Power Flow Control and Protection in Micro-grid

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***Abstract*—In this paper, a micro-grid consists of clusters of load and distributed generators that operate as a single controllable system is explored by means of computer simulations. The interconnection of distributed generator to the utility through power electronics converters has raised concern about safe operation and protection of the equipment. In this work, a method for power flow control between utility and micro-grid through back-to-back converters, which facilitates desired real power flow between utility and micro grid is presented. Controlled power flow between the micro-grid and the utility can be used in case of any contractual arrangement. In the case of a fault in either utility or micro-grid side, the protection system should act not only to clear the fault but also to block the back-to-back converters so that its dc bus voltage does not fall during fault. The converter's internal mechanism prevents it from supplying high current during a fault and this makes the operation of a protection system complicated. To overcome this, an admittance based relay scheme is proposed. The investigation reveals that the proposed protection and control schemes are able to ensure reliable operation of a micro-grid. The model of the power system is simulated in PSCAD.**

***Keywords*—Power flow control, Micro-grid, Protection, Mho Relay, Back-to-Back converter**

I. Introduction

The complete power system can be segregated into number of micro-grids. But micro-grid has its own structure. A micro-grid comprised of generators called micro-sources and its own loads called local loads. The concern is about proper load sharing between different distributed generators (DGs) and the utility grid. The DGs are interconnected to the grid through power electronic converters [2]. Generally micro-grid can be structured as a cluster of DGs, which are connected to the main utility grid. This interconnection is usually performed through voltage-source-converter (VSC) based interfaces.

It is crucial to achieve a proper load sharing by the DGs, while concerning the micro-grid interface to the utility. If the network is complex, in distribution level, load sharing with minimal communication is the best, which can be reconfigured and span over a large area. The most common method uses droop characteristics. Parallel converters are controlled to deliver fixed real power to the system. The use of local signals as feedback to control the converters is desirable, since in a real system, the distance between the converters may make an inter-communication impractical. With this in mind, this paper proposes a configuration that is suitable for supplying electrical power of high quality to the micro-grid, specifically when it is being supplied through controlled converters.

Protection of both the micro-grid and utility is the major concern in this divided power system technique [9]–[10]. The fault may occur either in utility or in micro-grid. The system protection is to be done by various techniques as the disturbance produced by the fault in micro-grid technically differs from the disturbance produced by the fault in utility

II. System Structure

A simple power system model comprises of back to back converters, one micro-grid load and two DG sources is shown in Fig.1. The real power drawn/supplied is denoted by P. The back to back converters are connected to the micro grid at the point of common coupling (PCC). Both the converters VSC-1 and VSC-2) are supplied by a common dc bus capacitor. DG-1 and DG-2 are connected through voltage source converters to the micro grid. The output impedances of the DGs are also show in the figure.

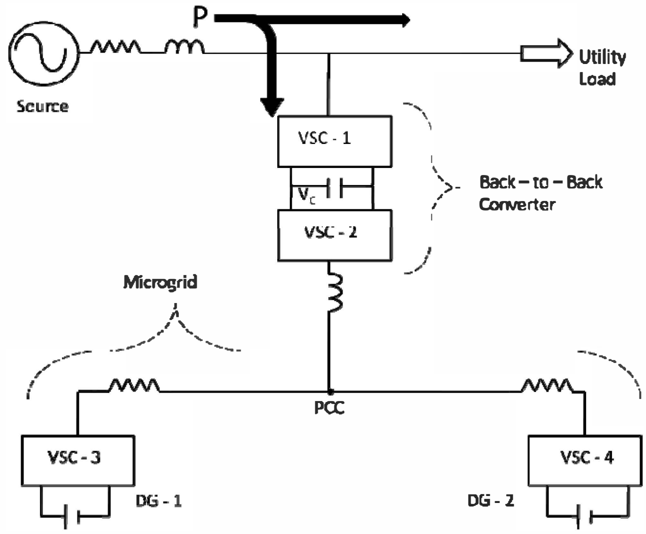

Fig.1 System structure of the test system

The test system can be operated in two modes. To mitigate the impact of grid disturbances on the micro-grid, back-to-back converters can deliberately be used. They can also provide power flow control between utility and micro-grid providing total frequency isolation between the utility and the micro-grid. In back-to-back, voltage or frequency fluctuation in the utility side has no severe impact on the voltage or power in the micro-grid side. The back-to-back converter is ensured, at in the above discussion for on line current harmonics. It consists simply of a force-commutated rectifier and a force-commutated inverter connected with a common dc-link. The properties of this combination are well known; the line-side converter may be operated to give sinusoidal line currents, for sinusoidal currents, the dc-link voltage must be higher than the peak main voltage, the dc-link voltage is regulated by controlling the power flow to the ac grid [3]. The next section discusses the structure of VSCs.

III. Converter Structure

The converter structure for VSC-3 is shown in Fig. 2. DG-1 is assumed to be an ideal dc voltage source supplying a potential of V_{dc} to the VSC. The converter contains three H-bridges. The output terminals of the H-bridges are connected to three single-phase transformers. The resistance R_f represents the switching and transformer losses. Here, an LCL filter structure is chosen to suppress the switching harmonics. This LCL filter comprises of leakage reactance of the transformers denoted as L_f, the filter capacitor C_f and L_1. The L_1 also represents the output inductance of the DG source. This LCL filter is connected at the output of the transformers. The converter structure of DG-2 (VSC-4) is same as DG-1. The notable thing is that, while VSC-2 has an output inductance L_G, VSC-1 is directly connected to the point A without an output inductance [1]. This implies that the voltage across the filter-capacitor C_f of VSC-1 is the voltage at the point A on the utility side. The control strategies for parallel connected inverters are briefly explained in the references papers [4]-[8].

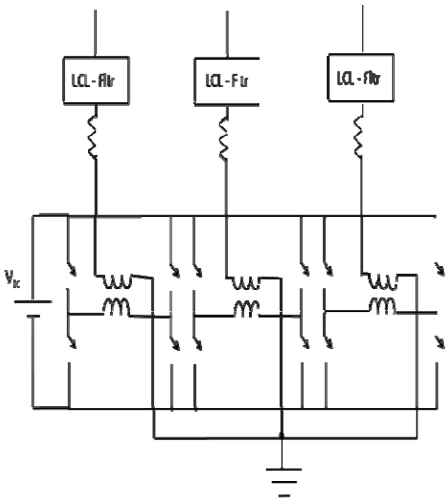

Fig. 2 Converter structure of the test system

IV. Back-to-back Converter

The converters of the back-to-back converter have same structure as VSCs of the DGs i.e., H-bridge converter structure but, in back-to-back converter both the converters are supplied by a common capacitor voltage V_c. The capacitor is used to create common dc link for both the converters. The pulse generation and triggering of back-to-back converters are done in the same way as for voltage source converters in DGs. The circuit shown in the Fig.3 functions as an ideal ac-to-ac power converter in which the real power can freely flow in either direction between the ac terminals of the two converters, and each converter can independently generate (or absorb) real power at its own ac output terminals. The inverter operates on the boosted dc-link, which makes it possible to increase the output power of a connected inductive load over its rated power. Added advantage in this application is that braking energy which is being wasted on a braking resistor can also be supplied back to the power grid. Hence back-to-back converter is a better option for better control in power flow [3]. The notable fact in back-to-back converter is that the power flow can be controlled faster.

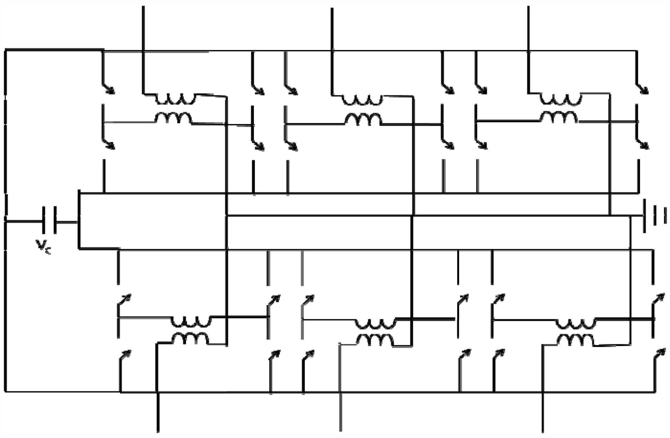

Fig. 3 Back-to-back converter

By controlling the power flow to the grid, the dc-link voltage can be maintained constant [3].

V. Direction of Power Flow

The power system can be operated in two modes. They are,

- Mode1: Power flow from utility to micro-grid
- Mode2: Power flow from micro-grid to utility

A. Mode1: Power flow from utility to micro-grid

The direction of the power flow in this back-to-back converter can be controlled by controlling the angle of triggering the VSCs. The angle generation for VSC-1 is done as shown in Fig. 4. Where, V_C is the voltage across the dc-link in back-to-back converter. For this mode i.e., power flow from utility to micro-grid, the angle of triggering for all the VSCs are zero. And no special controllers are needed.

B. Mode2: Power flow from micro-grid to utility

Here the angle of VSC-1 i.e. an inverter in back-to-back converter at the utility side is controlled by the angle controller shown in Fig. 4. Where, V_C is the instantaneous voltage of the dc-link and V_{Cref} is the reference voltage of the dc-link and K_P, K_I are proportional and integral gain respectively [1].

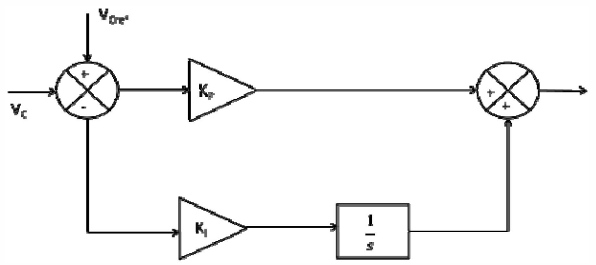

Fig. 4 Angle generator

This generating method can be used to generate the angle for all VSCs. The voltage and angle for other VSCs are done as follows,

1) For VSC-2: The angle and the magnitude of the voltage are decided using the same control scheme. The generated magnitude and the angle are given to the reference sinusoidal wave of the pulse generator. In the figure shown in Fig. 4 instead of the error between Vc and Vcref the error between the reference power and the actual power generated is taken into consideration. And thus reference voltage magnitude and angle are generated.

2) For VSC-3: The angle and magnitude generation for VSC-3 is different. It has been done using the equations given below,

$$\delta_3 = \delta_{3rated} - m_3 * (P_1 - P_{1rated}) \qquad (1)$$

Where, m_3 is droop coefficient and P_1isthe real power flow from DG-1.

3) For VSC-4: The angle and magnitude generation for VSC-4 is same as that of VSC-3. It has been done using the equations given below

$$\delta_4 = \delta_{4rated} - m_4 * (P_2 - P_{2rated}) \qquad (2)$$

Where, $m_4$is the droop coefficient and $P_2$is the real power flow from DG-2.

VI. Protection for the Power System

The utility side is protected by mho relay and the data required for mho relay have been calculated. The micro-grid is protected by over-current relay in which the rms (root mean square) value and the phase currents of the source are compared. The protection scheme for mho relay (i.e. at utility side) and over-current relay (i.e. micro-grid side) has been explained.

A. Utility Side:

The utility in our test system is protected by mho relay. The characteristic of the mho is been discussed in this session. When applying distance relays, it is necessary to describe their operating characteristics using the same voltage and current terms as used on the network. Distance relays operate according to the ratio of the voltage to current and consequently for any given ratio value there exists an infinite number of possible voltage and current states. To avoid this problem the operating characteristic is stated in terms of the ratio of volt to amperes or in other words in terms of impedance. The zone element in a distance relay is activated when the measured impedance lies within its operating characteristic, which is normally defined using a reactance-resistance diagram as shown in Fig. 5.

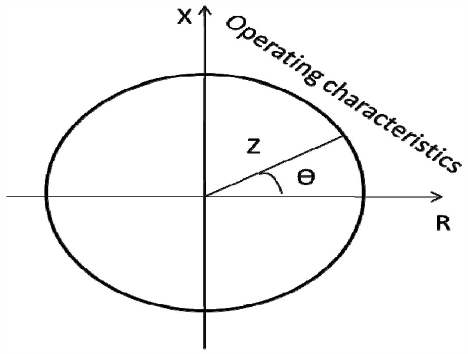

Fig. 5 R-X Diagram for MHO relay

This operating characteristic i.e., R-X diagram for a mho relay can be designed using the concept shown in Fig. 6

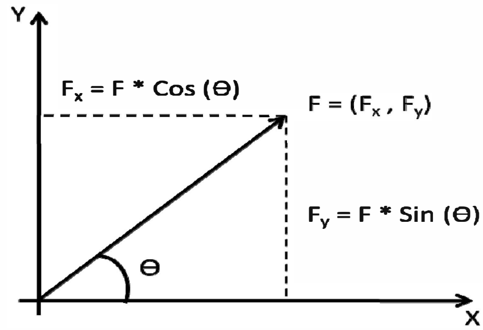

Fig. 6 Design of operating characteristics

In the diagram shown in Fig.6, the angle may be from 0 to 360. And using this concept the operating characteristics of the mho relay has been designed. The parameters required for the design of this protection are shown in Table 1.

TABLE I
ELEMENTS FOR MHO-RELAY

Elements	$\overline{V}$	$\overline{I}$
a-b	$\overline{V}$a - $\overline{V}$b	$\overline{I}$a - $\overline{I}$b
b-c	$\overline{V}$b - $\overline{V}$c	$\overline{I}$b - $\overline{I}$c
c-a	$\overline{V}$c- $\overline{V}$a	$\overline{I}$c - $\overline{I}$a
a-g	$\overline{V}$a	$\overline{I}$a + K_o * $\overline{I}_{res}$
b-g	$\overline{V}$b	$\overline{I}$b + K_o * $\overline{I}_{res}$
c-g	$\overline{V}$c	$\overline{I}$c + K_o * $\overline{I}_{res}$

In the Table 1, K_o is residual compensation. And the residual current value can be calculated by the equation (3)

$$\bar{I}_{res} = \bar{I}_a + \bar{I}_b + \bar{I}_c \quad (3)$$

The total scheme for working of mho relay is shown in Fig. 7. The voltage and current values of all the phases are processed. The processed signal will give the magnitude and phases of all currents and voltages. These values will be used to calculate the line to line impedance and line to ground impedance values.

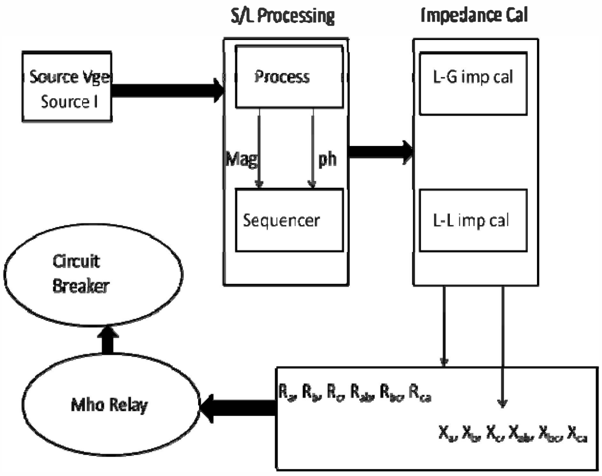

Fig. 7 Protection scheme for utility

The current and voltage signals are processed and sent to the sequence calculator. From that sequencer calculator, the sequence values will be sent to impedance calculator. There the line to line impedance and line to ground impedance are measured. The line to line impedance and line to ground impedance can be calculated using the equations (4), (5) respectively.

$$Z_{LL} = \frac{V_{phase1} - V_{phase2}}{I_{phase1} - I_{phase2}} \quad (4)$$

$$Z_{LG} = \frac{V_{phase}}{I_{phase} + k * I_0} \quad (5)$$

B. Micro-grid Side:

The utility in our test system is protected by over-current relay. And the relay used is inverse time over current relay. A current operated relay produces an inverse time-current characteristic by integrating a function of current F(I) with respect to time. The input to this component is a measured current signal. The function F(I) is defined as a trip when the input current is higher than the pickup current and reset when the current is less than the pickup current. This working principle has been schematically in Fig. 8.

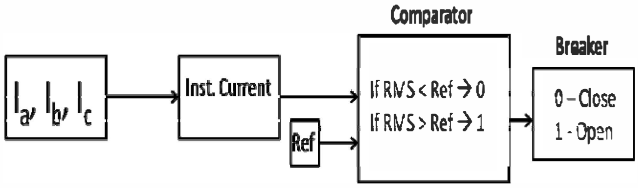

Fig. 8 Protection scheme for micro-grid

Where, I_a, I_b, I_c are the instantaneous values of the respective phase currents. They are compared with the pick-up current and if the instantaneous current values are greater than the pick-up current then the relay will trip the circuit breaker else the breaker will be closed.

VII. SIMULATION RESULTS

The simulations are carried out in PSCAD/EMTDC (Version 4.2). The DGS are considered as dc source supplied through VSCs. The system data and droop coefficients are taken as directed from the reference paper [1].

A. Bi-directional power flow:

The two ways of power flow as mentioned in section V are power flow from utility to micro-grid and from micro-grid to utility.

1) From utility to micro-grid: The powers from the DGs are generated and are used to supply the load in micro-grid. Some of the loads in micro-grid will also be supplied by the utility. It has been clearly in Fig. 9. Here the load side power flow is the

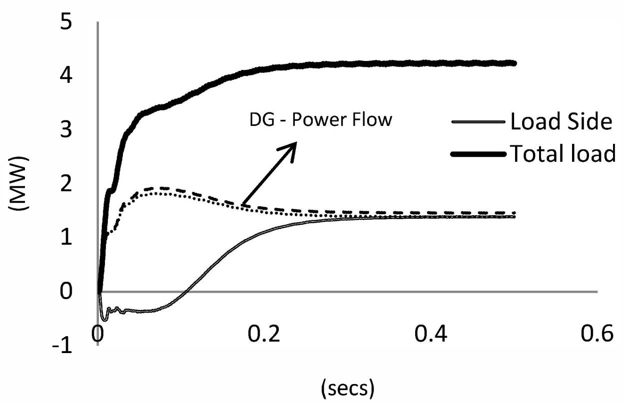

Fig. 9 Power flow from utility to micro-grid

power flow at the point of common coupling. The power flow is in positive direction, this shows that the power is flowing from utility to micro-grid.

2) From micro-grid to utility: The power from the DGs is generated and is used to supply the load in micro-grid. Some of the loads in micro-grid will also be supplied by the utility. It is clearly shown in Fig. 10. Here also as discussed earlier, the load side power flow is the power flow at the point of common coupling. The power flow is in negative direction, this shows that the power is flowing from micro-grid to utility.

B. *Protection:*

In the protection point of view, the power system has two areas to protect. First area is the utility side and the second is micro-grid side. The protection for the areas has been explained earlier, the results are discussed in this session

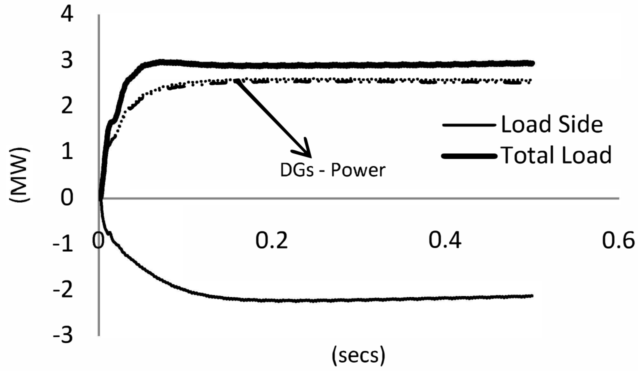

Fig. 10 Power flow from micro-grid to utility

1) Utility side: The utility side is protected using MHO relay and the explanation has been discussed. The experimentation has been done and displayed in Fig. 11.

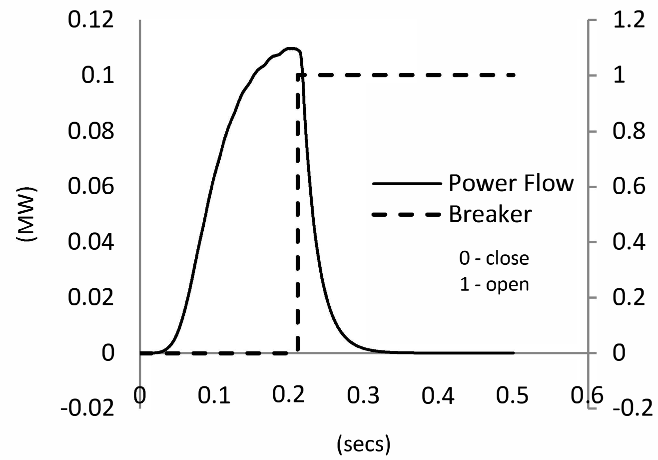

Fig. 11 Fault and breaker action in utility

At 0.2 sec a line to ground fault occurs and the line to ground impedances of the phase enters the operating zone which is shown in Fig.12 and this triggers the relay to operate. The operating characteristic regions of the mho relay, line to line impedances and line to ground impedances of all the phases are plotted. In the Fig.12, the power flows till 0.2 sec, at 0.2sec the fault occurs and the mho relay trips the breaker which is indicated by reading from zero to one. At zero the breaker is closed so that the load is supplied and at one the breaker is opened which means the load is isolated from the supply.

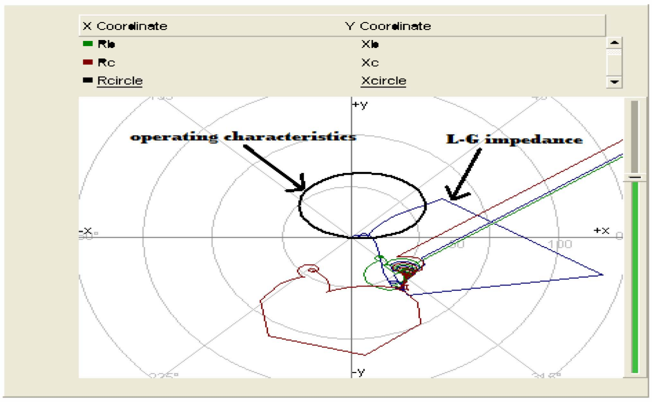

Fig. 12 R-X diagram with L-G fault

2) Micro-grid side: The micro-grid is protected using Inverse-time-over-current-relay. Since the theory and working parts are discussed earlier, the simulation results are shown in Fig. 13 and Fig. 14.

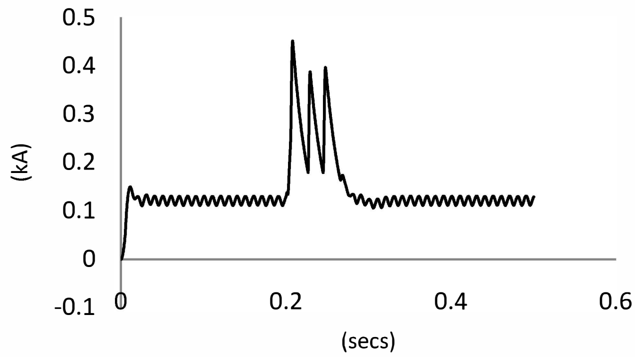

Fig. 13 Phase current of phase A

In Fig.11, the phase current of phase A is shown, in which at 0.2sec a fault occurs.

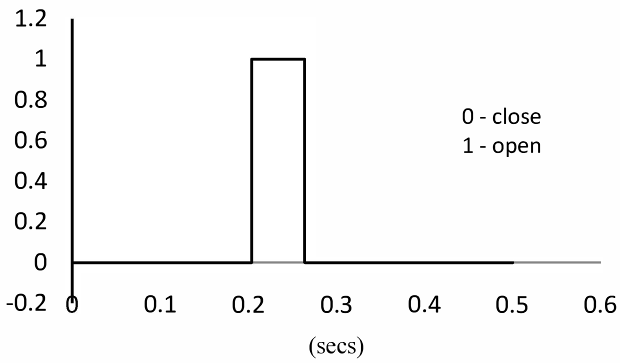

Fig. 14 Breaker action in micro-grid side

In Fig.12, the relay reads zero which means the breaker is closed. At 0.2sec, soon after the fault occurs, the relay trips the breaker and after the fault has been cleared the breaker gets closed again.

VIII. CONCLUSION

A micro-grid with two DGs interfaced with VSC is designed and analysed. A back-to-back converter is also been designed and power tested with some loads and a source. A load sharing and power flow control technique is proposed for a utility connected micro-grid. The utility distribution system is connected to the micro-grid through a set of back-to-back converters. The real power flow between utility and micro-grid can be controlled by setting the specified reference power flow for back-to-back converters module. The utility side is protected by mho relay and the data required for mho relay have been calculated. The micro-grid is protected by over-current relay in which the rms value and the phase currents of the source are compared. The protection scheme for mho relay (i.e. at utility side) and over-current relay (i.e. micro-grid side) has been explained.

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