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An innovative finite state automata based approach for fault direction estimation in transmission lines

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ABSTRACT

In this work finite state automata or finite state machine based directional protection scheme is proposed for transmission lines. Phase angle of positive sequence current is used as input to finite state automata based fault direction estimation module. Finite state automata is used as fault pattern recognizer which estimates the direction of fault. The output of the proposed FSM based scheme will be '−1' for reverse section faults and '1' for fault in primary section faults. The performance of the proposed technique is evaluated using data simulated for variation of fault type, fault inception angle, fault location, power flow angle, reverse power flow and fault resistance. Accuracy of the method is found to be 100% from all 11,500 fault cases. Proposed technique does not use voltage unlike conventional directional relaying schemes due to which there is no issue regarding close-in fault detection. The reach setting of the proposed method is up to 99.9% of line length which has advantage over conventional relaying schemes which have reach up to 80–85% of line. Although proposed method is a pattern recognition based technique, it does require an extra training module unlike artificial neural network to estimate the direction correctly. The proposed technique is effective because it do not require any training and the computation complexity is very less as compared to training based algorithms. Proposed method is also tested in an existing power system network of India, which shows accurate result in estimating fault direction.

1. Introduction

Protective relaying schemes in transmission lines are designed to clear the faults initiated in a line [1]. Most of the relays used for protection of transmission lines are distance relays or adaptive distance relays [2]. Directional relaying in transmission line is an important aspect of relaying which identifies the fault is in primary section or not. If fault in primary sections trip signals are sent immediately to open breakers. If fault is not in primary section of relay then trip signal will be issued after some delays (generally 2–3 cycle delay). Fundamentals of directional relaying and improvements in directional relaying are studied by researchers [3]. In conventional relaying schemes voltage is used as the polarising quantity to estimate the fault direction as suggested in [4]. But problem in this method occur when three phase fault occur near the relay bus. In this case the voltage becomes nearly zero due to which close in faults cannot be detected. Solution to close-in faults is discussed in [5] by computing positive sequence phasors of voltage and current signals. Other techniques like memory voltage polarization are also employed for fault direction estimation in transmission lines. Direction of faults in transmission lines is also estimated based on amplitude comparison [6] and polarity comparison [7] of travelling wave by using wavelet transform.

Data based techniques are also used for fault direction estimation in transmission lines. From all the data based techniques using artificial neural network for protection of transmission lines has been suggested by most of the researchers. Modular neural networks are also used for direction estimation in transmission lines in [8]. To increase the speed of directional relaying scheme mathematical morphology is used in [9]. Wavelets transform is also used for direction estimation in EHV transmission lines [10]. Fault directions are estimated in series compensated lines by taking positive sequence component as input in [11]. An integrated approach for fault direction estimation in double circuit transmission lines using multi criteria fuzzy decision tree approach is suggested in [12]. Directional relaying during single-pole tripping is designed using phase change in negative-sequence current in [13]. Fault direction estimation without voltage input is also proposed in [14]. Further directional relaying algorithms have been reported

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Nomenclature

CSEB	Chhattisgarh State Electricity Board
FSM	finite state machine
FSA	finite state automata
LG	line to ground
LLG	double line to ground
LL	line to line
LLL	triple line faults
NTPC	National Thermal Power Corporation
SCC	short circuit capacity

based on single terminal data of phase angle between positive and negative sequence components of current and voltage applied as input to Four classifier in series compensated lines in [15]. Directions are also estimated using artificial neural network and fundamental component of current in [16].

The problems in direction estimation in implemented protection scheme arise due to few reasons as given below:

1. The conventional relays used for fault direction estimation uses voltage as the polarising quantity [4]. When three phase fault occur near to relay end, voltage becomes very low (nearly equals to '0') due to which the polarising quantity may not be estimated correctly resulting wrong fault direction estimation.
2. First zone reach setting of the conventional relay is up to 80–85% of line length due to which remote end faults are identified after some delay. The remote ends faults comes in second or third zone of protection, which takes more time (up to 3–4 cycles), ant the associated equipments are exaggerated with high fault current for longer duration. A fault direction estimation scheme for transmission lines is essential which can overcome the limitations of conventional direction estimation schemes.

So, it is essential to design a directional relay which detects the fault direction in different fault situations with greater speed and accuracy. The designed relay should be easy to implement and efficient. In this work, FSM based direction estimation scheme is proposed which has detection time within half cycle and can operate in normal as well as extreme operating conditions. The paper is organised as follows – Section 2 introduces the concept of the finite state automata, Section 3 describes the proposed method for fault direction estimation, Section 4 exemplifies the test results, Section 5 compares the proposed scheme with other techniques and Section 6 concludes the present work.

2. Finite state automata/machine

The finite state machine (FSM) introduces concept of a state which represents all possible situations in which the state machine may ever be. Outputs may depend on the current state as well as on the inputs [17]. As the number of distinguishable situations for a given state machine is finite, the number of states is finite which is why it is called as finite state machine. FSM is represented with state transition diagram is transition of states from one state to another. Two elements are used in state transition graph, a circle to denote the state and an arc for the transition. The transition condition is written over the arc. The entry action is an action done when the state machine enters a state. The exit action is an action done when the state machine leaves the state. The input action is an action done when an input is true. Each state has its own set of input actions. Transition action is an action performed during the state change. Finite state machine represented with six tuples $\langle \Sigma, \Gamma, Q, Q0, \delta, \omega \rangle$, as shown in 1

$$FA = (\Sigma, \Gamma, Q, Q0, \delta, \omega) \quad (1)$$

where Σ is the input alphabet (a finite non-empty set of symbols), Γ is the output alphabet (a finite non-empty set of symbols), Q is a finite non-empty set of states, Q0 is an initial state, an element of Q, δ is the state transition function, ω is the output function [17].

A simple state transition diagram for representing finite state automata is shown in Fig. 1. In Fig. 1 Q0 is the initial state and Qf1 and Qf2 are final states. Initial state always has default transitions. Q1 and Q2 are the states through which it reaches to final state. State transitions occur by following certain conditions (C1, C2, C3, C4, C5 and C6).

Finite state automata are implemented in MATLAB with state flow. The state flow toolbox of Matlab® software works with simulink toolbox to model and simulate power system network. State flow is a graphical design and development tool for control and supervisory logic used in conjunction with simulink [18]. In these paper finite state automata is used for directional fault detection in transmission lines. States are designed for no fault, reverse fault and forward fault. Conditions required for state transition are designed to correctly estimate the fault direction.

3. Proposed finite state machine (FSM) based fault direction estimator

The flow diagram of the proposed FSM based fault direction estimation method is shown in Fig. 2. The relay is placed at section 2 which is considered as primary line to be protected by relay installed at Bus-2. The faults in section 2 are considered as forward faults and the faults in section 1 are considered as reverse faults. The proposed method identifies the fault direction that is the fault is in forward or reverse section and issues trip signals accordingly. Steps followed in the proposed method are described below in subsections.

3.1. Power system network

The single line diagram of the power system network under consideration is shown in Fig. 2. It consists of 400 kV, 50 Hz transmission line distributed into two sections of length 100 km each. Three phase source of 400 kV, 50 Hz is connected to bus-1 with 100 kW and 100 kVar load, the short circuit capacity of source is 1250MVA and X/R ratio is 10. At bus-3 a load of 250 kW is connected and another 3 phase source of 400 kV, 50 Hz, SCC 1250MVA, X/R ratio is 10 are connected. The relay is placed at sec-

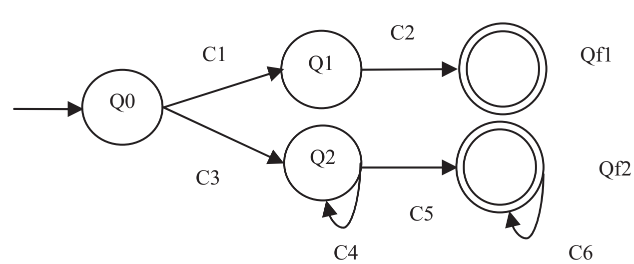

Fig. 1. Finite state machine representation.