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Busbar Protection Technique by using Traveling-Wave-Based Amplitude Integral

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Abstract: Now a day various substation busbars are used to connect a variety of elements, such as transformers as well as transmission lines and loads in the power system. In this paper presents an effective high-speed busbar protection technique according to the propagation theory of traveling wave. If the fault occurs on the busbar, then the detected initial traveling waves on all connected lines will come from their back and this process is defined as positive direction traveling waves. While a fault occurs on any one of these lines the healthy lines are called as positive direction traveling waves and faulted lines are called as negative traveling waves. In this paper presents an effective method for finding the fault direction. The fault direction can be established according to the amplitude integral relationships between the positive direction traveling wave and the negative direction traveling wave and for this purpose busbar protection scheme can be constructed. Simulation results show that the proposed method can rapidly and reliably discriminate the internal faults from external faults, and the protection performances are immune to fault resistances, fault inception angles, fault types, and current-transformer saturation. The software which is used to design this proposed system is Matlab for training the proposed busbar system.

Keywords: Busbar Protection, Traveling Wave, Amplitude Integral, Extra High Speed, Fault, Current-Transformer (CT).

I. INTRODUCTION

The most important elements in the entire power system are transformers, transmission lines and load. To connect these different elements substation busbar is required. When a fault occurs on a busbar, the busbar protection equipment should quickly disconnect all of the elements connected to this busbar. Once the corresponding protection device is active, it unavoidably leads to considerable losses of service and threatens the safety of other equipment, even results in a severe system disturbance. Therefore, it is very important to design an excellent protection scheme and select a fast protection algorithm in order to maintain the high reliability and fast operation speed of busbar protection.

The busbar protection method uses two types principles for which are based on power frequency components and transient components, respectively. Presently, the simple current differential scheme is widely used, but this scheme is likely to maloperate due to current-transformer (CT) error, ratio mismatch, or saturation of one of the CTs in the case of an external fault. Though those impacts can be countered by using a percentage-biased differential scheme, it reduces the sensitivity of the relay. To eliminate the impacts of transient components, the power frequency-based protections usually filter the high–frequency components.

However, the filter technique certainly postpones the signals process, further affecting trip speed.
In practice, fault-generated transient components contain a great deal of fault information, such as fault types, fault time, and fault direction, etc. If these fault characteristics can be precisely extracted, extra high–speed protection will be achieved [1]-[8].

The identification of the fault is done before the saturation of CT, therefore the high-frequency-components-based protection has already made. Therefore, the saturation of the CT does not produce a negative effect on the performance of such protection. Simulation results demonstrated that the proposed protection principle is immune to fault position, fault resistance, and fault type, etc. The software which is used to design this proposed system is Matlab for training the proposed busbar system.
In this paper presents an effective method for traveling-wave-based amplitude integral busbar protection technique. The main idea can be described as follows. When a fault occurs on a busbar, the direction of detected initial traveling waves on all lines connected to this busbar is positive. Assuming a fault occurs on one of these lines, the direction of detected initial traveling wave on healthy lines is positive, but that on the faulted line is negative. During a very short period of postfault, a busbar fault or line fault can be fast identified according to the amplitude integral relationships between positive traveling wave and negative traveling wave. To testify the feasibility and validity of the presented method, a typical substation model is established and simulated.

Organization of this paper is in the following way. Section II reviews the development of system; the different proposed methods used in this paper are presented in this section. In section III the experimental performance results are presented. And finally section IV concludes this paper.

II. DEVELOPMENT OF SYSTEM

This section reports the development of the proposed method this algorithm has been tested on training data set.

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There are seven data sets are used in this paper for testing the different signals.

A. The Fault-Generated Traveling Wave

A figure 1 shows the simple busbar configuration which is used to study this fault generated travelling wave. In which the lines are connected to busbar B, and R1 denotes the relay of line.

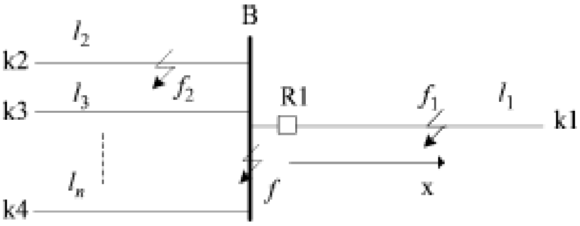

Fig. 1 Example of a simple busbar configuration in a substation

In this figure 1, when a fault occurs at on the line, the traveling waves generated by this fault will propagate to both ends from the fault point along this line. The reflection and refraction of traveling waves will appear at these points, where wave impedances are discontinuous, such as fault point and busbar. According to the telegraph equations, if R1 is assumed as the zero reference point, for any position, the transient voltage and current are as follows:

$$\Delta u = u^{+}\left(t-\frac{x}{v}\right)+u^{-}\left(t+\frac{x}{v}\right)$$
$$\Delta i = \frac{1}{z_c}\left[u^{+}\left(t-\frac{x}{v}\right)-u^{-}\left(t+\frac{x}{v}\right)\right] \quad (1)$$

where $v = 1/\sqrt{LC}$ and $z_c = \sqrt{L/C}$ represent the propagation velocity of the traveling wave and wave impedance of the line, respectively; L and C are the inductance and capacitance per unit length of the line; u+ and u- are the forward traveling wave along the positive direction and backward traveling wave along the negative direction of the line, respectively.

Equations (1), which represent the transient voltage and current at any position along this line, are the superposition of forward traveling wave and backward traveling wave. The forward wave and backward wave can be obtained by solving (2).

$$u^{+} = \frac{(\Delta u + z_c \Delta i)}{2}$$
$$u^{-} = \frac{(\Delta u - z_c \Delta i)}{2}. \quad (2)$$

B. Extraction of direction of Traveling Wave

Consider is a single-phase power system and the positive direction of the traveling wave is from the busbar to the line. For the line l_1, the direction of fault at f_1 is positive. The figure 2 shows the traveling-wave propagation lattice diagram for a forward fault.

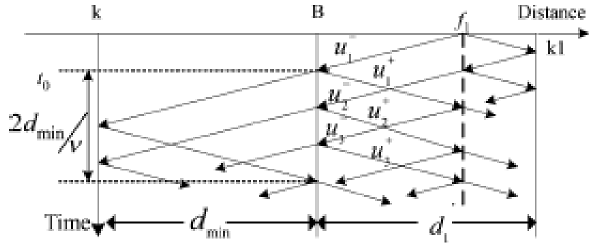

Fig. 2 Traveling-wave propagation lattice diagram for a forward fault

Assume t_o is the moment that the initial traveling wave arrives at busbar B, it can be seen from Fig. 2 that two types of transient traveling-wave signals at terminal B of I_1 appear. One is the positive direction traveling waves and another is the negative direction traveling waves. And this is given by equation (3).

$$u^{-} = u_1^{-} + u_2^{-} + u_3^{-} + \cdots$$
$$u^{+} = u_1^{+} + u_2^{+} + u_3^{+} + \cdots = k_f u^{-} \quad (3)$$

Figure 3 shows the traveling-wave propagation lattice diagram when a fault occurs at f_2 on the line l_2.

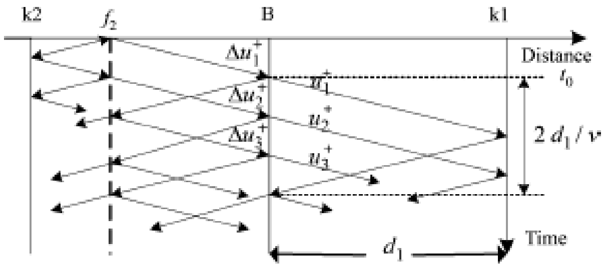

Fig. 3 Traveling-wave propagation lattice diagram for a backward fault

C. Busbar Protection Criterion

According to the aforementioned analysis, wherever a fault occurs on the busbar or line, within a specific time of postfault, the following conclusions can be drawn.

1) When a line has a forward fault, the positive direction traveling waves at one terminal of this line are equal to the negative direction traveling waves multiplied by the reflection coefficient. But if there is a backward fault to this line, the positive direction traveling waves are equal to the refraction waves of incidence waves from its back, and the negative direction traveling wave is equal to zero.

2) When a fault occurs on the busbar, the positive direction traveling waves at the terminal of each line can be observed, but the negative direction traveling wave will not appear.

3) For a positive direction fault, the amplitude of the positive direction traveling wave is less than that of the negative direction traveling wave. But for a backward fault, the amplitude of the positive direction traveling wave is much larger than that of the negative traveling wave.

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Traditional traveling-wave-based protection always has low reliability. One of the main reasons is that the transient signals are very weak when the fault inception angle is near zero. To make full use of transient traveling-wave energy, instead of using the front of initial traveling waves, the amplitudes of positive and negative traveling waves are integrated within a period of time of postfault, respectively. According to the ratio of two amplitudes, protection criterion will be established, and protection performance can be greatly improved.

For each line, defining the positive direction of the traveling wave is from the busbar to the line itself. Signals s1 and s2, which denote the sum of amplitudes of all detected positive and negative direction traveling waves, respectively, are as follows:

$$S_1 = \int_{t_0}^{t_0+\tau} u^+(t)\big| dt$$
$$S_2 = \int_{t_0}^{t_0+\tau} u^-(t)\, dt \qquad (4)$$

D. Protection Scheme Construction

According to the discussions in the last section, it is necessary to analyze the detected fault directions from all lines first, then determine whether the busbar has an internal fault or not. This paper designs a distributed busbar protection scheme, whose structure is shown in Fig. 4.

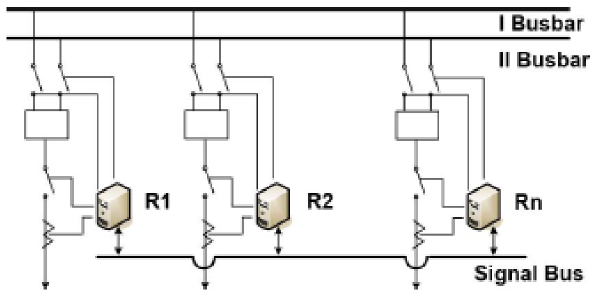

Fig. 4 System structure of the distributed busbar protection

The entire system consists of a signal bus and many protection units (R1 to Rn). The operation process of this distributed protection scheme is as follows: suppose there are N bay units (including feeders and transformers, etc.) connected to the same busbar; the protection system consists of N field protection units installed in the switchgear bay of a local control cubicle. Each protection unit independently acquires current and voltage signals of the local bay itself, discriminates the fault direction, and sends the discrimination result to all other units via the signal bus. Any unit, who thinks there is a positive direction fault, will not issue a tripping command to the local breaker. If one unit thinks there is a negative direction fault and all other units have the same discrimination results, then it will immediately issue a command to trip the local circuit breaker (CB). In this case, an internal busbar fault has been verified, and all units will issue the trip command at once, so the faulted busbar is separated. For any other situations, all protection units must be kept stable. The main advantages of this protection scheme include three aspects: first, each protection unit is only in charge of discriminating the fault direction to the line itself, and it does not require the synchronized data, so the protection algorithm is simple; second, due to the fast detection ability for a fault, the saturation of CT has no influence on the performance of busbar protection; and, finally, this scheme hardly has any maloperation. However, the distributed structure and communication may produce a negative influence on the reliability of this scheme, such as one of those protection units being out of service or having a problem, and this scheme will not normally operate. In order to maintain the reliability or normal operation of busbar protection, one proper solution is to assume the dual protection units for each bay, which will simultaneously operate. Once one protection unit fails to operate, another unit maintains the reliable operation. Besides the protection unit, it is suggested that the communication network should be duplicated.

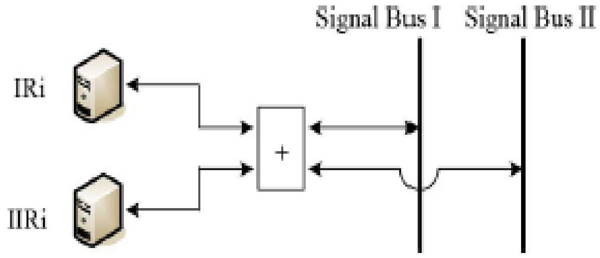

Fig. 5 Configuration of dual equipment

Aschematic configuration is shown in Fig. 5. In Fig. 5, IRi and IIRi denote the dual protection units for each bay. Signal Bus I and II are the dual communication networks. By a logic OR gate, the discrimination result of fault direction from the dual protection units is sent to the dual signal buses. At the same time, the fault direction results from the other bay are sent to the dual protection units via dual communication networks. Owing to the simple protection algorithm and cheap fiber-optic communication, this scheme will not increase the construction cost significantly, but the reliability of protection can be improved greatly. It is especially noted that this protection technique would be more useful in a digital substation.

III.EXPERIMENTAL RESULTS

This section shows the experimental results of proposed Busbar Protection Technique by using Traveling-Wave-Based Amplitude Integral. To verify the validity of the proposed busbar protection technique, this paper constructed a 230-kV busbar system model using the simulation tool Matlab. The researched object is busbar B, and protection units R1, R2, and R3 are installed at the terminal of each line. Defining the positive direction of the traveling wave is from the busbar to the line, and the sampling frequency is 100 kHz.

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The following simulation waveforms in figure 6 of the positive and negative direction traveling waves are shown in their absolute values.

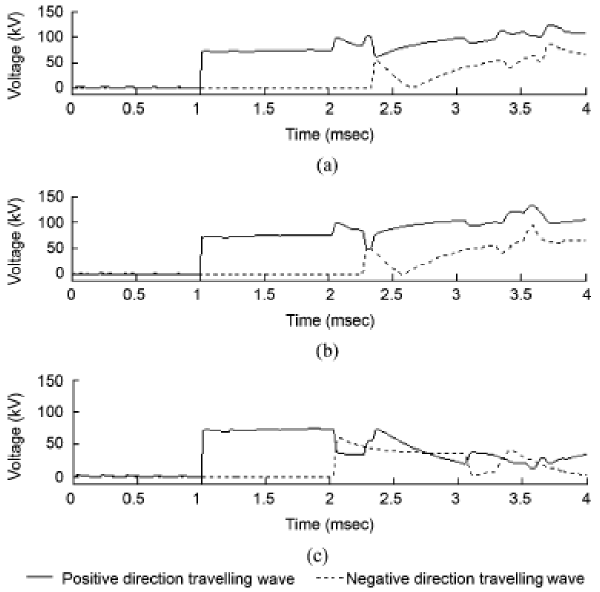

Fig. 6 Detected directional traveling waves for an internal fault at f1

Figure 6 (a)–(c) shows the detected waveforms of the positive and negative direction traveling waves of the aerial mode component at R1, R2, and R3, respectively, when an internal phase A to ground fault at f1 with a fault resistance of 50 ohm and fault inception angle of 60 occurs.

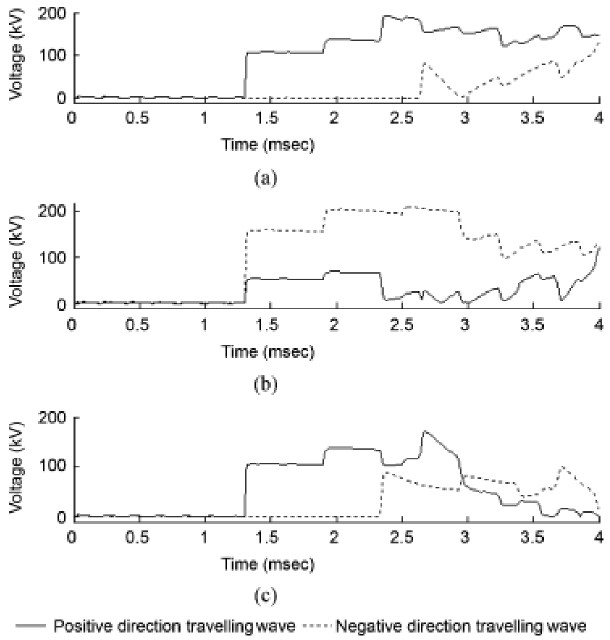

Fig. 7 Detected directional traveling waves for an external fault at f2

From Figure 6, it can be seen that is greater than for any unit, and the ratio is much greater than 1.5. Therefore, each protection unit determines that the fault direction is negative, which means this fault occurs on the busbar. So the discrimination result is correct. Figure 7(a)–(c) shows the detected directional traveling waves at R1, R2, and R3, respectively.

As a well-known theory, the performance of the traditional traveling-wave protection is affected seriously by the fault inception angle. The following simulations were performed to find out the effects of the fault inception angle to the proposed technique. Setting phase B to the ground fault at f3 away from the busbar 100 km with a fault inception angle of 10 degree, the protection performance is then tested. The waveforms of the directional traveling wave detected by R1, R2, and R3 are shown in Figure 8(a)–(c), respectively. Figure 8 illustrates that the traveling-wave signals are all very weak;

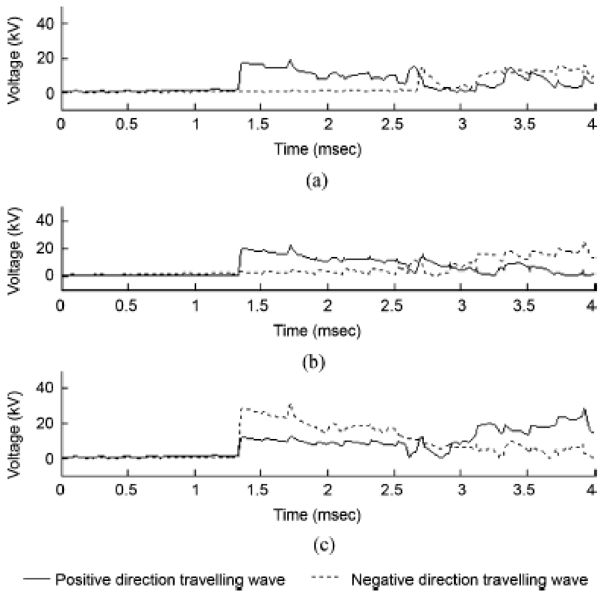

Fig. 8 Detected directional traveling waves for an external fault with an inception angle of 10 degree

According to the superposition principle of circuit, the additional fault voltage at the fault point is the same as the voltage of prefault in size, and opposite in sign. The smaller the fault inception angle is, the smaller the amplitude of additional voltage is, and the weaker traveling-wave signals generated by this fault are. Therefore, simulation results are consistent with the theory. But compared with the threshold, their ratios still have high sensitivity. What is the influence of a fault with an inception angle of 0 degree on the proposed method? For example, a phase A to ground fault occurs on the busbar, and the fault inception angle is 0 degree.

Figure 9(a)–(c) shows the detected directional traveling waves at R1, R2, and R3, respectively. From the aforementioned simulation figures and results, it can be seen that the criterion can correctly discriminate internal or external faults with a small inception angle, even 0 . The proposed protection technique is based on an amplitude integral of directional traveling wave, so it can make full use of transient fault components, including direct current components.

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Although the sensitivity of criterion may lower, it can make a correct identification for those faults with a very small inception angle.

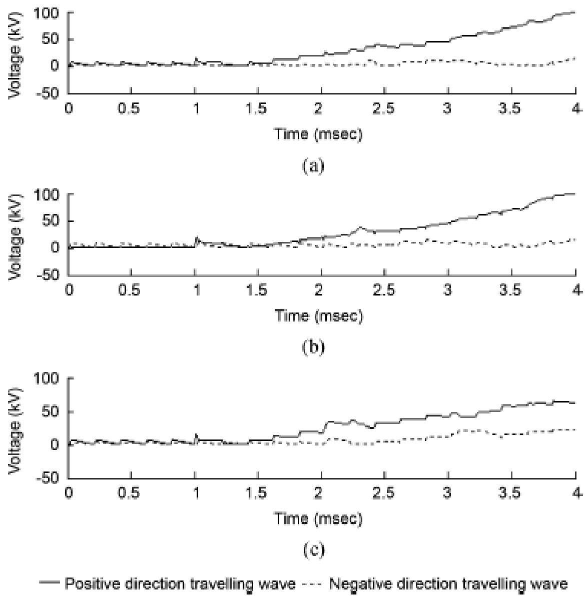

Fig. 10 Waveforms of the directional traveling waves for a busbar fault with an inception angle of 0 degree

If taking the communication time among units into account, the total time spent on the fault determination process is generally less than 3 ms. A single-phase-to-ground fault with a small inception angle has a slight influence on the amplitudes of directional traveling wave, but it has little impact on their ratio. The protection criterion is nearly immune to fault type, fault position, earth fault resistance, and CT saturation. In addition, whether a fault is internal or external, as long as the threshold value is set as 1.5, the criterion is able to provide adequate sensitivity and reliability. The transient noises are the major disturbance sources for the traveling-wave protections, and these disturbances mainly include CB operation, lightning stroke line, stochastic noise in a power system, etc. Besides, compared with the fault-generated traveling-wave signals, the energy of stochastic noise is very little, so it hardly has an influence on the proposed method. It has to specified, for the multiple faults, that this method may fail in discriminating the internal fault from the external fault. For example, if a fault occurs on a line and another simultaneous fault occurs on the busbar, the proposed method would not make a correct identification. However, in practice, this case is rare. Besides the aforementioned case, for those simultaneous faults occurring on the same line, the same busbar, or on different lines, this method can still identify the direction of fault correctly.

IV. CONCLUSION

The traveling wave is generated by using propagation theory; it is used to detect the fault in the wave by considering the configuration of the busbar. In this paper a technique which is based on transient directional traveling wave has high speed than the other methods. The characteristics of directional traveling waves on the faulted line and healthy lines are different, when one of the lines connected to the same busbar has a forward fault. For the internal fault on the busbar, the characteristics of directional traveling waves on all lines are the same. According to these different characteristics, the discrimination criterion for fault direction can be established. Through analyzing the fault directions to all lines, an internal fault or external fault can be determined. Simulation results demonstrate this protection technique has excellent performance, such as fast operation speed, high reliability, and sensitivity.

The performance of the forecasting model can be improved by considering the various parameters affecting the price volatility and also by using more historical price data which will indicate the behavior of price volatility in more detail. This work will be further improved to increase the efficiency in forecasting for support vector machine tool in Matlab.

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