

ADAPTIVE DISTRIBUTION FEEDER PROTECTION SCHEME TO HANDLE THE PENETRATION OF SEIG BASED WIND FARM

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Abstract: There is a potential threat to the conventional distribution overhead feeder protection due to the increasing penetration of Distributed Generation (DG). In order to cope up with this, adaptive feeder protection schemes are required. This work involves the development of an adaptive feeder protection scheme to surmount the impacts of wind based DG which is highly intermittent in nature. PSCAD® is used to carry out simulations. MATLAB based software package for distribution system conductor sizing and protection coordination studies are also presented.

Key words: Protection, feeder, SEIG, distribution system, relay coordination.

1. Introduction

DGs are salutary to meet increased demand for electric energy and to improve the reliability of electric power supply. But their penetration on the existing distribution system induces menace to the protection, operation and control of the electric distribution systems.

One of the most promising renewable energy based power generation is wind energy conversion technology. [1] Reports that worldwide penetration of wind energy systems is predicted to rise up to 8% in 2019 from 1.8%. This work presents an adaptive feeder protection scheme to overcome the impacts of Self Excited Induction Generator (SEIG) based wind energy system penetrated to the distribution system.

Protection conflicts in the presence of DG have been discussed by various authors. Analysis on the impacts of inverter interfaced DG on the distribution system OC protection with suggested solutions such as directional protection was presented in [2]. Impacts of OC protection in a radial distribution system due to the penetration of DG were discussed in [3].

Protection issues associated with disconnection of DGs were addressed in the context of a radial feeder in [4]. Detrimental effect of DG on the IEEE 34 node radial test feeder with OC protection was discussed in [5]. Reported impacts include increased short circuit current as well protection mis-coordination. Reference [6], suggested network based adaptive feeder protection strategies for distribution systems with distributed generation.

An adaptive scheme for optimal coordination of

overcurrent relays was presented in [7]. And the proposed scheme was applied to the IEEE 30-bus test system.

Effective and practical methods to solve malfunctioning of protective gear in the presence of DG have to be further investigated. Further, intermittent nature of DG on protection issues was not taken up in literature. Most of the studies were done assuming constant power from DG. Such a study is not realistic. Hence an adaptive feeder protection scheme considering the fault dynamics, intermittent protection; feeder; SEIG; distribution system; relay coordination.nature and location of the DG is proposed in this work.

The operation of OC protection scheme deployed to the radial distribution OH feeder system without DG is discussed in sections 3. Impacts due to the interconnection of DG into the existing distribution feeder are presented along with the proposed adaptive protection scheme in section 4. The proposed scheme was then applied to the system under study with DG to overcome the negative effects caused by it and the simulation results are presented in section 5.

2. Package for Distribution System Protection Studies

In order to execute protection scheme for distribution feeder systems, systematic design procedures should be followed.

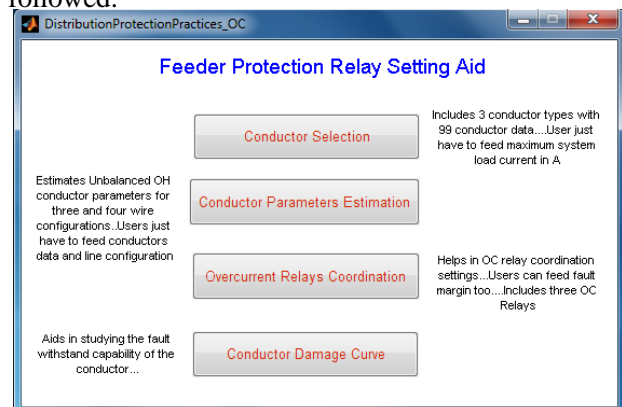


Fig. 1. Snapshot of the developed Feeder Protection Relay Setting Aid

This involves power system planning and protection coordination. The design procedures include selecting apposite conductor size upon knowing system load requirements, and estimating the parameters of the conductor. Relay setting involves pickup setting and protective devices coordination.

A guided tool for conductor sizing, parameters estimation and OC relay settings is developed in MATLAB platform. The snapshot of the developed GUI based software package is shown in figure 1. The software developed has provision for,

- Conductor Selection
- Conductor Parameters Estimation
- Overcurrent Relays Coordination
- Conductor Damage Curve

3. OC Protection Scheme

Single line diagram of the radial distribution overhead feeder system with overcurrent relays in PSCAD is shown in figure 2. Description on the entire system data is provided on Appendix. The system consists of three feeder segments (Feeder1, 2 and 3) supplying load 1, 2 and 3 from a utility of 33kV, 50Hz system through a 5MVA distribution transformer. Load 1 is tapped from node C, load 2 is tapped from node D and load 3 from node E. OC1, 2 and 3 are the overcurrent relays to protect feeder 1, 2 and 3 respectively. Selection of feeder conductors is based on the ampere requirement (current rating) of the system. Once system load requirements are known, suitable conductor can be selected with help of the GUI based guided tool discussed above.

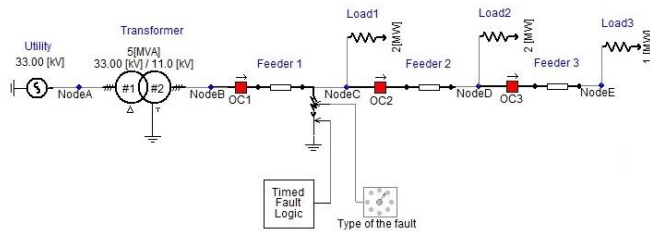


Fig. 2. SLD of the radial distribution OH feeder system with OC relays in PSCAD

For proper operation of overcurrent protection scheme, OC1, 2 and 3 are coordinated in such a way that for any fault in the feeder 3, OC3 is tripped. In case if OC3 fails to trip for a fault on feeder 3, then OC2 will backup, in case if OC2 too fails, then OC1 will backup. Similarly for a fault on feeder 2, OC2 will be operated. In case if OC2 fails, OC1 will back it up. For any fault on feeder 1, OC1 will operate.

Upon knowing the system maximum load current and fault level, relays OC1, OC2 and OC3 are set with the following values of pickup level and time dial.

Current-time (i-t) characteristics of the relays are chosen based on IEEE C37-112. GUI discussed on section II is used for relay coordination setting.

Relay setting of OC relay 1, 2 and 3 are shown below.

OC Relay 1:

- TD = 0.15 s
- Pickup = 4.0625 A
- Curve type: IEEE Moderately Inverse

OC Relay 2:

- TD = 0.1 s
- Pickup = 3.8751 A
- Curve type: IEEE Very Inverse

OC Relay 3:

- TD = 0.05 s
- Pickup = 3.4650 A
- Curve type: IEEE Extremely Inverse

The OC relays 1, 2 and 3 coordination curves along with fault margin is shown in figure 3.

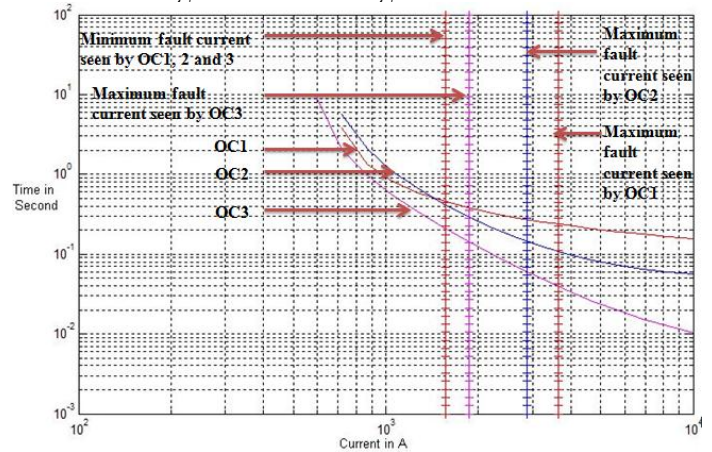


Fig. 3. OC relays coordination curve along fault margin

To validate the relay setting, various types of faults are applied at different locations of the feeder1, 2 and 3 of the system shown in figure 2. The operations of the relays OC1, 2 and 3 for various test cases are summarized in table 1.

OC protection of the radial distribution OH feeder system in the presence of DG is discussed in the next section.

4. OC Protection Scheme with SEIG Based Wind Farm

A transient behavioural model of Self Excited Induction Generator (SEIG) based wind farm of 1.5 MVA rating is simulated in PSCAD with pitch angle control to extract optimum power output at higher wind speeds.

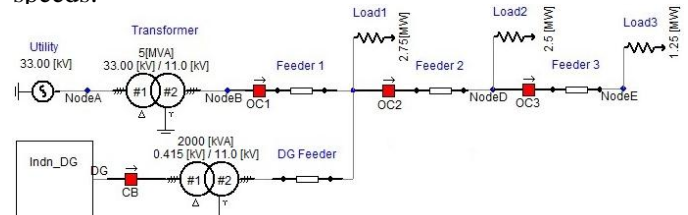


Fig. 4. SLD in PSCAD showing OC protection of Radial OH distribution system with DG at node C (SEIG based WECS)

Table 1

Operation of OC1, 2, and 3 for various test cases

| Case No. | Fault location | Fault Type | Fault Duration in second | Primary Relay | Backup Relay | Loads affected after clearing the fault | Relays Operated | Relay Operating Time in second |
|----------|------------------------|------------------------|--------------------------|---------------|--------------|---|-----------------|--------------------------------|
| 1 | At the end of feeder 1 | SLG(Phase A to ground) | 1 | OC1 | - | All | OC1 | 0.1259 |
| 2 | At the end of feeder 1 | LL(Phase B and C) | 1.5 | OC1 | - | All | OC1 | 0.1145 |
| 3 | At the end of feeder 1 | Three phase to ground | 2.5 | OC1 | - | All | OC1 | 0.0955 |
| 4 | At the end of feeder 2 | SLG(Phase A to ground) | 1 | OC2 | OC1 | Load 2 and 3 | OC2 | 0.1410 |
| 5 | At the end of feeder 2 | LL(Phase B and C) | 1.5 | OC2 | OC1 | Load 2 and 3 | OC2 | 0.1105 |
| 6 | At the end of feeder 2 | Three phase to ground | 2.5 | OC2 | OC1 | Load 2 and 3 | OC2 | 0.0895 |
| 7 | At the end of feeder 3 | SLG(Phase A to ground) | 1 | OC3 | OC2 and OC1 | Load 3 | OC3 | 0.1300 |
| 8 | At the end of feeder 3 | LL(Phase B and C) | 1.5 | OC3 | OC2 and OC1 | Load 3 | OC3 | 0.1090 |
| 9 | At the end of feeder 3 | Three phase to ground | 2.5 | OC3 | OC2 and OC1 | Load 3 | OC3 | 0.0850 |

In order to foresee the consequences of inserting distributed generators into an existing feeder; SEIG based wind energy conversion system (DG) is penetrated at node C and node D of the radial distribution OH feeder. The SLD of the distribution system with DG (SEIG based wind energy conversion system) at node C is shown in figure 4. The impacts of the DG on the OC feeder protection and the proposed adaptive OC protection scheme are discussed below.

A. Impacts

When DG is penetrated the fault margin of the system is altered due to the additional fault current contributed by the DG. The new levels of fault currents with DG at node C and at node D are given below. The relay coordination curves with the new fault margin are shown in figure 5. From figure 5, it is clear that there is a coordination mismatch between relays OC1 and OC2 and hence their operations are affected in this case.

1) Fault level with DG at node C:

The minimum and the maximum fault currents seen by the three relays OC1, 2 and 3 with the penetration of DG at node C are given below. The minimum fault current is estimated by applying a single line to ground fault at the end of the feeder and the maximum value of the fault current is estimated by applying a three phase to ground fault respectively.

OC Relay 1:

Minimum fault current seen by the relay = 1253.3A

Maximum fault current seen by the relay = 3627.4A

OC Relay 2:

Minimum fault current seen by the relay = 1672.4A

Maximum fault current seen by the relay = 3507.2A

OC Relay 3:

Minimum fault current seen by the relay = 1672.4A

Maximum fault current seen by the relay = 2015.3A

2) Fault level with DG at node D:

The minimum and the maximum fault currents seen by the three relays OC1, 2 and 3 with the penetration of DG at node D are given below.

OC Relay 1:

Minimum fault current seen by the relay = 1414.2A

Maximum fault current seen by the relay = 3627.5A

OC Relay 2:

Minimum fault current seen by the relay = 1414.2A

Maximum fault current seen by the relay = 2870.8A

OC Relay 3:

Minimum fault current seen by the relay = 1746.5A

Maximum fault current seen by the relay = 1845.6A

Looking at the fault analysis data after the penetration of SEIG at node C and D of the radial OH distribution feeder system protected by OC relays, the following observations can be summarized.

1. There is a considerable change in fault current in the distribution system due to the presence of SEIG at node C and D for single line to ground faults, line to line faults, and line to line ground faults.
2. Minimum and the maximum fault currents seen by the relays OC1, 2 and 3 are different.

Hence there is a change in the fault margin.

3. If the relays are not coordinated within the fault margin, then protection miscoordination occurs.

In order to overcome the high fault current and OC relays protection miscoordination, an adaptive OC protection scheme is necessary.

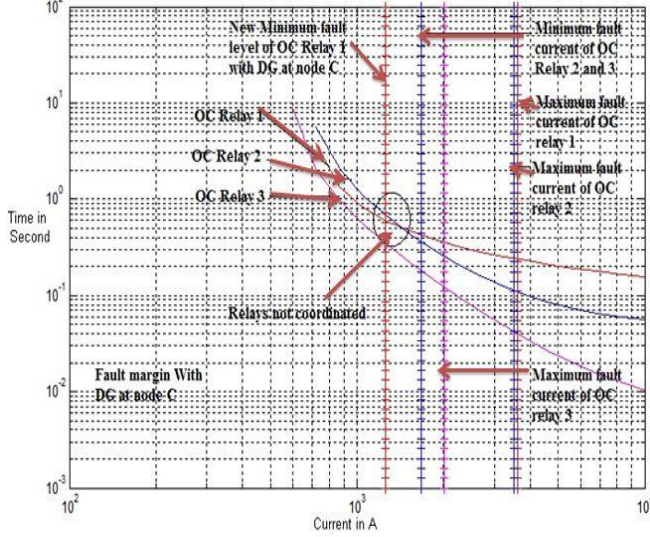


Fig. 5. OC relays 1 and 2 coordination mismatch due to the DG penetrated at node C

B. Proposed Adaptive OC Protection Scheme

The proposed adaptive feeder protection scheme considers the fault dynamics, intermittent nature and location of the DG. The flowchart of the proposed scheme is shown in figure 6. According to the proposed scheme the OC relay settings should be dynamically altered based on the availability of the resource. During various stages of operation based on availability of communication aid and data, fault level can be fed to the OC coordination setting of the relay. The following are some of the features of the proposed adaptive OC protection scheme.

1. Coordination irrespective of the availability of the resource: This guarantee OC protection coordination in the presence as well as absence of DG.
2. Intermittent nature of the wind is considered.
3. Dynamics of DG is considered.
4. Dynamic relay multiple settings based on the source availability.
5. Reliable.
6. Software package aids in new settings: This setting is selected automatically in firmware on acquiring status of energy availability from wind mill.

5. Evaluation of the Proposed Adaptive OC Relay

The above proposed scheme is evaluated by deploying it to the distribution radial OH feeder protected by OC protection scheme with DG on node C and node D.

The new coordination settings for OC1, 2 and 3 with DG at node C and node D with the proposed adaptive scheme is shown in figure 7 and 8 respectively.

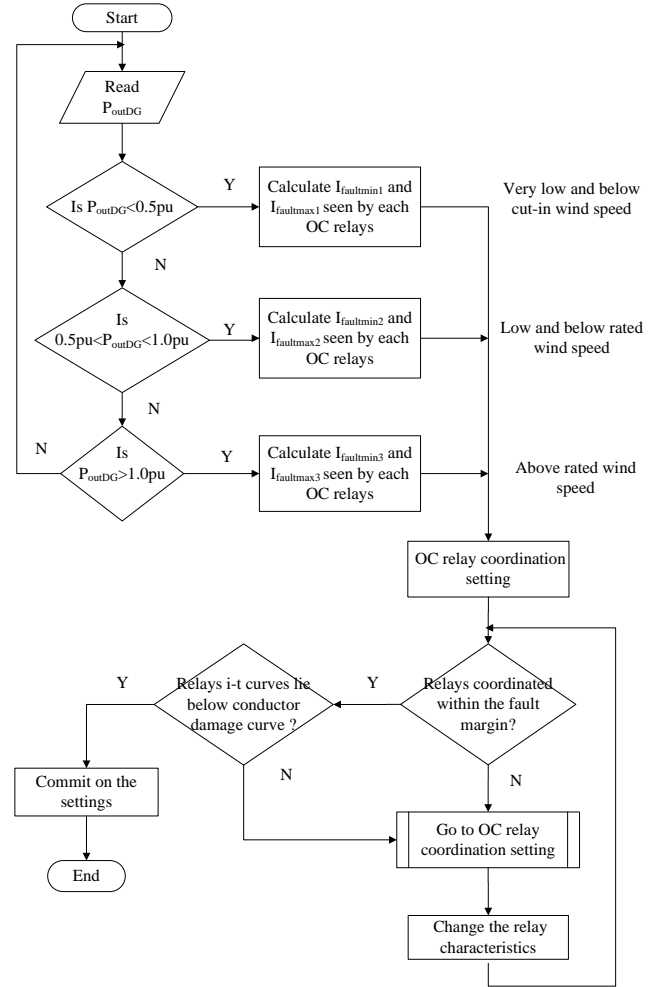


Fig. 6. Flowchart of the proposed adaptive feeder OC protection scheme for DG penetrated radial OH distribution systems

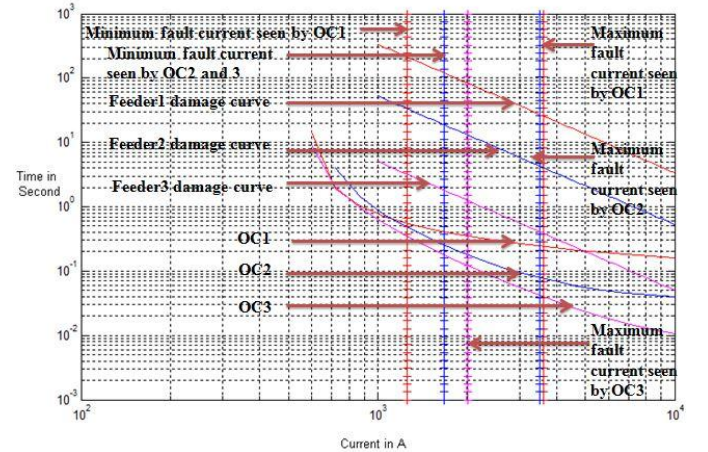


Fig. 7. OC relays coordination curves and conductor damage curves with DG at node C using the proposed adaptive feeder protection scheme

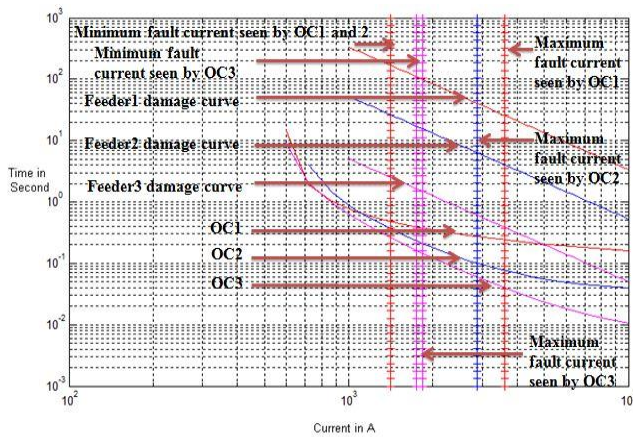


Fig. 8. OC relays coordination curves and conductor damage curves with DG at node D using the proposed adaptive feeder protection scheme

From figure 7 and 8, it can be observed that the relays OC1, 2 and 3 are coordinated between the fault margin (i.e. OC1 will lay above OC2 and OC3. OC2 will lie above OC3 within the maximum and minimum fault currents). It can also be observed from the same figures that the conductor damage curve of feeder 1, 2 and 3 lie above i-t characteristics of OC relay 1, 2 and 3. A three phase to ground fault is applied at 4s of the simulation time on the end of the feeder1. Figure 9 shows the current through feeder 1 and figure 10 shows the operation of the overcurrent relay OC.

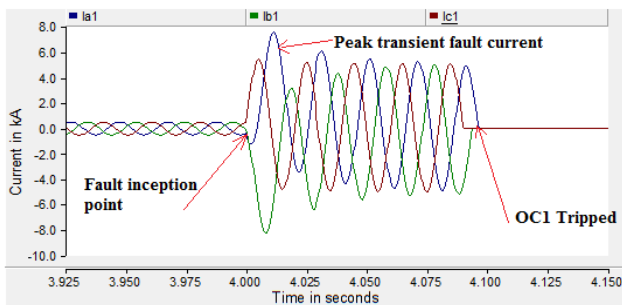


Fig. 9. Current through feeder 1 for a three phases to ground fault applied at the end of feeder 1

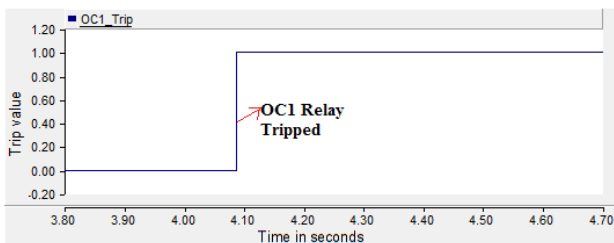


Fig. 10. Operation of OC1 Relay for a three phases to ground fault applied at the end of feeder 1.

6. Conclusion

A software package for conductor sizing and protection coordination settings is presented. OC protection of radial OH distribution feeder system is implemented. The impacts of the OC protection due to the presence of DG are analyzed. An adaptive feeder OC protection

scheme is proposed and evaluated considering the intermittent nature and dynamics of SEIG based wind energy conversion system.

Appendix

Parameters of the simulated system:

Utility: 33kV line-line, 50Hz.

Feeder 1: Length-2112 ft.

Phase conductor: 4/0 ACSR diameter= 0.5630 inch, GMR= 0.00814 ft., Resistance=0.5920 ohm/mile.

Feeder 2: Length-2112 ft.

Phase conductor: 1.0 ACSR diameter= 0.3550 inch, GMR= 0.00418 ft., Resistance=1.38 ohm/mile.

Feeder 3: Length-2112ft.

Phase conductor: 6.0 ACSR diameter= 0.1980 inch, GMR= 0.00394 ft., Resistance=3.98 ohm/mile.

Distribution Transformer: 3 phase, 5MVA, 33kV /11kV, $Z=6.0$.

Load 1and 2: 3 phase resistive, 2 MW each.

Load 3: 3 phase resistive, 1 MW.

Parameters of the simulated system: When DG is present

DG Feeder: Length-1056 ft.

Phase conductor: 4.0 ACSR diameter= 0.2500 inch, GMR=0.00437 ft., Resistance= 2.5700 ohm/mile.

DG Transformer: 3 phase, 2MVA, 0.415kV /11kV, $Z=4.0$.

Load 1: 3 phase resistive, 2.75MW.

Load 2: 3 phase resistive, 2.5MW.

Load 3: 3 phase resistive, 1.25MW.

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