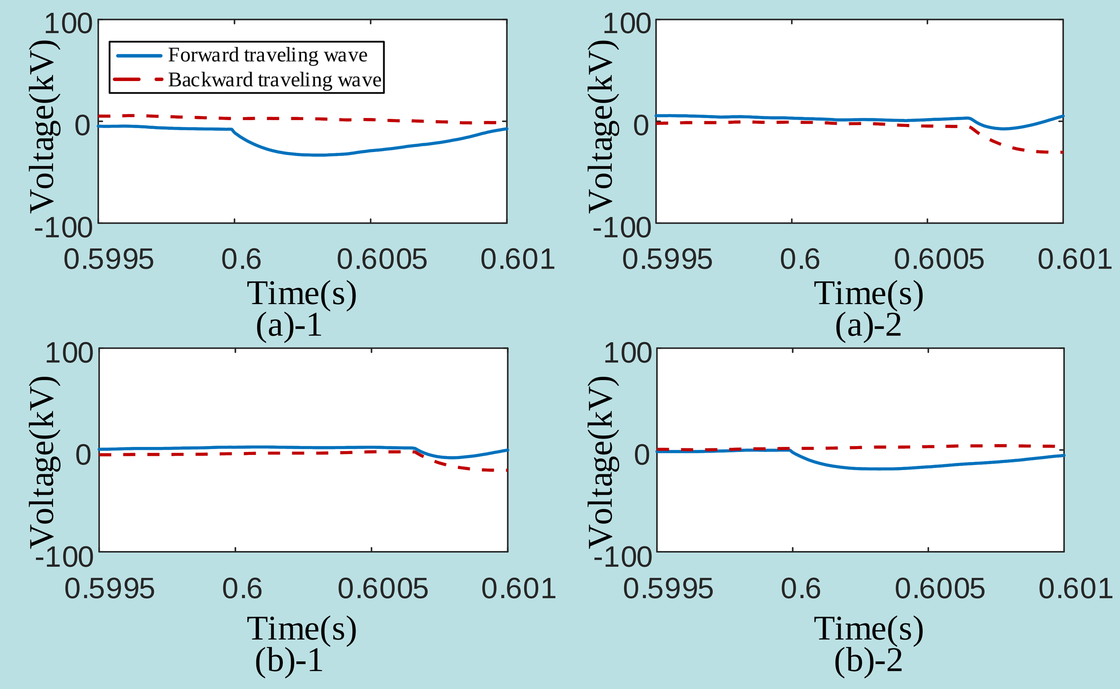


Fig.7. Forward and backward traveling waves under external PG faults, (a)PPF at F2, (b) PPF at F3, "-1" represent the relay12 while "-2" represent the relay21

V. CONCLUSION

This paper presents a backup protection method based on the characteristics of line-mode fault traveling wave. Based on the characteristics of the forward and backward traveling waves arriving at the same time and the forward wave immediately increases after plunging, the protection criterion is formed by using the derivative of the forward wave and the amplitude of the backward wave. A large number of simulation tests have proved the feasibility of the protection scheme. The proposed protection scheme has the following advantages:

1) The protective device only relies on local information when making judgment. Only logical signals need to be transmitted instead of a large amount of electrical information, which make the protection has little reliance on communication.

2) There is no requirement for high sampling frequency. The protection has a good performance when the sampling frequency is only 100kHz.

3) The protection principle has a certain universality, and can be applied to DC lines without boundary current limiting reactor.

4) Good sensitivity and selectivity. It can withstand a transition resistance of 300 Ω or less for a pole-to-ground fault.