Impact of DG Integration on Protection Coordination & Possible Solutions

Arpan Banerji, Member IEEE
School of Electrical Engineering
IIT Bhubaneswar
Bhubaneswar,India
arpan.sprite@gmail.com

Pratyusha Biswas Deb *Dept. of Electrical Engineering Narula Institute of Technology,*
KOLKATA, INDIA
pratyusha.biswasdeb@nit.ac.in

Ambarnath Banerji, Sr. member IEEE,
Dept. of Electrical Engineering Narula Institute of Technology, KOLKATA, INDIA ambarnath.banerji@nit.ac.in

Sohini Pal
Dept. of Electrical Engineering
Narula Institute of Technology,
KOLKATA, INDIA
sohinip815@gmail.com

Suvargha Ghosh Dastidar *Dept. of Electrical Engineering*
Narula Institute of Technology,
KOLKATA, INDIA
suvargha2000@gmail.com

Hiravra Koley
Dept. of Electrical Engineering
Narula Institute of Technology,
KOLKATA, INDIA
koleyhiravra2@gmail.com

***Abstract*—Every power system is armed with its own protection system to protect it from most types of faults. Coordination is maintained between the various protective gears to avoid failure of the protection system. This coordination gets disturbed when a Renewable energy based Distributed Generation is integrated into the distribution system. A number of issues come up, which does not allow the normal protection system to function properly. Many researchers have been presented solutions to overcome these issues. The present work attempts to bring out the impact of these issues on the protection coordination and the possible solutions proposed by various researchers to overcome these problems. The present work will help the potential researchers with a list of protection issues due to impact of DG / microgrid integration & their possible solutions and help them to further their research for more efficient and better protection system.**

***Keywords*—Microgrid, Protection Coordination, Overcurrent Protection, Distance protection, Adaptive Protection.**

I. Introduction

Fast depleting fossil fuel, global warming and environmental sustainability are causing a paradigm shift in the way electricity is generated. Further generation capabilities are being created using renewable energy resources. Most of these generations are small in size and are generated near the loads. These generations are called Distributed Generations (DG). Hence for grid connection these generations are connected to the distribution side of the grid [1]-[3].

Furthermore, most of these DGs are not interconnected. There is a trend to have flexible connection strategies of these DGs and have the benefit similar to that of the grid. The MicroGrid (MG) concept is built out of this desire for a system with flexible interconnection [4]-[5]. Thus a MG is a low voltage (LV) distribution which provides for:

(1) Quality power to the customer with mission critical loads.
(2) Relief to the Distribution Network Operators (DNOs) as their distribution system is already overloaded.
(3) Where the load centre is remote from the utility grid.

II. Protection Issues

A. Basic Issues

A desired power system is one which is free from all types of faults and supplies loads without interruption. Such a system is either not feasible or is beyond reasonable cost. So, protection systems are designed to protect the power systems against most possibly occurring faults.

Sometimes the DGs are connected to directly feed into the distribution network. DGs that operate through synchronous or induction generator units and directly feed into the distribution network cause a change in the fault current level as both kinds of generators can add to fault currents [1].

When Inverter interfaced distributed generation (DGs) units are directly connected to distribution network, fault current is restricted to a smaller number. Inverter interfaced DG supplies limit fault level to about twice its rated value.

Therefore, the contribution of the DGs to fault level is dependent on the capacity of DG, the placement location of DG and finally on the technology used for the DG.

DGs may be interconnected to form a Microgrid. These Microgrids can run in both grid-connected and islanded modes of operation. As required for all types of power systems, it is important to protect the microgrid, in both modes of operation against all types of faults [5]-[6].

B. Effect of DG Integration

1) Over-reach of relay or Loss of relay sensitivity:-
During a grid connected mode of operation of the distribution system a fault downstream of the DG location causes the short circuit current to increase. This is due to the DG adding its contribution to the short circuit current.

$$I_{f\_total} = I_{f\_grid} + I_{f\_DG} \tag{1}$$

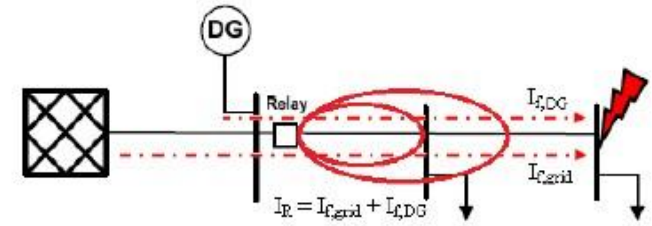

Fig.1 Over-reach of relay due to DG integration

As the fault current increases the relay sees the impedance up to the fault point to be lesser than it actually is. The relay identifies the fault to be much closer (in a different zone) than actual. Thus causing the Over-Reach of the relay [7].

2) Blinding of overcurrent protection or Under-reach

With the grid connected if a fault occurs between the grid and the DG, there is a reduction of current contribution from the grid. This is due to the fact that a part of the fault current is contributed by the DG.

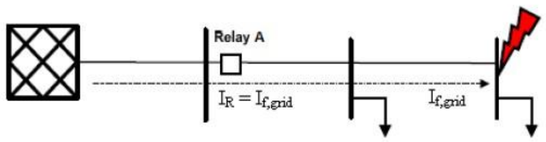

Fig.2 Overcurrent protection without DG

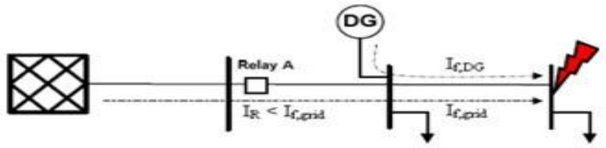

Fig.3 Overcurrent protection with DG integration.

In Fig.2 it is observed that the utility grid is supplying power to the fault that has occurred at the far end of the grid. The whole fault current flows through the relay A. In Fig.3 it is observed that a DG has been connected to the bus in between the relay and the fault point. Therefore, the total fault current supplied by the grid gets decreased. The relay A, due to the reduced current, will see the impedance upto the fault point to be much higher. Therefore, it considers the fault to be much further away. This lead to under-reach of the relay [7].

3) Sympathetic tripping or False tripping of overcurrent protection

With the grid connected to the distribution system and if a fault occurs on a feeder adjacent to that having a DG connected, the DG's current contribution may exceed the pickup setting of the overcurrent relay, if the DG's capacity is sufficiently large as shown in Fig. 4. This leads to a false tripping of the breaker [7].

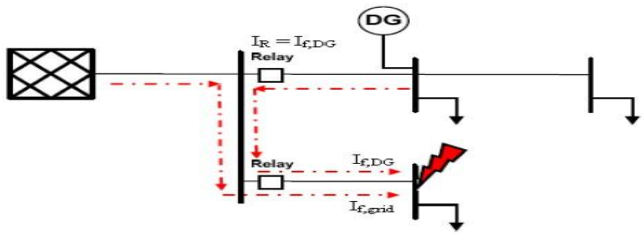

Fig.4 False tripping of overcurrent relay

4) Selectivity problem /protection coordination problem

Presence of DGs within a microgrid causes bidirectional flow of power and fault currents in both modes of operation, grid-connected mode and islanded mode.

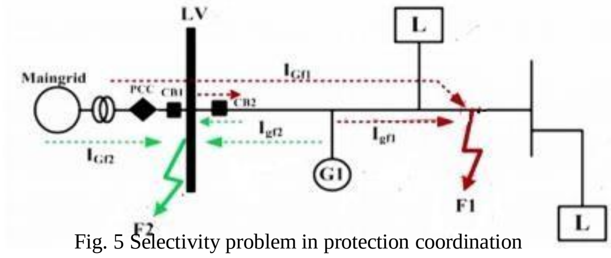

Fig. 5 Selectivity problem in protection coordination

From the Fig. 5 it can be observed that for each fault the direction of fault current changes. Traditional unidirectional overcurrent relays are unable to provide safety protection to microgrid [7].

5) Ineffective use of overcurrent protection

A microgrid in islanded mode and having inverter interfaced DGs has fault current limited to around tywice the rated current of the power electronic devices ued in the inverter.

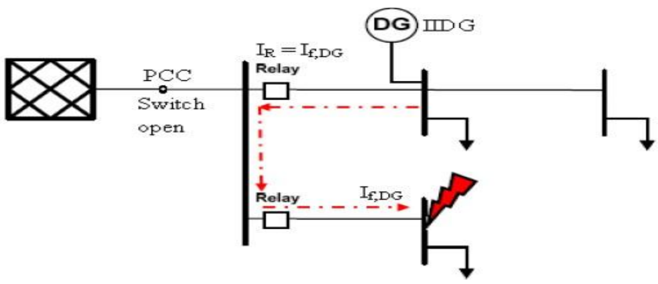

Fig. 6 Ineffective use of overcurrent relays

Insufficient fault current contribution from inverter-interfaced DGs will not exceed the overcurrent setting of the relay causing maloperation of the relay [7].

III. Solutions to Protection Issues

A. Distance Protection

This protection scheme uses either admittance or impedance measurements to detect faults. It has inverse time characteristics according to the different zones of protection. Relays with this scheme can detect faults in all modes of operation whether the microgrid is in islanded mode or in grid connected mode.

They can isolate a fault that happens on either side of the protected circuit. But the important point to be kept in mind is that the reach settings must be different for forward and reverse faults.

The drawbacks being that there might be error in the measured admittance up to fault point. A suitable correction can be applied. Further there might be loss of accuracy which might arise due to problems with fundamental extraction due to harmonics, current transients and decaying DC magnitude [8]-[9].

Distance protection uses measured current and voltage values at the relay location to calculate fault impedance using

$$Z = \frac{U}{I} \quad (2)$$

U and I represent the voltage and current measured at the relay location respectively and Z is the apparent impedance seen by the relay.

If an intermediate infeed in the form of a DG source is present between the relay location and fault point, the DG will feed the fault as well and consequently, the voltage measured at the relay location will be higher. Thus, the relay will see an impedance value higher than the actual. It might infer that the fault is at a higher time-graded zone and introduce unnecessary tripping delay or even not trip at all.

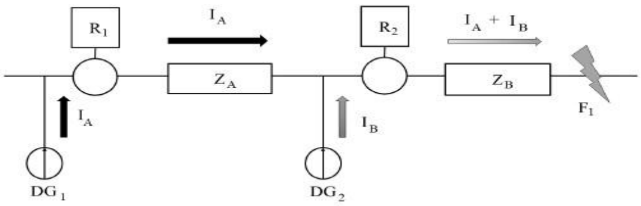

Fig. 7 Distance protection with DGs integrated

In the above situation, for the fault F1, UA and IA are the current and voltage measured by Relay R1 respectively.

$$U_A = I_A Z_A + (I_A + I_B) Z_B \quad (3)$$

$$Z_1 = \frac{U_A}{I_A} = Z_A + \left(1 + \frac{I_B}{I_A}\right) Z_B \quad (4)$$

Therefore there will be difference in the actual and measured Z_1.

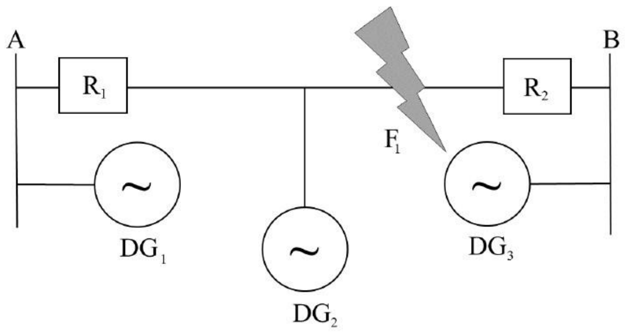

Fig. 8 Distance Protection with communication between relays

In the circuit relay R_2 sends the value of current measured by it to relay R_1. Also, DG_2 communicates its connection status to R_1. Since power can flow in either direction, R_2 also receives the value of current measured by R_1 and the connection status of DG_1. The error in impedance measurement is (IB/IA) times the value of Z_b. If the value of the current measured by R_2 is known, the measurement error can be calculated and subtracted from the impedance measured by R_1.

The expression for corrected impedance value is given by (5)

$$Z_{corrected} = Z_1 - \left(\frac{I_B}{I_A}\right) Z_B \quad (5)$$

B. Current Limiting Protection Schemes

(a) Use of External Devices

Fault Current Limiter (FCL) is used to overcome the impact of fault current feed from DGs. FCL is placed in series with the DGs in the distribution system [7].The DGs' fault current contribution is limited to a magnitude which is less than the trip setting value of the relay by the large impedance of the FCL. This effect is obvious for use with synchronous, induction machine based distribution generation to bring the magnitude of the fault current to the lower level of fault contribution by inverter-interfaced sources of distribution generation

The method has advantage as it retains coordination among original protective devices.

(b) For Inverter based DGs of Islanded Microgrid, protection can be achieved by limiting the current flow through the switches of the inverter [6].

A voltage and current controller of the inverter is used to detect and thereby limit the large current during faults. Voltage/ current signals are transformed from *abc* coordinate to rotating *αßo*-frame, the disturbances are identified, and fault occurrence is detected. Further a signal is sent to a logical controller which causes operation of the circuit breaker/static switch to isolate the faulty section. The healthy phases remain undisturbed. As conventional protection devices like relays are not incorporated, the fault identification to clearance process is very fast.

C. Adaptive Protection Scheme

It is applied to conventional protection system to vary the parameter settings or the relay operating characteristics in response to the changes in the power system [10]. This protection scheme is implemented using extensive communication among the numerical relays. It mainly consists of two stages:

1)Topology Sensing:-

Analyses of actual operating condition of the microgrid are done by continuous measurement of the breaker position, penetration levels of the DGs and other grid parameters. It also detects values to be altered for the adjusted tripping characteristics. During a fault, trip signal to the respective circuit breaker is generated.

2) Calculation of Relay Settings:-

Predicted data of the DG availability is utilized in order to review the range of microprocessor base relays for each new operating condition.

Adaptation takes place if selectivity is not given any longer. If the adaptation is successful and the boundary conditions are not broken, the tripping characteristics of respective relays will be matched. Therefore it makes adjustment to protection function according to the changes in the power system.

The Master Control Protection Unit (MCPU) monitors the Static Switch and C.B status of the microgrid continuously. Whenever there is a change in the monitored breaker position, an interrupt signal is sent to MCPU and the new DGs fault current contribution is calculated and updated in the relay operating data.

But this algorithm may not be appropriate for large microgrid setups because analysis is done offline and requires excessive memory to store all the data.

For any relay, the operating fault current is calculated by,

$$I_{relay} = (I_{fault(grid)} \times OM) + \sum (k_i \times I_{fault(DG)} \times SB) \tag{6}$$

OM = Operating Mode

SB = Status of Breaker

ki= Impact factor of i^{th} distributed generator on the fault current sensed by the relays

D. Genetic Algorithm based Differential zone protection

Differential protection in general uses an ideal number of relays and sensors inside each protection zone. Current sensors is positioned on the secondary side of transformers for every load as well as relays located at the source location of distribution generation [8] [12].

Zone relays detects a fault when the distribution generation source currents go beyond the sum of load currents inside the protection zone.

Then the relays sends a signal to the distribution generation source at the faulty zone and makes it trip.

A genetic algorithm is used to find the best placement for sensors, circuit breakers and relays to decrease total cost to a minimum. The steps involved are:-

1) Short-circuit current (kA) is found by short-circuit analysis.

2) Result of the short-circuit analysis helps to develop the coordination between the protection elements .

3) The complex protection coordination between protection elements is solved and optimized with the help of Genetic Algorithm.

E. Protection Scheme for Loop Based Microgrid

For this protection scheme Illinois Tech microgrid configuration was used as the test bed [12]. The microgrid is operated by the Robert W. Galvin Center in which the power is supplied to various loads by the utility as well as the microgrid sources in normal grid condition.

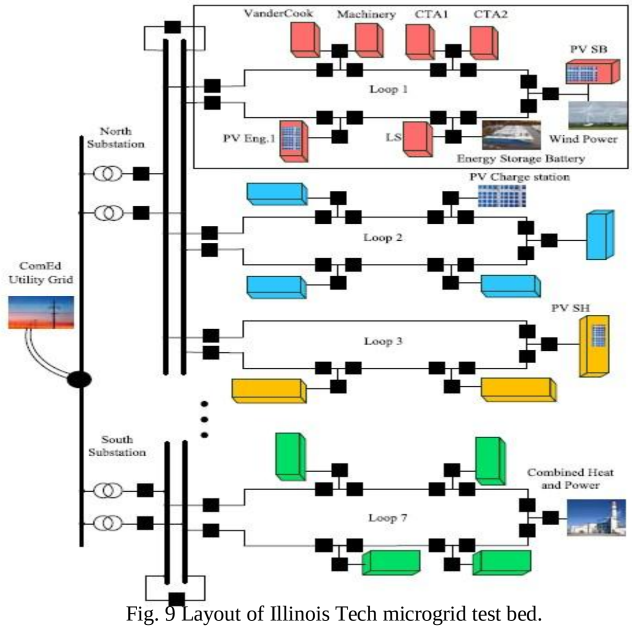

Fig. 9 Layout of Illinois Tech microgrid test bed.

The protection is divided into four levels including

- Microgrid
- feeder
- loop-way
- load-way level

The four levels of protection can be adopted to isolate both internal and external faults in microgrids.

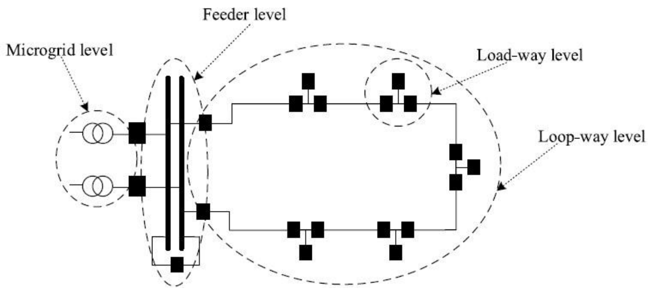

Fig. 10 Different levels of protection for a loop in microgrid

The load-way level is the basic protection element which is integrated with various DGs and loads. The protection zones include Area 'a' among breakers and Area 'b' of DG/load.

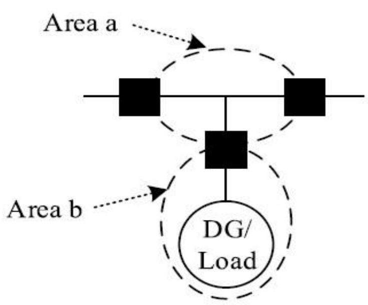

Fig. 11: Protection zones for load –way level.

The short-circuit current in the grid-connected mode is different from that in the island mode because the inverter-based DGs cannot supply sufficient short-circuit currents.

Therefore, a dual-strategy protection is developed for certain parts and a single-strategy protection for others.

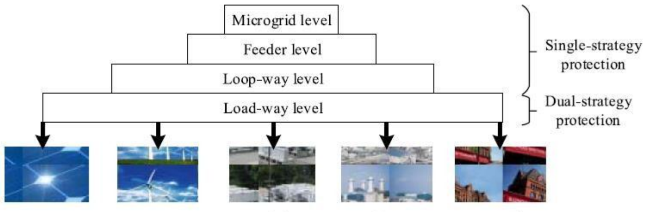

Fig. 12 Strategy allocation for different levels.

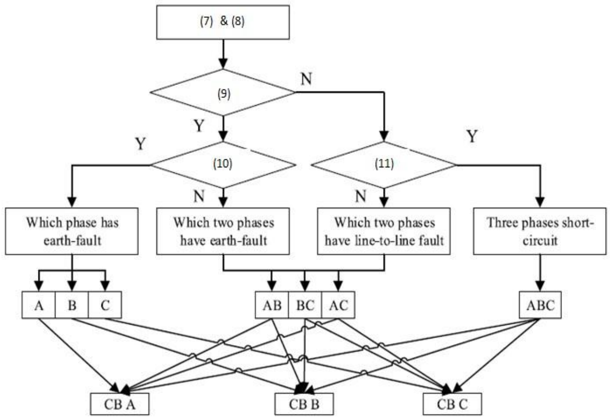

Fig. 13 Flow chart for fault analysis.

(7) and (8) are the initial conditions which are taken at the load loop level.

$$I_{abc}|_{t0+\Delta t} - I_{abc}|_{t0} > I_{se} \quad (7)$$

$$i_a + i_b + i_c > \quad (8)$$

The phase selector criterion is represented by (9)

$$\frac{|I_a + I_b + I_c|}{3} > \varepsilon_1 \quad (9)$$

ε_1 is a small value to check the zero sequence current

The single phase or two phases with an earth fault is identified using (10).

$$\max(\Delta I_{ab}, \Delta I_{bc}, \Delta I_{ca}) >> \min(\Delta I_{ab}, \Delta I_{bc}, \Delta I_{ca}) \quad (10)$$

ΔI_{ab},ΔI_{bc},ΔI_{ca} are differential line currents in Δt time interval.

Identification of the two phases with line-to-line faults or faults that include the three phases is done using (11)

$$\max(\Delta I_a, \Delta I_b, \Delta I_c) >> \min(\Delta I_a, \Delta I_b, \Delta I_c)\text{-} \quad (11)$$

ΔI_a,ΔI_b,ΔI_c are differential phase currents in Δt time interval.

IV. Conclusion

This paper presents the various issues that crop up when the DGs are integrated with the distribution. Then when the DGs are pooled together to form a microgrid and which is then integrated with the distribution network more issues crop up due to the fact that the microgrid can operate both in grid connected and islanded mode. The present work summarizes the methods proposed by various authors to overcome the protection issues, when DGs either alone or in the form of a microgrid are integrated with the distribution system. An attempt has been made to collate all the protection issues related to DG integration and various solutions proposed, in this work, so that future investigators can have an insight into the problem in a single paper and can work on more advanced solution to the problem.

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