# CHAPTER 5

# ADAPTIVE RELAYS HIERARCHIES

## 5.1 INTRODUCTION

A relay can act as a primary or a backup, where a backup relay must operate atleast after a minimum coordination time interval when a primary relay fails to operate. If a backup relay gets tripped before its primary then unnecessarily large area of loads may get disconnected from the system, which may lead a blackout, voltage collapse, deterioration of the system equipment, and a heavy economical loss. Therefore, tripping of relays in a hierarchal manner is one of the crucial steps while designing a protection scheme. Determining the relays hierarchies (RHs) considering the variability of the operating mode due to the connection and disconnections of DGs, grid-connected and islanding mode, and feeder reconfiguration is a major challenge since every change in the operating mode may require a different set of RHs. In addition, increasing proliferation of the DGs and looping of the network are transforming the conventional radial network into a complex one. This results in increment in the number of fault currents paths in the network, which in turn, raises the total number of relays required to clear a fault completely. Thus, determining the RHs for a large number of relays in a complex network makes the selection of hierarchies more challenging.  Furthermore, the occurrence of any unplanned or unknown changes in the operating mode and loss of any relevant information due to the FRC event (pre-fault failure of the relays and its communication links) will make the process of selecting the hierarchy levels even more challenging. All these factors demand a new adaptive algorithm for determining the RHs which can intelligently follow the changes in the system conditions. This chapter proposes an adaptive algorithm for selecting the RHs considering the variability and unpredictability of the operating mode with the aim of minimal area isolation and fast clearance of the fault with prevailing the coordination between the relays. The proposed algorithm provides a response-

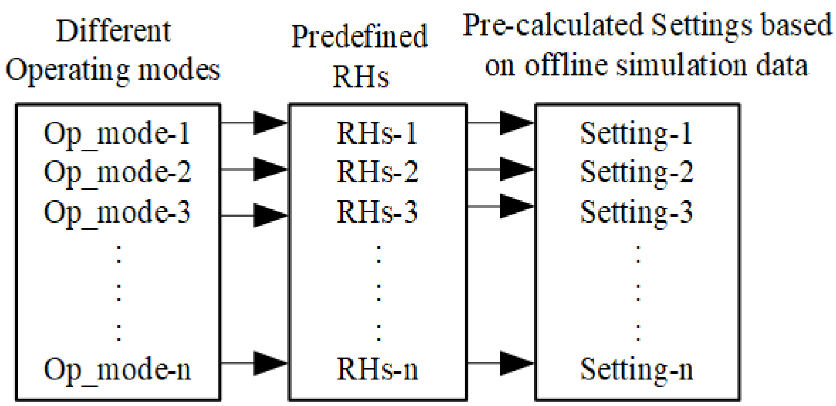



Figure 5.1 Pre-determined RHs for variable operating mode

based RHs by using the few online information from the advanced relays.

## 5.2 Limitations of pre-determined based relays hierarchy's selection

In most of the literature work, pre-determined based RHs has been used while devising the adaptive settings for relays. But this method has some limitations, as discussed ahead, which must be considered while designing an adaptive protection scheme.

In the existing method, RHs have been pre-determined by manually or offline considering the known set of operating modes. Where, different sets of RHs corresponding to different operating modes have been stored in a lookup table. Where, in this table, corresponding to each RHs group, a pre-calculated settings group is also assigned by using the offline simulated data. This is depicted in Figure 5.1. So, when a fault occurs, the existing approach first identifies the system's operating mode by gathering the connection and disconnection status of the system's relays with the help of communication facilities. Then, corresponding to the detected op-mode, it selects a setting group from the lookup table corresponding to the appropriate RHs set and then updates the relays with new set of settings. However, there are some limitations of the existing RHs approach, which are as follows.

- The first limitation is that the existing approach is completely dependent on the information collected by the communication system, where it requires complete information associated with the changes in operating mode such as number and location of DGs, and network configuration to detect the operating mode to select the suitable RHs group. So, in the presence of any missing information due to FRC event, it may interpret a wrong topology and as a result, may fail to select the correct RHs group.
- The second limitation is that it is based on pre-determined data, known situations and operating modes. If a system appears in an unknown operating mode due to any sudden change, then the existing method may fail to work or decide suitable RHs.
- The third limitation is that, it doesn't consider the FRC events of feeder relays while setting up the relays, and resulting, provides the same settings whether FRC is present or absent.
- The fourth limitation is that that it needs a large set-back as it needs the knowledge of all possible operating modes and configurations in advance, and also needs the human input for the preparation of this table and finally it requires that the operating mode should always match one of the pre-determined op-modes.

Thus, a pre-determined based RHs approach may fail to provide the adaptive protection. In the next section, the solution method for the above-discussed problem has been proposed.

## 5.3 ADAPTIVE RELAYS HIERARCHIES ALGORITHM (RHs-algo)

An online based algorithm for determining the adaptive RHs has been proposed as a solution method. As explained in Section 3.2.1, each relay generates a *PS* which gets high when the relay experiences an abnormal condition (non-faulty or faulty). By using the available information of *PS* transferred from the working relays, the CPC first confirms the faulty condition and detects the faulted zone by using the DFD-algo as explained in the previous Chapter 4. Then, in the next step, it determines the RHs by using the proposed RHs_algo, where it uses only the available PS from the relays.

The selection of the RHs depends upon the type of backup-tripping considered by the system. In this context, the existing schemes [18]-[20], [60], [64], [90], [92], [93], [99], [103]-[107] follow the conventional unidirectional pattern of choosing the backup-tripping, in which far adjacent relay takes the place of backup hierarchy for a relay with preceding hierarchy. For e.g. in Figure 4.3, $R_{far}^{zu\_a^{th}}$ will carry 'B1' hierarchy for the $R^{zu}$ end-relay which has a 'P' hierarchy. While the proposed RHs_method utilizes the bidirectional properties of the modern relays and uses both near and far adjacent relays for the consecutive backup-tripping RHs. For

Table 5.1 outputs of RHs-algo

| h | Hierarchy | Abbrev. |
|---|---|---|
| 0 | No hierarchy | NH |
| 1 | Primary | P |
| 2 | Backup 1 | B1 |
| 3 | Backup 2 | B2 |
| 4 | Backup 3 | B3 |

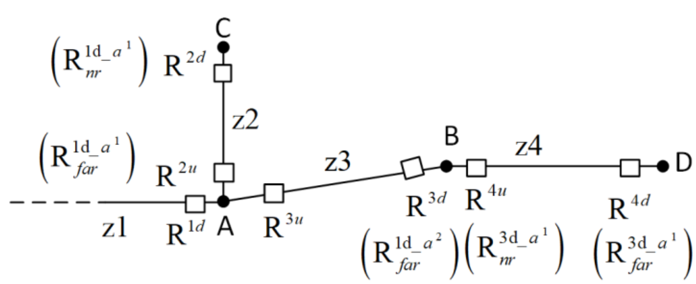



Figure 5.2 A sample network

example, in the same Figure 4.3, $R_{nr}^{zu\_a^{th}}$ and $R_{far}^{zu\_a^{th}}$ will carry ‘B1’ and ‘B2’ backup hierarchies respectively for a Rzu end-relay with ‘P’ hierarchy. Here, each relay is assigned with a binary bit named *BT* for backup-tripping.

In the proposed RHs-algo, both near and far adjacent relays are assigned with *BT*=1. While, for the conventional backup tripping, *BT* for near and far relays will be 0 and 1 respectively. The merits of the BBT compared to UBT is explained in detail in later Section (5.4.2).

### *5.3.1 Description of the RHs-Algo algorithm*

This algorithm basically determines a ‘*h*’ number (as algorithm’s output) for the selected $R^{er}$ and for its $R_{nr}^{er\_a^{th}}$ and $R_{far}^{er\_a^{th}}$ adjacent relays of all the connected $a^{th}$ adjacent zones (as shown in Figure 4.3) in a single loop. Here, a *h* number indicates the hierarchy of a relay. If output ‘*h*’ comes with 0, 1, 2, 3, or 4, it means the hierarchy of the associated relay is ‘NH’, ‘P’, ‘B1’, ‘B2’, or ‘B3’ respectively, as shown in Table 5.1. Figure 5.3 shows the workflow of the proposed RHs_algo. As shown in Figure 5.3, this algorithm generates an intermediate *x* variable that helps to find the *h* by using the relay’s *PS* and *BT* information available at the CPC. In figure, ($PS^{er}$, $PS^{nr}$, and $PS^{far}$), ($BT^{er}$, $BT^{nr}$, and $BT^{far}$) and ($h^{er}$, $h^{nr}$, and $h^{far}$) denotes the *PS*, *BT*, and *h* number of the $R^{er}$, $R_{nr}^{er\_a^{th}}$ and $R_{far}^{er\_a^{th}}$ relays respectively, and ($x^{er}$, $x^{nr}$, and $x^{far}$) are the associated intermediate *x* variables.

### *5.3.2 Functioning of the RHs-algo algorithm*

Using the general representation of the typical feeder branches as shown in Figure 4.3, a sample feeder network (as shown in Figure 5.2) has been created using which the proposed

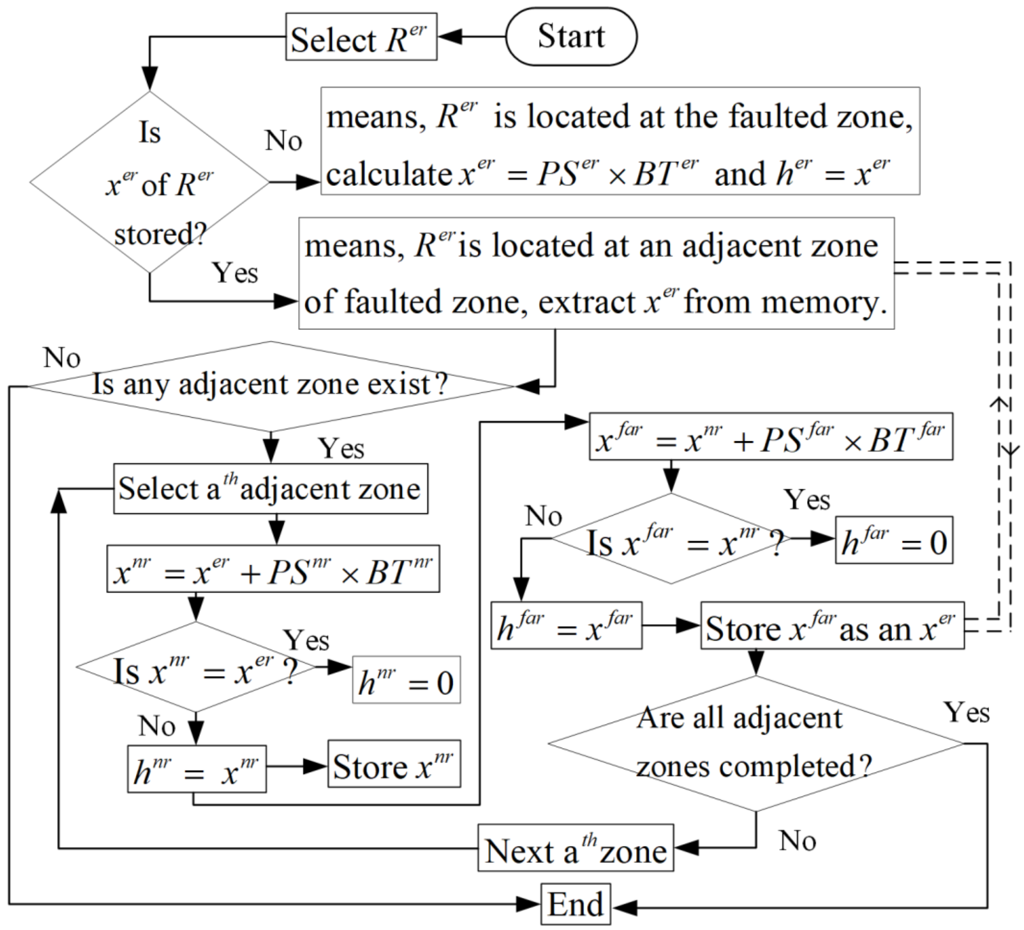



Figure 5.3 Proposed RHs-algo algorithm

relays-hierarchy assignment is explained for the relays of 'd' side of the zone z1 at which a fault-occurrence is assumed. In this sample network, four-zones (z1, z2, z3, and z4) with the connections of three DGs (DG-B, DG-C, DG-D) at B, C, and D nodes respectively have been shown. Two different fault cases for z1 zone's fault have been assumed in Figure 5.2 to explain how the algorithm selects hierarchies.

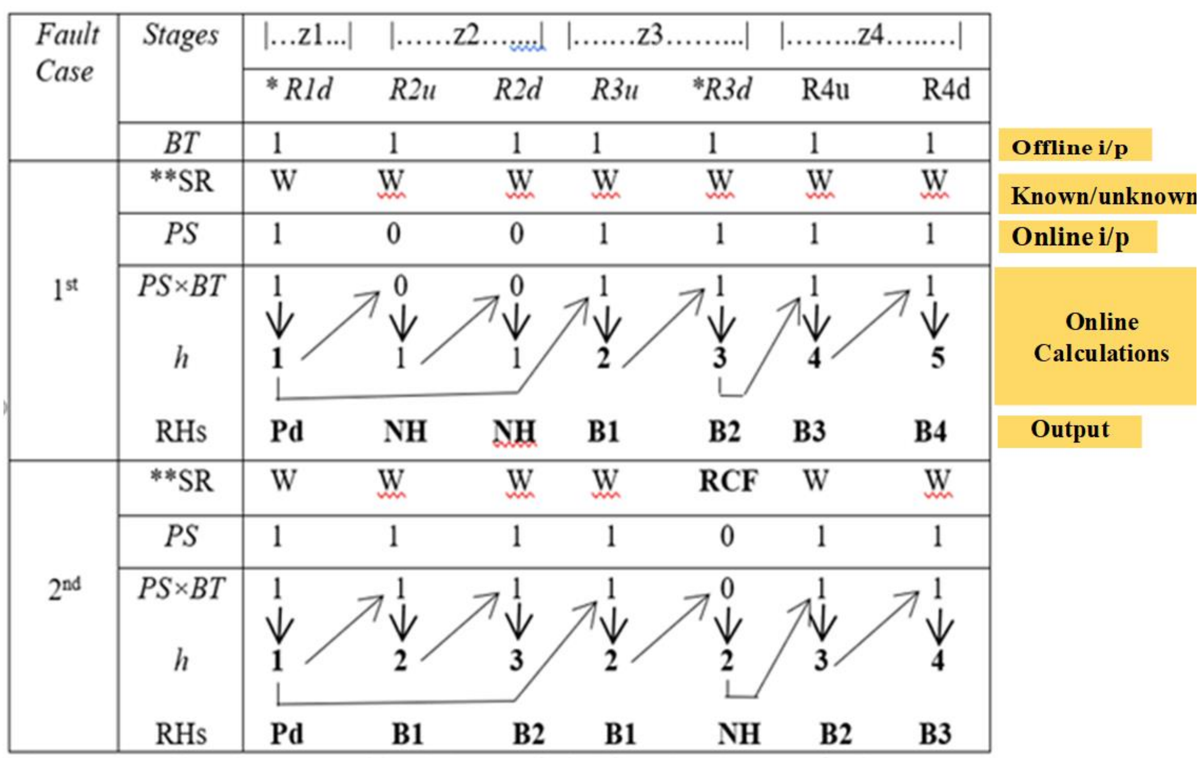
In the first fault-case, a fault at z1 takes place when only two DGs (DG-B and DG-D) are connected and all the relays along with its communication links are in working state to transfer *PS* to the CPC. While, in the second fault-case, the fault at z1 takes place when all three DGs are connected and a relay R3d has failed to send the information due to the FRC event. Under these circumstances, a protection scheme will confront mainly with two types of problems when the second fault-case will happen after the first one. The first problem will occur due to change in the operating topology because of the inclusion of one more DG into the system. This results in an increment in the fault current levels and the total number of fault currents' paths which will demand new hierarchies and settings for the relays. While the second problem is due to the R3d's FRC event. In this event, either the relay or its communication link, or both can fail to function. If the relay fails to function then it can either fail to take the measurements or can fail to calculate the equality constraint for the high *PS*. As a consequence, instead of a faulted situation, it will get a normal situation and will not trigger its communication link to send *PS* to the CPC or RCU. In the other case, if, instead of a relay, it's communication link fails to function, then it will fail to send both, the self-testing unit's result and the output results (including *PS)* to the CPC or RCU. Consequently, during the FRC situation, at the CPC, there would be no change in the low default value of the *PS* of the failed relay ($R^{3d}$). As a result, CPC will perceive that either the relay is experiencing a normal situation or there is no fault current flowing over it, which is not the exact situation here.

Figure 5.4 shows how the RHs-algo determines the hierarchies of 'd'-side' relay for the detected faulted zone z1 (in Figure 5.2), by using only the online available information at the RCU irrespective of the separate knowledge of the operating modes. To determine the RHs for 'd'-side relays, the algorithm first selects the $R^{1d}$ as a $R^{er}$ and calculates the *h* numbers for $R^{1d}$ and its both near and far relays at its all adjacent zones (i.e.an z2 and z3), as depicted in Figure 5.4. In next rounds, the algorithm will select far end relays $R^{2d}$ and $R^{3d}$ (both as $R^{er}$) to determine the further hierarchies. During execution with the $R^{2d}$ relay, the algorithm will find the absence of the adjacent relays and consequently will end the flow. Whereas, during execution with $R^{3d}$ as a $R^{er}$, as depicted in Figure 5.4, it will determine RHs for both near and far relays located at the z4 adjacent zone. Thus, likewise, the ‘d’ side relays, hierarchies for the ‘u’ side relays of the z1 zone can be determined. Thus, this section describes how RHs-algo provides RHs dedicatedly to the present fault-case by using the system’s online information in the form of ‘0’ and ‘1’.

## 5.4 Comparative Performance Analysis, Results And Discussion

### 5.4.1 **Results and Discussion**

The performance of the RHs-algo has been tested in the same test system (in Figure (2a)) and simulation set up as described in Section 3.3.1. The obtained results have been compared with the conventional RHs method for both grid-connected and islanding modes. The obtained




*acts as R$^{er}$ **SR denotes ‘Working (W) or pre-fault failure (FRC) status of relays’

Figure 5.4 Stages of determining RHs for z1’s d-side relays using RHs-algo

results demonstrate the individual impact of the proposed adaptive RHs with respect to the conventional RHs. The Tables 5.2 and Table 5.3 show the RHs, *TMS*, and *Tr* respectively for the conventional PMSold and the proposed HPMS based settings. While the Table 5.4 and Table 5.5 show $T_R$*_sum* obtained by both methods for both FRC and Non-FRC events.

The comparative performance analysis and advantages of the proposed scheme are discussed below:

1. The RHs-algo is based on the online *PS* signals. So, whatever the system's operating mode including grid-connected or islanding mode, radial or meshed configuration, connections of synchronous or IBDGs, it successfully determines the RHs for the current system's conditions. Thus, unlike the conventional method, the RHs-algo is independent of the additional information related to the operating mode. In other words, there is no need to collect this amount of information via communication facilities to decide the RHs. Here,

TABLE 5.2
COMPARATIVE PERFORMANCE OF RHS_ALGO IN MESHED ISLANDING-MODE WITH IBDGS (With PMSold) (FAULT CASE: A LG FAULT AT Z26, RF=20)

| | Using RHs_old | | | Using RHs_prop | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Conventional | | | Non_FRC | | | FRC1 (R26d) | | | FRC2 (R26d, R27d) | | |
| Relays | *RHs* | TMS | Tr | RHs | TMS | Tr | RHs | TMS | Tr | RHs | TMS | Tr |
| R(26u) | Pu | 0.0100 | 0.0606 | Pu | 0.0100 | 0.0606 | Pu | 0.0100 | 0.0329 | Pu | 0.0100 | 0.0329 |
| R(27d) | * | | | B1 | 0.0100 | 0.4906 | B1 | 0.0206 | 0.3329 | * | | |
| R(27u) | B1 | 0.0122 | 0.4906 | B2 | 0.0161 | 0.7906 | B2 | 0.0379 | 0.6329 | B1 | 0.0199 | 0.3329 |
| Rdg3_nr | * | | | * | | | * | | | | | |
| Rdg3_far | B2 | 0.1512 | 0.7906 | * | | | * | | | | | |
| R(28d) | * | | | * | | | * | | | | | |
| R(28u) | B2 | 0.0100 | 5.4082 | * | | | * | | | | | |
| R(26d) | Pd | 0.0100 | 0.1403 | Pd | 0.0100 | 0.1403 | * | | | | | |
| R(25u) | * | | | B1 | 0.2067 | 0.4403 | Pd | 0.0237 | 0.0300 | Pd | 0.0237 | 0.0300 |
| R(25d) | B1 | 0.2804 | 0.4403 | B2 | 0.3476 | 0.7403 | B1 | 0.1667 | 0.3300 | B1 | 0.1667 | 0.3300 |
| R(3u) | * | | | * | | | * | | | * | | |
| R(3d) | B2 | 0.0723 | 0.7403 | * | | | * | | | * | | |
| *$T_R$_sum (s)* | | | 8.0707 | | | 2.6625 | | | 1.3586 | | | 0.7258 |
| *T_conv (s)* | | | 0.0120 | | | 0.0117 | | | 0.0135 | | | 0.0124 |
| *Tot_constr* | | | 7 | | | 6 | | | 5 | | | 4 |
| %reduction in *Tr_sum* w.r.t. previous stage | | | | | | **67.010%** | | | **48.972%** | | | **46.578%** |

just the online *PS* signal is enough to decide the RHs. The results of Table 5.2 and Table 5.3 show that the relays settings determined using the proposed RHs successfully provide a coordinated protection to the distribution system with variable operating modes.

TABLE 5.3

COMPARATIVE PERFORMANCE OF RHS_ALGO IN MESHED GRID-CONNECTED MODE WITH SYNCHRONOUS-DGS (With HPMS)

(Fault Case: A LLG FAULT AT Z4, $R_F$=4.3)

| Relays | Using RHs_old (conv.) | | | Using RHs_prop | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | For both Non-FRC & FRC | | | Non-FRC | | | **FRC[1] | | |
| | *RHs* | *TMS* | $T_R^h$ | *RHs* | *TMS* | $T_R^h$ | *RHs* | *TMS* | $T_R^h$ |
| R(4u) | Pu | 0.0148 | 0.0300 | Pu | 0.0148 | 0.03 | Pu | 0.0148 | 0.03 |
| R(3d) | * | - | - | B1u | 0.1625 | 0.33 | B1u | 0.1625 | 0.33 |
| R(3u) | B1u | 0.1596 | 0.3300 | B2u | 0.3047 | 0.63 | B2u | 0.3047 | 0.63 |
| R(25d) | * | - | - | * | - | - | * | - | - |
| R(25u) | B2u | 0.0179 | 0.6300 | * | - | - | * | - | - |
| R(2u) | * | - | - | * | - | - | * | - | - |
| R(2d) | B2u | 0.1796 | 0.6300 | * | - | - | * | - | - |
| R(4d) | Pd | 0.0100 | 0.1061 | Pd | 0.01 | 0.1061 | * | - | - |
| R(5u) | * | - | - | B1u | 0.0383 | 0.4061 | Pd | 0.01 | 0.1061 |
| R(5d) | B1d | 0.0381 | 0.4061 | B2u | 0.0663 | 0.7061 | B1d | 0.0381 | 0.4061 |
| R(29u) | * | - | - | * | - | - | * | - | - |
| R(29d) | B2d | 0.0331 | 0.7061 | * | - | - | * | - | - |
| R(6u) | * | - | - | * | - | - | * | - | - |
| R(6d) | B2d | 0.0863 | 0.7061 | * | - | - | * | - | - |
| $T_R$*_sum (s)* | | | 3.5445 | | | 2.2084 | | | 1.5023 |
| *T_conv (s)* | | | 0.0260 | | | 0.0228 | | | 0.0209 |
| *Tot_constr* | | | 8 | | | 6 | | | 5 |
| Achieved Reduction in $T_R$*_sum* | 53.5% (w.r.t. Conv.) | | | 70.9% (w.r.t. Conv.) | | | 31.9% (w.r.t. Prop. (Non-FRC)) | | |

2. Now, as described in Section 5.3, the algorithm decides the RHs by using the current status of *PS* signals during a fault, irrespective of the operating mode. This feature of the RHs-algo helps to design a protection scheme independent of the known or unknown operating modes and fault event, and thus a self-adaptive scheme. On the other hand, in the

conventional method, the calculation of setting is based on pre-determined RHs, which is fixed for a known operating mode. Consequently, the settings based on fixed RHs may fail

TABLE 5.4

TOTAL SUM OF OPERATING TIMES OF RELAYS IN VARIOUS FAULT CASES IN GRID-CONNECTED MODE (WITH HPMS)

| Zone | Non-FRC/ FRC | RHs Method | $T_R$_*sum* in Radial (in s) | | | | | | $T_R$_*sum* in Mesh (in s) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | SDGs | SDGs | SDGs | IBDGs | IBDGs | IBDGs | SDGs | SDGs | SDGs | IBDGs |
| | | | LLLG | LLG | LG | LLLG | LLG | LG | LLLG | LLG | LG | LLLG |
| | | | solid | *Rf*=4.3 | *Rf*=100 | solid | *Rf*=4.3 | *Rf*=100 | solid | *Rf*=4.3 | *Rf*=100 | solid |
| z4 | Non-FRC | With RHs_old | 3.2793 | 3.8118 | 4.6964 | 3.4972 | 3.9956 | 4.2579 | 3.2400 | 3.5445 | 5.5759 | 3.2792 |
| | Non-FRC | With RHs_prop | 2.0095 | 2.4089 | 3.0723 | 2.1729 | 2.5467 | 2.7434 | 1.9800 | 2.2084 | 3.7319 | 2.0094 |
| | FRC [1] (R4d) | With RHs_prop | 1.3697 | 1.6359 | 2.2051 | 1.4786 | 1.7278 | 1.9542 | 1.3500 | 1.5023 | 2.6955 | 1.3696 |
| | FRC [2] (R4d, R4u) | With RHs_prop | 0.7397 | 1.0059 | 1.4418 | 0.8486 | 1.0978 | 1.2248 | 0.7200 | 0.8723 | 1.8766 | 0.7396 |
| z29 | Non-FRC | With RHs_old | 4.8393 | 5.0244 | 8.5858 | 5.0966 | 5.7316 | 6.6996 | 4.8000 | 4.9014 | 9.9919 | 4.8065 |
| | Non-FRC | With RHs_prop | 3.5695 | 3.7083 | 5.0638 | 3.7624 | 5.3674 | 4.6269 | 3.5400 | 3.6160 | 8.5567 | 3.5449 |
| | FRC [1] (R29u) | With RHs_prop | 1.7491 | 2.0991 | 3.5728 | 2.0540 | 3.5731 | 2.9210 | 1.7100 | 1.8583 | 5.9508 | 1.7149 |
| | FRC [2], (R29u, R6d) | With RHs_prop | 1.0843 | 1.3287 | 2.4482 | 1.3332 | 2.3309 | 1.9648 | 1.0500 | 1.1622 | 3.8969 | 1.0549 |

TABLE 5.5

TOTAL SUM OF OPERATING TIMES OF RELAYS IN VARIOUS FAULT CASES IN ISLANDING MODE WITH IBDGS INTERCONNECTIONS (WITH HPMS)

| RHs Method | Non-FRC/FRC | Fault Location - Z29 | | | | | Non-FRC / FRC | Fault Location - Z26 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | LLG, *Rf* =15 | | LLG, *Rf*=30 | | | | LG, *Rf*=10 | | LG, *Rf*=20 | |
| | | Mesh | Radial | Mesh | Radial | | | Mesh | Radial | Mesh | Radial |
| With RHs_old | Non-FRC | 3.3894 | 2.5157 | 3.8568 | 2.8267 | | Non-FRC | 2.6836 | 2.0146 | 2.7364 | 2.0688 |
| With RHs_prop | Non-FRC | 2.7098 | 2.5098 | 3.1448 | 2.6991 | | Non-FRC | 2.0536 | 2.0132 | 2.1035 | 2.0623 |
| | FRC [1], R29u | 1.8181 | 1.7485 | 2.1059 | 1.9764 | | FRC [1], R25d | 1.6716 | 1.3777 | 1.4352 | 1.4228 |
| | FRC [2] (R29u, R30u) | 1.1385 | 1.0370 | 1.3939 | 1.2241 | | FRC [2], (R25d, R27d) | 0.9773 | 0.7431 | 0.8024 | 0.7792 |

to protect the system if an unknown operating mode appears or any change in the operating mode occurs (for ex: disconnection of a DG and/or islanding formation).

3. In other words, this algorithm is able to provide a dedicated RHs to a protection scheme to calculate the relays settings, which are more optimal and provide faster protection to the current operating mode, as shown in results. This can be seen in the results-tables Table 5.2 to Table 5.6 and the figures shown in Figure 5.5 and Figure 5.6.
4. Unlike the conventional method, the RHs-algo eliminates those pairs of primary and backup relays which are not necessary to clear the present fault in the system with variable operating modes.
5. As a result of the above-discussed point 4, while optimizing the comprehensive settings for the variable operating mode, it relaxes the number of coordination constraints corresponding to the eliminated relays pairs and just takes the constraints related to the present operating mode. Thus, this RHs-algo promotes a constraint reduction-based optimization which further assists in accomplishing an optimization with lesser *T_conv*. This can be seen in the results Tables 5.2 and Table 5.3.
6. While the selection of the RHs, the RHs-algo also eliminates those relays which get failed due to the FRC event and thus helps to relax the corresponding minimum operating time constraints while optimizing the settings. This further eliminates some constraints from the optimization problem and provides the optimal solution with lesser *T_conv*.
7. One of the main contributions of the RHs-algo is that it takes account of the present FRC failure of the relays while determining the adaptive RHs. It devises two different dedicated RHs separately for the FRC and Non-FRC events and consequently yields two different

sets of TMS that provide relatively more optimal protection compared to the conventional method, as shown in Table 5.2 to Table 5.6.

Table 5.6
Advantages by adapting the relays hierarchies considering the FRC events (*Fault case-A)

| | PMSold | | | HPMS | | |
|---|---|---|---|---|---|---|
| | Non-FRC | FRC[1] (R4d) | FRC[2] (R4d, R4u) | Non-FRC | FRC[1] (R4d) | FRC[2] (R4d, R4u) |
| *Tr_sum (s)* | 7.6132 | 6.7141 | 6.0796 | 3.5445 | 2.5396 | 1.6317 |
| *Tot_constr* | 8 | 7 | 6 | 8 | 7 | 6 |
| *T_conv(s)* | 0.0294 | 0.0275 | 0.0244 | 0.0260 | 0.0242 | 0.0232 |
| %Reduction in *Tr_sum* | | 11.81% (w.r.t. PMSold, Non-FRC) | 9.45% (w.r.t. PMSold, FRC[1]) | | 28.35% (w.r.t. HPMS, Non_FRC) | 35.75% (w.r.t. HPMS, FRC[1]) |

* Fault case-A: (Grid-connected, Meshed, LLG fault with *Rf*=4.3 Ω at z4, and maximum hierarchy is 'B2')

8. As a result of above point 7, the RHs-algo saves unnecessary protection latency due to the failed relays. This can be observed by the obtained results for a **Fault case-A**: (Grid-connected, Meshed, LLG fault with *Rf*=4.3 Ω at z4, and maximum hierarchy is 'B2') in Table 5.6. The results of Table 5.6 show the importance of only considering the FRC event while determining the UBT based RHs either with $PMS_{old}$ or *HPMS*.
9. The obtained results of this table also show that as the number of FRC failed relays increases, the advantages of the FRC based RHs becomes more prominent. This can be seen in Figure 5.5 and Figure 5.6.
10. Another advantage is that this algorithm is based on the online information which is in the form of '0' and '1' binary bits. Therefore, this method has the ability to cope up easily with the new advancements in the protection technologies.

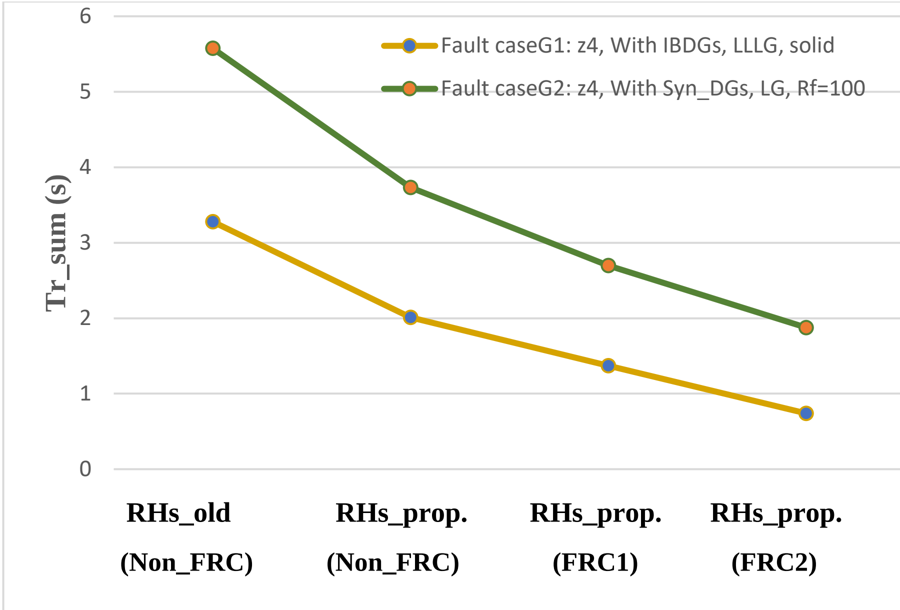



Figure 5.5 Comparative Reduction by RHs_prop in relays operating times in different FRC conditions in Meshed Grid-connected operating mode

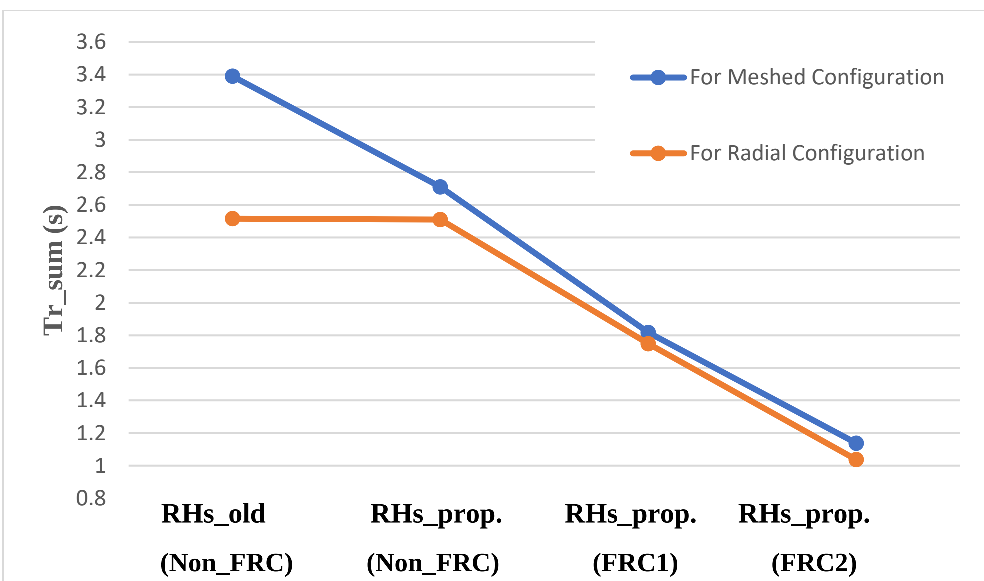



Figure 5.6 Comparative Reduction by RHs_prop in relays operating times in different FRC conditions in Islanding operating mode for LLG fault (Rf=15) at z29

### 5.4.2 Merits of Bidirectional Backup Tripping (BBT)

The RHs-algo is flexible and programmable and can be workable for any kind of backup tripping (*BT*): unidirectional UBT, bidirectional (BBT), or mixed BT. Where, the BBT based tripping has more benefits compared to the UBT, this is explained as below:

1. BBT utilizes both end relays of an adjacent zone in providing backup protection. Whereas UBT uses only one end-relay (far end relay) while skips the use of another end-relay (near end-relay), and thus, does not fully-utilize the presence of two end-relays in a feeder.
2. During provide the primary level protection in a bidirectional fault, unlike the UBT, BBT prevents the disconnection of the adjacent feeder along with the faulted feeder to avoid the fault current flow from the other end's side and provide various benefits. For example, in UBT, to clear the fault from the z4 zone in the test system, R3u and (R25u and R2d) will get tripped in order to provide the backup-1 (B1) and backup-2 (B2) protection respectively. Whereas, if z3 is facilitated with BBT, then instead of prior RHs, R3u and R3d relays will get tripped with 'B1' and 'B2' respectively. This concludes that, in UBT, to provide the backup protection up to 'B2', three feeder zones (z3, z2, and z25) have to be isolated from the healthy part of the system. As a result, all three zones would not get power for their loads. On the other side, in BBT, even in the presence of one zone z3 with BBT, both z2 and z25 zones will continue to get supplies for their loads even after the accomplishment of 'B2' backup protection.

3. Besides the above advantages, BBT enhances the protection significantly compared to the UBT in terms of *Tr_sum*, *T_conv*, and *Tot_constr*. This is shown in Table 5.7. This table shows that with both PMSold and HPMS, the presence of even one feeder facilitated with BBT makes the protection respectively 42.46% and 17.77% faster.

Table 5.7

Enhanced protection in the presence of only z3 feeder zone with BBT (i.e. 1 BBT) while all other zones with UBT.

| | **PMSold.** | | | **HPMS** | | |
|---|---|---|---|---|---|---|
| | **No BBT** | **1 BBT** | | **No BBT** | **1 BBT** | |
| ***Tr_sum(s)*** | 7.6132 | 4.3810 | | 3.5445 | 2.9145 | |
| ***Tot_constr*** | 8 | 7 | | 8 | 7 | |
| ***T_conv(s)*** | 0.0294 | 0.0272 | | 0.0260 | 0.0243 | |

TABLE 5.8

Enhanced protection in the presence of all BBT compared to 1 BBT with both $PMS_{old}$ and HPMS

| | **PMSold** | | | **HPMS** | | |
|---|---|---|---|---|---|---|
| | **1 BBT** | **all BBT** | **%red*** | **1 BBT** | **all BBT** | **%red*** |
| ***Tr_sum(s)*** | 4.3810 | 2.8003 | 36.080 | 2.9145 | 2.2084 | 24.227 |
| ***T_conv(s)*** | 0.0272 | 0.0258 | 5.147 | 0.0243 | 0.0217 | 10.69959 |
| ***Tot_constr*** | 7 | 6 | - | 7 | 6 | - |

*Denotes % reduction with BBT w.r.t. 1 BBT

4. Moreover, due to minimal area isolation as explained in the above-discussed point-2, maximum loads can be benefited with the supply in the presence of BBT. Thus, in the presence of BBT, the system is exposed to lesser negative impact compared to the UBT. For example: in UBT, due to the disconnection of z2 zone in the test system, a large part of the system will be deprived of getting the supply from the grid, which can aggravate a large disturbance in the demand-supply of the system, because of which the regulation center will have to take the remedial actions at a large scale.

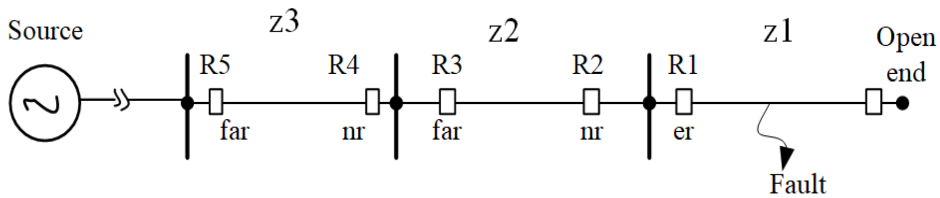



Figure 5.7 A sample radial feeder network

TABLE 5.9
Contingency analysis with BBT and UBT for Case-1

| Method | Action | No. of affected components | Contingency |
|---|---|---|---|
| **Conventional (UBT)** *Event: R1 as P fails.* | R3 trips, z1 and z2 get disconnected. | $N_R$=1<br>$N_Z$=2<br>$N_{RZ}$=3 | ($N_R$ -1)<br>($N_Z$ -2)<br>($N_{RZ}$ -3) |
| **Proposed (BBT)** *Event: R1 as P fails.* | R2 trips, z1 get disconnected. | $N_R$=1<br>$N_Z$=1<br>$N_{RZ}$=2 | ($N_R$ -1)<br>($N_Z$ -1)<br>($N_{RZ}$ -2) |

5. In a system, if there is a provision to arrange all feeder zones with BBT, then this will further enhance the overall protection. This can be seen in the Table 5.8 that compared to the 1-BBT, both conventional and Hybrid method, respectively, clears the given fault 36.08% and 24.23% faster in the presence of all-BBT.

6. The impact of the BBT on the contingency analysis has also been discussed here to show the further effectiveness of the BBT approach. Now, while planning the system's security, the general approach is to perform a single (N-1) contingency analysis. Compared to the conventional UBT, the BBT approach provides better performance in terms of the contingency analysis. To explain this, a sample feeder network (in Figure 5.7**)** is taken. In Figure 5.7, suppose, a fault occurs at the z1 zone; and during a contingency,

   The number of tripped relays is: $N_R$

   The number of disconnected feeder zones is: $N_Z$

TABLE 5.10
Contingency analysis with BBT and UBT for Case-2

| Method, event | Action | No. of affected components | Contingency |
|---|---|---|---|
| **Conventional (UBT)**<br>*Event: R1 as P, and R3 as B1 fail.* | R5 trips, z1, z2, and z3 get disconnected. | $N_R$=1<br>$N_Z$=3<br>$N_{RZ}$=4 | ($N_R$ -1)<br>($N_Z$ -3)<br>($N_{RZ}$ -4) |
| **Proposed (BBT)**<br>*Event: R1 as P, and R2 as B1 fail.* | R3 trips, z1 and z2 get disconnected. | $N_R$=1<br>$N_Z$=2<br>$N_{RZ}$=3 | ($N_R$ -1)<br>($N_Z$ -2)<br>($N_{RZ}$ -3) |

The number of affected relays and feeder zones: $N_{RZ}$

Now consider the following two cases, Case1 and Case2:

**Case-1:** *If the corresponding primary relay (P) fails to provide the protection, while the RHs are designed to provide the backup protection upto the first backup (B1).*

**Case-2:** *If the corresponding primary (P) and backup-1 (B1) relays fail to provide the protection, while the RHs are designed to provide the backup protection upto second backup (B2).*

The contingency analysis for these Case-1 and Case-2 are shown in Table 5.9 and Table 5.10 respectively.

These results show that, in terms of $N_R$, both UBT and BBT consider (N-1) contingency. Whereas, in terms of $N_Z$ and $N_{RZ}$, with BBT, there are fewer numbers of contingencies compared to UBT.

## 5.5 CONCLUSION

This chapter first discusses the limitations of the existing RHs method and a necessity of a new adaptive approach for determining the RHs for the distribution system with DGs. An online based algorithm for determining the adaptive RHs has been proposed in this chapter. This algorithm is based on online binary information collected from the distribution system. In this RHs method, unlike the existing method, there is no need to know the information regarding the present operating mode (including disconnection of a DG, islanding formation, and/or change in the feeder configuration). The obtained results show that the inclusion of the proposed RHs while setting up the relays not only provide the faster relays total operating times but also reduce the optimization convergence time and the total number of constraints, irrespective of the variable operating modes. It also prevents unnecessary protection latency due to the FRC events. This RHs-algo is programmable and flexible, and can be implemented with any hierarchy-based protection scheme to make the protection more adaptive to the present faulted operating mode. In addition, it can also cope up easily with new advancements in the protective devices.