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Wide area backup protection algorithm for transmission lines based on fault component complex power

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ABSTRACT

In this paper a new wide area backup protection algorithm based on the fault component complex power is proposed to overcome the problem of maloperation of conventional backup protection in highly stressed conditions of power system operation. Firstly, suspected faulty lines are detected using measured values of fault component voltages known as faulted area identification (FAI) criteria. Then, the fault component voltages and currents provided by phasor measurement units (PMUs) are applied to calculate the injected complex power to both terminals of the suspected faulty lines. The ratio between sum and difference of injected complex power to the both terminals of the suspected faulty lines is used as faulted line identification (FLI) criteria. The simulation studies performed on the IEEE 10 generator 39-bus system verify effectiveness of the proposed algorithm under various conditions and fault types.

Introduction

Power system and its protection system are planned in such a way that the system can operate through a sequence of credible contingencies without contributing to widespread outages. However, it has been observed that maloperations of conventional protection system in abnormal condition of power system operation have led to large blackouts [1].

In order to comprehensive understanding of issue it is necessary to review conventional protection of transmission line. Recommended practice in the National Grid Company is that transmission line is protected using two main protections including phase and earth fault differential protection and phase and earth fault distance protection with time delayed backup [2,3]. Backup protection includes overreaching zone 2 and zone 3 of distance protection and earth fault overcurrent protection. If fault had not been cleared by main busbar protection, zone 2 elements are expected to detect phase and earth faults on the busbar at theremote end of the line with a time delay of the order of 15–30 cycles. Zone 3 elements are required to detect phase and earth faults on any transmission line connected to the remote end of the main protected line with a typically time delay about 90 cycles. Earth fault overcurrent elements are required to detect resistive earth faults in operating time normally about 1–3 s.

Recent blackouts have attracted attention to the role of zone 3 of distance protection schemes. It has been reported that unwanted trips of zone 3 caused by unexpected loading conditions such as overload and flow transfer have often contributed to the cascading outages eventually result in large blackouts [1]. Moreover, setting mistakes due to complex principle of conventional backup protection setting lead to hidden failures [4,5].

Different solutions have been proposed to deal with this issue ranged from suggestion to completely eliminating the zone3 from the protection system to using blocking type distance protection schemes. With recent developments in computer networks, communication, information technology and advent of synchronised phasor measurement unit (PMU) and wide area measurement system (WAMS), nowadays it is possible and necessary to have a wider view to the power system in order to eliminate many shortcomings of conventional protection system [6,7]. One of the most effective solutions under investigation, which is proposed to eliminate conventional backup protection, is using WAMS to provide all backup protection as wide area backup protection (WABP) [8].

Recently, some algorithms have been proposed for WABP. A protection scheme based on comparing magnitude of positive sequence voltages and difference between positive sequence current phase angles at both terminals of lines is proposed in [9]. This algorithm is unable to reflect high resistance faults. An algorithm based on fault component voltage distribution is proposed in [10]. In this algorithm the measured values of fault component voltage and current at one terminal of the line are used to estimate

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Nomenclature

FAI	faulted area identification
PMU	phasor measurement unit
FLI	faulted line identification
WABP	wide area backup protection
WAMS	wide area measurement system
PCR	protection correlation region
FCF	fault correlation factor
U_1	positive sequence bus voltage
U_2	negative sequence bus voltage
U_0	zero sequence bus voltage
ΔU	fault component bus voltage
Δu_f	fault component voltage source
z	line impedance
z_f	ground fault impedance
z_i	network equivalent impedance at bus i
z_j	network equivalent impedance at bus j
a	percentage of line length from bus i at which fault has occurred
S_i	injected complex power to bus i
S_j	injected complex power to bus j
k	faulted line identification criteria
$k0$	zero sequence faulted line identification criteria
$k1$	positive sequence faulted line identification criteria
$k2$	negative sequence faulted line identification criteria

the fault component voltage at the other terminal. Then the faulted element is identified by using the ratio between the measured and estimated voltages. Moreover, the faulted element identification algorithm is accelerated by applying a faulted area detection scheme. This algorithm is able to identify faulted line in complex conditions such as high resistance fault and flow transfer. It needs to line impedance to estimate voltage at the other terminal of line. An algorithm based on fault steady state component is proposed in [11] to identify faulted branch. In this algorithm in normal condition of power system operation, on the basis of the network topology and PMUs placement, buses are classified into subsets named protection correlation regions (PCRs). When a fault occurs, the fault correlation region is determined by analysing the fault steady state component of differential current injected into each PCR. Then a fault correlation factor (FCF), using prefault and fault component currents and voltages, is calculated to identify the faulted branch. Unlike the two above-mentioned algorithms, this algorithm does not require to install PMU at all buses. The algorithm identifies high resistance fault correctly but it uses line impedance and bus impedance matrix of each PCR in its calculation. An analytical approach using dispersed PMUs and bus impedance matrix is proposed in [12]. In this approach, fault zone is first detected by local PMUs, then the suspected faulty lines are diagnosed and finally the fault line is identified and the fault point is located. This approach is successful even in case of the fault line, which is not equipped with PMU on either side.

This paper proposes a new wide area backup protection algorithm based on fault component sequence voltages distribution and fault component complex power. The algorithm comprises two parts including faulted area identification (FAI) and faulted line identification (FLI). Phasor of sequence currents and voltages of all buses of power system, provided by PMUs, are monitored in the centre of WABP. In order to reduce the calculations some lines are selected as suspected faulty lines using FAI criteria, which are based on fault component sequence voltages distribution in the power system. Then, FLI criteria, which are defined based on injected complex power to both terminals of line, are deployed to identify faulted line. The algorithm uses only measured voltages and currents to calculate the criteria and it does not need to system parameters such as line impedance and bus impedance matrix. It also identifies faulted line in different conditions such as high resistance fault and flow transfer.

Faulted area identification

When a fault occurs on a transmission line, the sequence currents in power system are calculated using symmetrical components method. Considering the sequence currents and impedances, the sequence voltages distribution along the faulted line and equivalent sources of other elements of the power system is shown in Fig. 1. The fault is a resistive fault.

According to Fig. 1, it can be concluded that: (1) The positive sequence voltage amplitude is minimum at the fault point and it is maximum at the source points. (2) The zero and negative sequence voltages amplitudes are maximum at the fault point and it is minimum at the equivalent source points and (3) among the voltages of all buses of a power system, the positive sequence voltage amplitudes of the two terminals of the faulted line are minimum, and the zero and negative sequence voltage amplitudes of the two terminals are maximum.

Considering above points, the positive sequence voltage amplitudes of two buses at both terminals of the faulted line are minimum and the zero and negative sequence voltages amplitudes of these two buses are maximum among the voltages of the other buses of power system.

On the basis of aforementioned explanation, the bus with minimum positive sequence voltage or maximum zero and negative

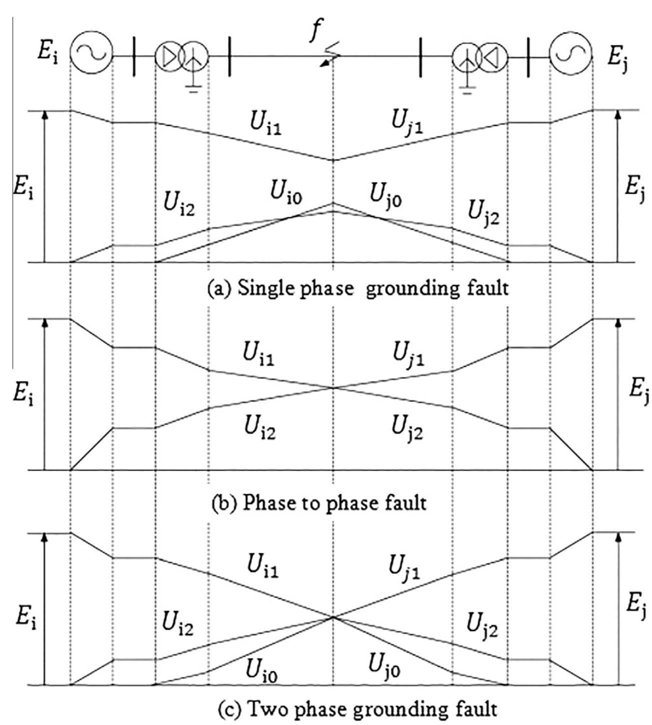

Fig. 1. Distribution of sequence voltages in a faulted power system.