# A Pilot Protection Scheme for Active Distribution Networks Considering Branches

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**Abstract.** The structure of conventional distribution system is radial, and overcurrent relays are widely used as primary protection. When a large number of distributed generations (DGs) are introduced, the system becomes an active distribution network. It is necessary to study new protection schemes applicable to active distribution network. This paper proposes a pilot protection scheme for active distribution network considering branches. The relationship of current phase variation direction and load power flow direction are used to build a criterion. Simulation results show the protection scheme can accurately identify the faults.

## Introduction

Conventional distribution network is radial and supplied with a single source. The protection is usually overcurrent protection [1]. With the integration of DGs, the distribution system becomes a network with muti-source structure, which brings new issues to distribution system protection, such as blinding, false tripping and loss of grading [2]. It is necessary to study new protection schemes applicable to active distribution network.

Many novel protection schemes have been proposed to solve these issues. The protection schemes based on local information can act rapidly without communication channels [3]-[5]. However, as this kind of schemes only use the local information, it is easily affected by the system operating modes and DG power output. The centralized protection schemes can act accurately, as the information of multiple points is used [6]-[8]. This kind of protection schemes need to install a control center to receive large amount data and calculate the fault section. It puts forward strictly demands to the communication channels and calculation ability. The pilot protection uses the information of two points, can solve this problem to some extent.

This paper proposes a pilot protection scheme for active distribution network. The current phase variation characteristics of the fault current are studied. The relationship of current phase variation direction and load power flow direction are deduced. Then a criterion using this relationship is proposed. To protect the distribution line with no branch, it is only needed to utilize current values as the load power flow directions of the two terminals are the same. The directions of the current phase variation are transmitted to the relay of the opposite terminal. If there exist branches in the pilot protection zone, voltage values are employed to obtain power flow direction in normal operation status. By using directions of current phase variation and load power flow, the fault can be identified. Simulation studies with IEEE 30-bus system are carried out by PSCAD.

## Relationship of Current Phase Variation and Load Power Flow

Fig. 1 shows a simple distribution network. “Network 1” and “Network 2” represent two parts of distribution network, which may connect with different types of DGs or main network. F and $F'$ represent different fault points. The power flow direction is set from M to N. $\dot{I}_{pre}$ is the pre-fault load current. When a fault occurs, voltage phase angles of M and N change slightly, ranging from 0.2° to 0.5° [9]. The following passages will mainly study the current phase angle variation of fault and pre-fault conditions by single-phase circuits.

The pre-fault current of line MN in Fig. 1 can be expressed as [10]

$$\dot{I}_{\text{pre}} = \frac{\dot{U}_{\text{M}} - \dot{U}_{\text{N}}}{Z_{\text{MN}}} \tag{1}$$

where $\dot{U}_{\text{M}}$ and $\dot{U}_{\text{N}}$ are the bus voltages. $Z_{\text{MN}}$ is the impedance of line MN.

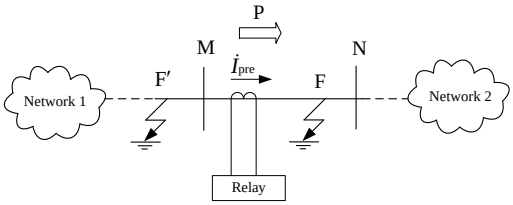
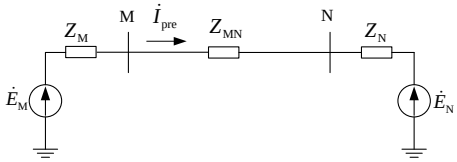
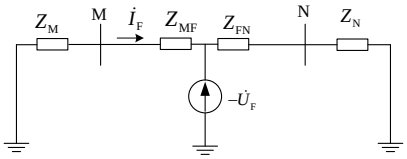



Fig. 1. A simple distribution system with relays.

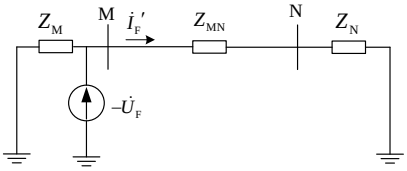
Using superposition theorem, the system fault equivalent circuit can be expressed by a pre-fault circuit superimposed with a fault component circuit. Fig. 2(a) shows the pre-fault circuit. Fig. 2(b) and Fig. 2(c) show the fault superimposed circuits of faults at F and F', which are in the positive and negative direction of the power flow, respectively. $\dot{U}_{\text{F}}$ is the voltage of F under normal condition, $-\dot{U}_{\text{F}}$ is used to denote the superimposed component voltage source. $Z_{\text{MF}}$ is the impedance from M to F, $Z_{\text{FN}}$ is the impedance from F to N, $Z_{\text{M}}$ and $Z_{\text{N}}$ are the system impedances of Network 1 and 2, respectively. The reference direction is set from bus to line.




(a) Pre-fault circuit.




(b) Fault superimposed circuit positive direction fault.




(c) Fault superimposed circuit for negative direction fault.

Fig. 2. Distribution network fault equivalent circuit.

When a fault occurs at F, the fault superimposed circuit is illustrated in Fig. 2(b). Superimposed component currents can be expressed as

$$\dot{I}_{\text{F}} = -\frac{-\dot{U}_{\text{F}}}{Z_{\text{M}} + Z_{\text{MF}}} = \frac{\dot{U}_{\text{F}}}{Z_{\text{M}} + Z_{\text{MF}}} \tag{2}$$

For the fault at F, the total currents flow through the relay can be expressed as

$$\dot{I} = \dot{I}_{\text{pre}} + \dot{I}_{\text{F}} = \frac{\dot{U}_{\text{M}} - \dot{U}_{\text{N}}}{Z_{\text{MN}}} + \frac{\dot{U}_{\text{F}}}{Z_{\text{M}} + Z_{\text{MF}}} \tag{3}$$

When a fault occurs at F', the fault superimposed circuit is illustrated in Fig. 2(c). Superimposed component currents can be expressed as

$$\dot{I}_{\text{F}}' = \frac{-\dot{U}_{\text{F}}}{Z_{\text{MN}} + Z_{\text{N}}} = -\frac{\dot{U}_{\text{F}}}{Z_{\text{MN}} + Z_{\text{N}}} \tag{4}$$

For the fault at F, the total currents flow through the relay can be expressed as

$$\dot{I}' = \dot{I}_{\text{pre}} + \dot{I}_{\text{F}}' = \frac{\dot{U}_{\text{M}} - \dot{U}_{\text{N}}}{Z_{\text{MN}}} - \frac{\dot{U}_{\text{F}}}{Z_{\text{MN}} + Z_{\text{N}}} \tag{5}$$

The phasor diagram is shown in Fig. 3. As the load power flows from M to N, the voltage phasor $\dot{U}_{\text{M}}$ is leading to $\dot{U}_{\text{N}}$. The system impedance angle is deemed to be the same as the line impedance angle, and the line resistance is ignored. As a result of it, the phase angle difference of superimposed component current and voltage source is nearly 90°. It is shown that the total fault current $\dot{I}$ is lagging to the pre-fault current $\dot{I}_{\text{pre}}$ and the total fault current $\dot{I}'$ is leading to the pre-fault current $\dot{I}_{\text{pre}}$. A rule of current phase variation can be stated as shown follow.

When a fault occurs at F, the phase angle difference between the fault current $\dot{I}$ and pre-fault current $\dot{I}_{\text{pre}}$ is $\Delta\phi = \arg(\dot{I} / \dot{I}_{\text{pre}}) < 0$, the direction of current phase angle variation is negative. When a fault occurs at F', the phase angle difference between the fault current $\dot{I}'$ and pre-fault current $\dot{I}_{\text{pre}}$ is $\Delta\phi' = \arg(\dot{I}' / \dot{I}_{\text{pre}}) > 0$, the direction of current phase angle variation is positive.

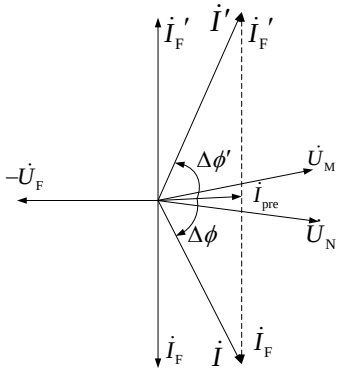



Fig. 3. Phasor diagrams for faults at F and F'.

With the analysis above, a principle can be stated as follow.

When a fault occurs in the positive direction of the load power, the current phase variation is negative. When a fault occurs in the negative direction, the current phase variation is positive.

By using the directions of load power and current phase variation, the fault direction can be determined. If the reference direction is set as from the bus to the line, the possible fault direction judgement results are shown in Tab. I.

Table I Fault direction judgement results

| **No.** | **Load power direction** | **Current phase variation** | **Fault direction** |
|---|---|---|---|
| 1 | + | − | + |
| 2 | + | + | − |
| 3 | − | − | − |
| 4 | − | + | + |

The fault direction of No.1 and 4 in Tab. I is positive. The principle to determine the fault section when the protection zone exists branch is shown as follow.

When the two relays of the pilot protection both determine the fault is in the positive direction, the fault is judged as internal.

If there is no branch in the protection zone, the principle is shown as follow.

When an internal fault occurs, the current phase variation directions of the both ends are opposite. When an external fault occurs, the current phase variation directions of the both ends are the same.

## Protection Scheme

The relationship of current phase variation and pre-fault power load flow direction is studied above.

Then a pilot protection criterion according to this relationship can be deduced.
If there is no branch in the pilot protection zone, the current values are adopted to build protection scheme. The protection criterion is shown as follow.

- When the current phase variation directions of the two relays are the same, the fault is judged as external. When the current phase variation directions of the two relays are opposite, the fault is judged as internal.

If there exists branch in the pilot protection zone, voltage values are also needed.
The pre-fault power flow directions of the two relays are the same:

- When the current phase variation directions of the two relays are the same, the fault is judged as internal. When the current phase variation directions of the two relays are opposite, the fault is judged as external.

The pre-fault power flow directions of the two relays are opposite:

- When the current phase variation directions of the two relays are the same, the fault is judged as external. When the current phase variation directions of the two relays are opposite, the fault is judged as internal.

A pilot protection scheme based on the above criterion is proposed. Fig. 4 shows the block diagram of the proposed pilot protection scheme considering branches.

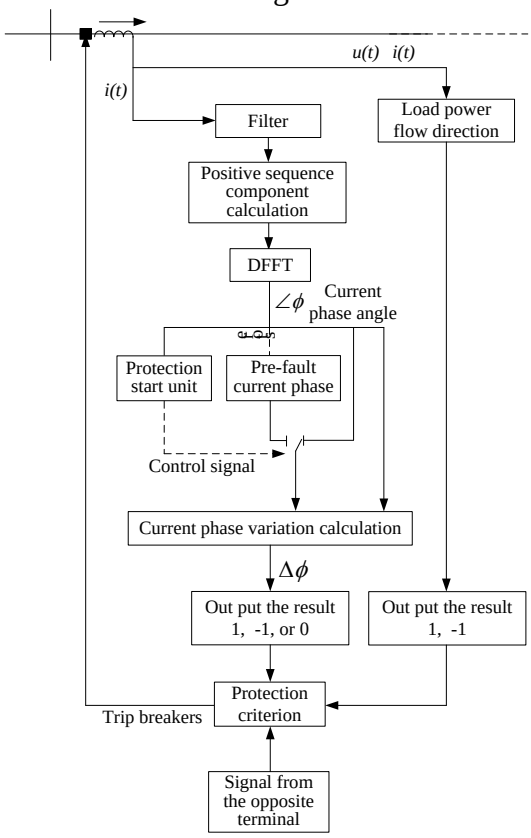



Fig. 4. Block diagram of the proposed pilot protection scheme.

If there exist any branches, voltage values are also needed to obtain the load power flow direction, as Fig. 4 shows. The current phase angle in the pre-fault statues is obtained and stored in the memory. When the protection scheme identified a fault, the current phase variation is calculated and a result is output. The load current flow directions are also expressed by “1” or “−1” to indicate the positive direction or the negative direction, respectively. Then according to the protection criterion, the fault is identified, and the trip signals are sent to the corresponding breakers. If the protection zone does not exist branch, the voltage values are not needed.

## Simulation Analysis

A PSCAD model of the IEEE 30-bus system is adopted in order to validate the protection scheme.

The system is a mesh network, consisting of 30 buses, with voltage levels of 132 kV and 33 kV. The system information is provided in [11]. The distribution part of this network which is studied in this paper is shown in Fig. 6. There are 40 relays totally installed at each end of the lines. Three 10 MVA DGs are connected to the network. The configuration of relays is shown as Fig. 6. Some pilot protection zones which are formed by relays contain branches.

When a two-phase fault occurs at F which is in the middle of line 11-14, the simulation results are shown in Tab. II.

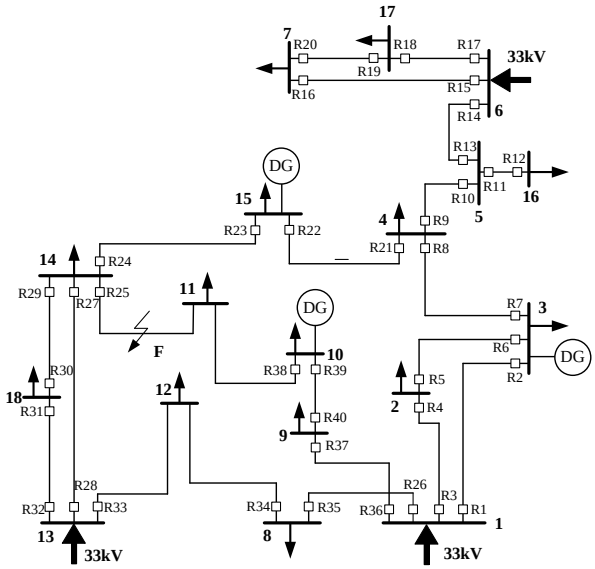



Fig. 5. A IEEE 30-bus distribution network.

Table II Simulation results for two-phase fault at F of IEEE 30-bus network

| Relay no. | Current Phase Variation/(°) | | | | Pre-fault Power | Fault Location |
|---|---|---|---|---|---|---|
| | *Pre-fault* | *Fault* | *Difference* | *Results* | | |
| R23 | −4.1 | −81.6 | −77.5 | −1 | * | External |
| R24 | 175.9 | 98.4 | −77.5 | −1 | * | |
| R25 | −56.1 | −83.7 | −27.6 | −1 | 1 | Internal |
| R38 | −22.1 | −85.1 | −63.0 | −1 | 1 | |
| R27 | 138.4 | 96.6 | −41.8 | −1 | * | External |
| R28 | −41.6 | -83.3 | −41.7 | −1 | * | |
| R29 | 1.1 | 102.2 | 101.1 | 1 | * | External |
| R30 | −178.9 | −77.8 | 101.1 | 1 | * | |
| R39 | −95.1 | 99.1 | −165.8 | −1 | * | External |
| R40 | 84.9 | −80.9 | −165.8 | −1 | * | |

Tab. II shows that when a two-phase fault occurs at F, the current phase variations of relay 25 and 38 which are in the two ends of the fault line are calculated, the output results are both “−1”. The output results of the load power flow direction are both “1”. The judgement result according to the protection criterion are “Internal”. The protection scheme can identify the fault correctly.

## Conclusion

This paper studies the relationship between the current phase angle variation and load power flow direction. Then a pilot protection scheme is proposed. When the pilot protection does not exist branch, only current values are required to calculate the current phase variation. When there exist any branches in the pilot protection zone, voltage values are needed to obtain the load power flow direction. Only the pre-fault voltage is needed to obtain the load power flow direction. The current phase variation is calculated locally without synchronous sampling of the two ends. It is only needed to transmit logical signals to the opposite terminal, which reduces the requirements on the communication channel. The simulation results indicate that the scheme is reliable to identify the fault.

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**References**

[1] Hussain B, Sharkh S M, Hussain S, et al. An adaptive relaying scheme for fuse saving in distribution networks with distributed generation [J]. IEEE Transactions on Power Delivery, 2013, 28(2): 669-677.

[2] Martinez J A, Martin-Arnedo J. Impact of distributed generation on distribution protection and power quality[C] // Proceedings of IEEE Power and Energy Society General Meeting, July 26-30, 2009, Calgary, Canada.

[3] Zeineldin H H, Sharaf H M, Ibrahim D K, et al. Optimal protection coordination for meshed distribution systems with DG using dual setting directional over-current relays[J]. IEEE Transactions on Smart Grid, 2015, 6(1): 115-123.

[4] Chilvers I, Jenkins N, Crossley P. Distance relaying of 11 kV circuits to increase the installed capacity of distributed generation[J]. IEE Proceedings - Generation, Transmission and Distribution, 2005, 152(1):40-46.

[5] Jalilian A, Hagh M T, Hashemi S M. An innovative directional relaying scheme based on postfault current[J]. IEEE Transactions on Power Delivery, 2014, 29(6): 2640-2640.

[6] Ustun T S, Ozansoy C, Zayegh A. Modeling of a centralized microgrid protection system and distributed energy resources according to IEC 61850-7-420[J]. IEEE Transactions on Power Systems, 2012, 27(3): 1560-1567.

[7] Xyngi I, Popov M. An intelligent algorithm for the protection of smart power systems[J]. IEEE Transactions on Smart Grid, 2013, 4(3): 1541-1548.

[8] Protection technique for complex distribution smart grid using wireless token ring protocol

[9] Garcia-Gracia M, EI Halabi N, Montanes A, et al. Improvement of DEA performance against harmonic distortion[J]. Electric Power Systems Research, 2010, 80(5): 582-591.

[10] Ukil A, Deck B, Shah V H. Smart distribution protection using current-only directional overcurrent relay[C]// Proceedings of Innovative Smart Grid Technologies Conference Europe, October 11-13, 2010, Gothenburg, Sweden.

[11] Unive Washington. Seattle, March 2010 [Online]. Availableat: http: // www. ee. washington. edu /research /pstca/