Review of Status of Protection Issues and Schemes in Smart grids

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Abstract: *A nanogrid is a small scale power system that consists of two or more distributed sources that supply power to nearby loads. Typically, the total load on a nanogrid is less than 20kW, and the loads are located within 5km of the sources. The sources are primarily renewable based, although non-renewable sources such as battery storage and diesel generation may be included to ensure supply reliability in the presence of the fluctuating renewable sources. The integration of individual DERs can cause variety of problems like local voltage rise, violations in thermal limits of certain lines and transformers, unintentional islanding etc. DG Protection coordination (selectivity) is adversely affected by DG penetration in distribution systems. Traditional over current protection is designed for radial distribution systems with fault current flow in single direction; whereas the connection of DERs into distribution networks changes the singly fed radial networks into complicated ones having multiple sources* and thus the flow of fault current is changed from unidirectional to bidirectional [1].

Key words: Distributed energy resources (DER), Fault current, Protection issues, Protection schemes

1. Introduction

The conventional power system operates radially, that means the generating stations such as thermal power plant, hydro power plants, and nuclear power plants are centralized. The energy from these generating stations is transmitted through transmission lines over long distances. In this radial system the power flows from one direction only i.e. from generating station to customers. If the fault occurs in this system then the magnitude of fault current is proportional to the fault location and its protection is only done by over current based principle devices and time graded coordination principle to set primary and back up protection scheme. [1] Whereas by using distributed generation systems we can have decentralized and flexible power generation that can be possible to set up near the load centre also. This Distributed system may use renewable energy sources for their generation with storage devices to maintain the stability of the power supply. And if we integrate these DGs to the distribution network, then it will change the protection scheme of the network. It not only changes the magnitude of fault current but also changes the direction of fault current.

2. Protection issues in Smart grids:

The Distributed power generation is the one of the best options for local generation and distribution. One such independent power system is a Nanogrid. A nanogrid is similar to the microgrid concept proposed in [2]. A nanogrid is similar to microgrid, but the size of nanogrid is smaller than microgrid, with a capacity of 2-20 kW, basically it plays main role in the remote areas for supplying power to that area.

- Nanogrid protection issues can be broadly divided into two categories:
  - When Nanogrid operates in grid-connected mode and
  - When Nanogrid operates in islanded mode.

1) Dynamics in level of fault currents:

Fig. 1 shows how the magnitude of current changes as per the operating mode of the nanogrid.

a) Grid-connected mode:

If any fault occurs, let us say it present here at point 'F' then, I_{GF} the fault current is going to be driven by this grid and also fault current will be contributed by $G_1$and G_2.

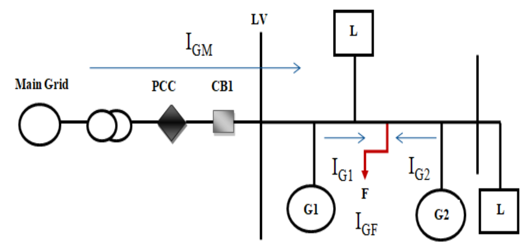

Fig. 1 Magnitude of fault current during grid-connected mode

$$I_{GF} = I_{GM} + I_{G1} + I_{G2} \quad \text{………………..(1)}$$

I_{GF} = Fault current

I_{GM} = Main grid current

I_{G1} = DG_1 current

I_{G2} = DG_2 current

This G_1 and G_2 are two renewable energy sources. Now, finally this fault current I_{GF} is the summation of I_{G1} and $I_{G2.}$ This is the scenario when a grid connected mode of operation.

b) Islanded mode:

Let us say now the grid is disconnected from the rest of the network due to the opening of the circuit breaker. That means, these two DGs are disconnected from the main grid in that case what will happen? So, in this case the fault current is equal to sum of only these two DG currents, there is no question of the I_{GM} the main grid current which is equal to zero. So here the fault current is less that the grid connected mode. So, the conclusion is the fault current level is different during different modes of operation.

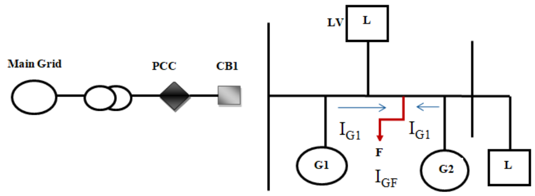

Fig. 2 Magnitude of fault current during islanded mode

$I_{GF} = I_{G1} + I_{G2}$ …………………. (2)

The fault current level is higher when they operate in a grid connected mode as compared to an islanded mode of operation. Similarly, if Inverter Based DER (IBDER) is there, then fault current is 2 to 3 times the rated current. But when DER is Synchronous Based (SBDER) then fault current is 6 to 7 times rated current.

2) Change in direction of fault current:

The penetration of DG not only changes the level of fault current but also alters the direction of fault current also. Traditional over current relays are unable to provide safety protection to the Nanogrid from this fault current. So we have to add directional unit along with over current relay.

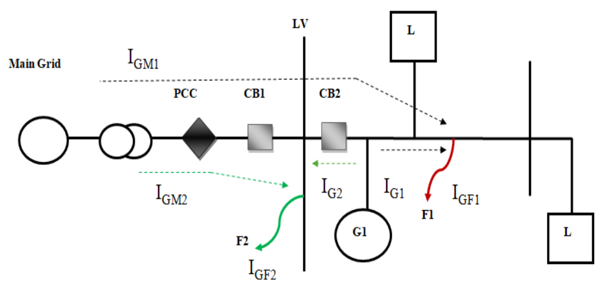

Fig. 3 Bidirectional of fault current

$I_{GF1} = I_{GM1} + I_{G1}$

$I_{GF2} = I_{GM2} + I_{G2}$

The green line indicates the fault current develops due to change in fault location.

3) False Tripping:

False tripping means the relay in the healthy feeder get trip due to the fault in the other feeder. We can add one directional unit here so that it can be easily understood that the healthy feeder relay should not trip.

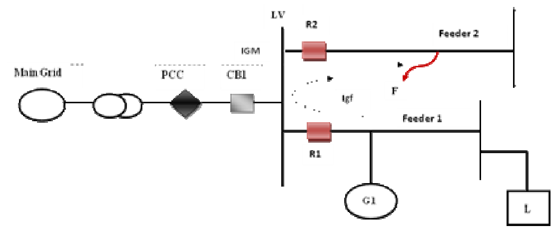

Fig. 4 False tripping

If any fault occurs like one fault is developed in feeder 2 then what will happen? This DG is going to contribute current to this fall point. At the same time main grid will also contribute some, current to this fault point; so there are 2 fault components because there are 2 sources so; obviously, we have 2 fault currents.

$I_F = I_{gf} + I_{GM}$

Where

I_F = Fault current

I_{gf} = Current supplied by DG_1

I_{GM} = Current supplies by Main grid

Here are two relays R1 and R2. This R1 is basically over current relay protecting this particular feeder 1 and this R2 is protecting feeder 2. Now here feeder 2 is basically in the faulty section and the feeder 1 is not the faulty section. So, it is not necessary to disconnect feeder 1; it is only necessary to disconnect this feeder 2. Due to this fault this relay R1 will see this I_{gf} amount of current that is also fault current. When there is some fault, the fault current magnitude increases. Now due to this particular fault, R1 is going to trip if it is an over current relay because this fault current magnitude may exceed the set threshold value.

4) Blinding of protection:

Utility grid contribution to the fault current is reduced due to contribution from DG sources. If initially there is no DG the fault current is supplied by the main grid only. But when DG is penetrated then fault current also given by DG source. So that the contribution of main grid faults current is reduced. The relay setting does not identify the fault in the grid.

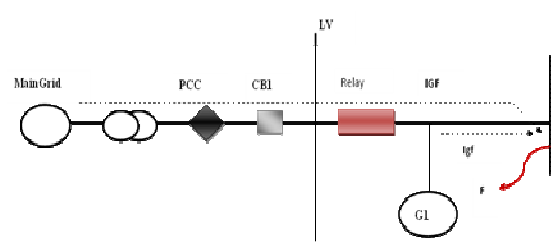

Fig. 5 Blinding of protection

In figure 5 if the distributed energy resource DER DG1 is not present, then if a fault occurs the fault current is supplied by only the main grid and according to that relay is set. But if DG_1 is penetrated in the line and then fault occurs, the fault current is the summation of both DG_1 current and main grid current. But as fault current remains same, so that main grid supplies least amount of current, so due to this the relay is not going to trip because of its setting. This is called as blinding of protection, i.e. fault is not identified by the relay.

3. Protection challenges in DC Nanogrid

- Limited fault current contribution of inverter- based DG sources in the island mode and inability of single setting over current relays in protection of dual-mode micro grids are common between AC and DC systems.
- Grounding
- Lack of natural zero-crossing current [3]

Solutions for protection challenges in DC Nano grids:

- Proper grounding architecture
- Fault current limiting method
- DC current interruption approaches
- Proper DC circuit breaker are required

4. Protection issues in AC Nanogrids:

1. Protection coordination with DG

If Distributed generators are added in the distribution networks, then it will affect the performance of the protective devices, because of conventional protection devices are designed to operate on radial system. But after addition of DGs the system changes to ring system.

Also other adverse effects of DG penetration are as follows: false tripping, nuisance tripping of protective devices, blinding of protection, and dynamics in level of fault current, unnecessary islanding operation.

So if Inverter Based DER (IBDER) is there, then fault current is 2 times the rated current. So that protection system with these sources may operate very slowly or may not response to the fault current during the fault at the time of island mode of operation.

Whereas when DER is Synchronous Based (SBDER) then fault current is 5 times rated current.

5. Protection issues in grid connected mode:

- **Selection of protection device/switch**

  For the selection of the proper protection device following points can be considered:

  1. Required speed of operation,
  2. Voltage level as well as the
  3. Availability of fault current
- **Spurious separations or false trips**

  It may occur, for example, due to failure of PCC device to discriminate whether the fault is on the utility side or within the Nanogrid.
- **Re-synchronisation**

  The process of re-synchronize and reconnection may either be manual or automatic and it may need several seconds to several minutes depending on the characteristics of the system.

6. Protection issues in islanded mode:

When there is islanded mode, then the fault current nature is different from the grid connected mode. As in grid connected mode the fault current is very much high sometimes it is 15-50 times the full load current, but in islanded mode the fault current is only 5-6 times the full load current. Whereas over current protection devices are set for the fault current 15-20 times the full load current. So the protection devices in island mode will not operate.

Anti-islanding protection:

7. Protection schemes for grid connected mode

Sr. No.	Protection Scheme	Advantages	Limitations
1	Over current (OC) principle and time dependent characteristics of current [4,5]	To prevent high fault clearing times and maximizing DG connection to distribution networks	This scheme is unclear about high impedance faults (HIF) and is more effective with increased number of relays
2	An adaptive over current pickup strategy [6]	This strategy helps to update the minimum pick up current of the overcurrent relay, according to the changes the fault analysis of the system.	This protection scheme works properly when the system operates with less number of DGs.
3	An intelligent agent based protection scheme [7]	1. The scheme assumes peer to peer communication between IEDs. 2. The scheme provides higher speed of backup protection as compared to conventional protection, autonomous system monitoring and adjustment of parameters,	But needs high speed communication.
4	Use of a fault current limiter (FCL) [8]	With this original directional OC relay setting can be used without disconnection of DG.	
5	The use of TCSC (Thyristor Controlled Series Capacitor) as an FCL [9]	No DG disconnection, use of original relay settings, avoid up grading of equipment for handling large currents	But impedance of FCL increases with increase in individual DG capacity hence its cost increases.

8. Protection schemes for only Islanded mode

Sr. No	Protection Scheme	Advantages	Limitations
1	Harmonic content based protection scheme [10]		For correct relay to trip, relays must be synchronised using communication link.
2	A voltage based protection scheme [11,12]	This scheme can be verified with the help of simulations for different types of faults at various locations.	In this protection scheme the following faults are not considered High Impedance Fault (HIF) Single-pole tripping Trip decision depends on the communication link.
3	Symmetrical components and residual current based measurement scheme [13]	No use of the communication link and provides full protection from LG and LL faults	Three phase and high impedance faults and single pole tripping not considered.
4	An adaptive protection scheme based on telecommunication and modern protection relays or IEDs [14]		Adaptable to operational modes of Nanogrid but highly dependent on communication link, Similarly here, the results of simulation are not considered clearly for the particular type of fault.

9. Protection schemes for both grid-connected and islanded mode

Adaptive protection schemes: Protection scheme will operate with the change in system condition [15, 16]. It can be defined, as according to changes in the system condition and other factors protection relay setting changes.

Adaptive protection can be defined as responding to various changes in the power system and other environments by calculating and adjusting the line protection settings and behaviour characteristics online [17]. To apply adaptive protection scheme following points are required:

1. It requires communication network.

2. Collective action of different protection scheme is required for getting optimum protection of the system.

3. For each and every fault there may be different relay settings and different methods may be used.

4. For getting solutions network may be divided into small zones [18].

a) Adaptive overcurrent scheme: [19]

Here are three tables that consist of event, fault current and action table. To update these tables and store the periodical data in the adaptive overcurrent protection scheme, central protection unit is used. All possible configurations of smart grid with corresponding status of Distributed sources are recorded in the event table. In the fault current table the current measured by relay for different combinations is stored. Whereas in the action table, different relays for particular fault type with its time delay are listed. According to the status of all three tables, the central Protection unit is able to give the tripping signal to the particular relay. If by some means if that relay does not trip, then, according to the time delay setting the next relay will operate as secondary backup protection. If a fault occurs near to the main grid, then the relay closer to the fault will operate and disconnect the main grid, operating the system into islanded mode [20]. This adaptive overcurrent protection scheme faces some problems which are as follows:

1) All combinations have to be considered with different locations and faults.

2) Sometimes with large network complicated analysis has to be done.

3) The installation cost of communication unit is more.

b) Differential protection schemes:

Generally differential protection is done for elements such as busbar, transformer, line, etc. this scheme operates on the basis of comparison of current measured by relays which are placed at the both ends of these elements. If any fault occurs in this protected element, then the difference between the measured values go above the threshold value which makes relay to trip to disconnect the faulty section from the network. In addition to this relay, there is a backup protection is available with some time delay. [21, 22]. The protection consists of a differential method with conventional over current scheme in addition with communication device is proposed to protect the medium voltage microgrid both inverter based DG (IBDG) and synchronous based DG (SYBDG). This system is unable to protect the unbalanced load grid [23].

One researcher has given another method of protection which consists of a differential method with digital relays and phasor measurement units (PMUs) in addition with communication units [24]. This method also provides protection against (HIFs) that is a High Impedance fault. As PMU has high cost so that this method is costly.

Protection scheme for microgrids both radial and looped feeder is introduced in the reference [25]. Here protection is designed for busbar and the DG sources. Busbar has a current differential relay, and for the protection of DG sources this scheme provides over voltage and under voltage protection, reverse power flow protection, and synchronisation check relay. This methodology gives robust protection, but it has some issues related to unbalanced load and switching transients.

With this differential protection there are some drawbacks which are listed as follows:

1. It needs communication devices as the main element, if failure in such method makes protection of microgrid in danger.

2. Use of costly equipment used for measurement of synchronization checking.

3. Some difficulties related to unbalanced load are still there. And some problems are persisting during switching of DG sources.

c) Distance protection schemes:

For the protection of AC microgrid and its subgrids, distance protection is another way. The basic operation of the distance relay is based on the impedance calculation after measuring the value of voltage and current at the fault location to the identified the fault location. Before the occurrence of fault the impedance value is high because it has the load impedance. During the fault the impendence is less, because it includes only line impedance. Thus, by measuring the impendence value before and after the fault, it is useful for finding the location of fault [26, 27].

In the distance protection, the line is divided into three zones. In the first zone the relay protects 80% of the line length immediately, no time delay is provided here. In zone 2 relay provides protection to first zone line as well as the 20% of the next line with some time delay. In the next zone relay protects the both previous zones with 25% protection of that zone line with some tripping time.

The study about this protection scheme was explained in the [28, 29]. Here a new admittance protection scheme was explained which works on the basis of inverse tripping time characteristics. The proposed relay has the capability to operate on different types of fault conditions. Though this method has some drawbacks which are as follows:

1. It depends on the arrangement of microgrid and nature of DG sources.

2. There may be errors due to resistances in impedances measured by relays.

3. Difficulties may occur in short lines while measuring impedances,

d) Pattern recognition schemes [30, 31]:

A new approach of protection scheme was explain in reference [32], where it uses a time frequency transform technique, which has the capability to take care of many faults in grid connected as well as islanded mode. In this proposed scheme, for the extraction of spectral energy contents, S-transform is applied. Afterwards, for different fault patterns are recorded according to energy calculations. The protection scheme operation, i.e. detection of fault and isolation of the faulty section is based on the preset threshold values in different fault patterns.

This proposed scheme is less responsive to the synchronization errors. To work with this scheme it is necessary to train the system. This training work is done with the simulations and with the actual cases and that's why it is not practically possible.

For adaptive protection scheme we require communication system. These communication systems are different according to the use of its, means whether it is used directly for protection or only for communication and just transferring data / information [33].

10. Conclusion

This paper presents the different protection issues which are takes place in smart grid when it is operated in different modes such as grid connected mode and island mode.

Also, it presents the different protection schemes that can be used in different modes. Basically an Adaptive protective scheme is used because it will operate with the change in the system mode or conditions.

As for the operation of adaptive methods it requires a transfer of data or information in the form of measured quantities such as voltage, current and phase angle, etc. Also it requires interconnecting signals between different devices with some communication units. So for effective operation of this protection method, the communication link should be good in condition.

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