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# Flexible Reliability Modeling in Hybrid AC-DC Microgrid

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**Abstract:** In this paper, a new concept of serving flexible reliability (FR) is introduced in distribution network level. FR is defined as the ability of a grid to continue servicing the high priority customers in contingency states. Customers' priority is recognized based on their required value of service reliability. Regarding this matter, the philosophy of designing a hybrid AC-DC microgrid is introduced with the ability of offering an alternative resource for each individual customer in contingency states. The analytical modeling of FR analysis besides the overall reliability analysis is proposed and the new FR index of expected energy retrieved (EER) is introduced. The performance of the proposed hybrid microgrid in serving FR is demonstrated through a numerical study on modified distribution network for Bus-4 of Roy Billinton Test System (RBTS).

**Keywords:** Flexible reliability, renewable energy resource, hybrid AC-DC microgrid, roy billinton test system (RBTS).

Indices:

| | |
|---|---|
| $i$ | Index of load-points (LPs) |
| $j$ | Index of elements |
| $k$ | Index of fuses or breakers |
| $l$ | Index of renewable energy resources |
| $m$ | Index of controllable distributed generators |
| $n$ | Index of demand response resources |
| $o$ | Index of electrical energy storage systems |

Numbers:

| | |
|---|---|
| $N_{DG}$ | Total number of controllable distributed generators (DG) in the distribution system |
| $N_{DRR}$ | Total number of demand response resources |
| $N_e$ | Total number of elements in the system |
| $N_{ESS}$ | Total number of electrical energy storage systems |
| $N_p$ | Total number of LPs in the system |
| $N_{pr}$ | Total number of fuses or breakers between LP $i$ and the failed element $j$ |
| $N_{RER}$ | Total number of electrical energy storage systems |

Parameters:

| | |
|---|---|
| $AR_i$ | The amount of available alternative resource in LP $i$ |
| $EENS$ | Total expected energy not served of the system |
| $EENS_i$ | Expected energy not served of LP $i$ |
| $EENS_{ij}$ | Expected energy not served of LP $i$ caused by failure of element $j$ |
| $EER$ | Total expected energy retrieved of the system |
| $EER_i$ | Expected energy retrieved of LP $i$ |
| $EER_{ij}$ | Expected energy retrieved of LP $i$ caused by failure of element $j$ |
| $L_i$ | The average load of LP $i$ |
| $p_a$ | Probability of load transfer in LP $i$ |
| $p_k$ | Probability of fuse/ breaker k operates successfully |
| $P^{inv}$ | Converted power of the inter-grid inverter from AC sub-system to DC sub-system |
| $P_o^{ESS}$ | Generated power of electrical energy storage system |
| $P_m^{DG}$ | Generated power of DG |
| $P_n^{DRR}$ | Generated power of demand response resources |
| $P_l^{RER}$ | Generated power of renewable energy resources |
| $\bar{p}^{AC}$ | Rated power of AC feeder |
| $\bar{p}^{DC}$ | Rated power of DC feeder |
| $r_{ij}$ | The repair time for an affected LP $i$ due to failure of element $j$ |
| $r_j$ | Average repair time for a failed element $j$ |
| $s_j$ | Average switching time for a failed element $j$ |
| $SC^{AC}$ | Servicing capacity of AC sub-system |
| $SC_i^{AC}$ | Servicing capacity of AC sub-system in LP $i$ |
| $SC^{DC}$ | Servicing capacity of DC sub-system |
| $SC_i^{DC}$ | Servicing capacity of DC sub-system in LP $i$ |
| $\lambda_{ij}$ | The failure rate for an affected LP $i$ due to failure of element $j$ |
| $\lambda_j$ | Average failure rate for a failed element $j$ |

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## 1. Introduction

### A. Motivation and Aim

Customers' requests from electricity networks are changing and they ask more efficiency, reliability, security, and quality of service from power service providers. Obviously, upgrading the current power system to meet completely the customers desires is very costly. Moreover, finding the optimal upgrading level has constantly been one of the main issues in operation and planning studies [1]. Customers have different desires depending on their type, location, and time [2]. Thus, inaccurate estimation in average customers' desire will lead to over/under investment in power system expansion planning. It can be predicted that a power system requires the ability of delivering electricity to individual customers in different reliability levels and each customer can choose his/her desired level of reliability.

### B. Literature Review and Contributions

Smart grid could monitor, control, and automate the system for achieving a positive integration of the various distributed energy resources (DER) with an increased utilization of the existing distribution assets. This active management of the distribution networks may have a twofold impact on the distribution system reliability. On one hand, it can enhance the traditional reliability indices, e.g. system average interruption frequency index (SAIFI), and system average interruption duration index (SAIDI), for passive loads and the availability of the connection for independent producers by means of specific operation practices, such as: on-line reconfiguration to alleviate load transfer restrictions [3], intentional islanding to improve the reliability of customers supplied with pure radial network schemes [4, 5], self-healing and auto-reconfiguring networks to drastically reduce the number of customers that suffer a long interruption [6, 7], coordinated Volt/VAR control to limit the occasions of curtailment or complete disconnection of independent producers in case of abnormal operating conditions [8]. On the other hand, there are some concerns, particularly from utilities, that the adoption of smart grid technologies can jeopardize the high level of reliability generally achieved by current distribution systems [9]. If an optimal fixed reliability level is calculated in planning studies and be employed in a part of the grid, there may be some free-ride customers that do not require such level of reliability but possibly will enjoy from the advantages of higher reliability level [10]. Alternatively, some power sensitive customers that expect more reliability level may suffer from uniform level of reliability. Although in smart grid environment distinct nodal reliability can be served high reliability in distribution network and the resolution of the distinct nodal reliability levels may become smaller [11, 12], always there are some free-ride customers. In this paper, using the concept of flexible reliability (FR) the number of free-ride customers will be reduced in the distribution network.

Within the above context, the contributions of this paper are threefold:

1) It presents the concept of FR, discusses its opportunities for operation of distribution network, and determines its positive impacts on the planning studies.
2) It proposes an analytical procedure for modeling the FR assessment and calculating FR indices (EER).

It considers hybrid AC-DC microgrid equipped with demand-side resources for enabling the concept of FR.

### C. Approach

In this paper, a new concept of serving FR is introduced in distribution network level. FR is defined as the ability of a grid to continue servicing the high priority customers in contingency states. Customers' priority is recognized based on their tendency for continuance of being supplied that represents their value of service reliability. Regarding this matter, the philosophy of designing distribution network architecture is presented with the ability of offering an alternative resource for each individual smart customer in contingency states. The proposed architecture is referred to as hybrid AC-DC microgrid, which consists of AC and DC loads, renewable energy-based resources (RERs), controllable distributed generators (DGs), demand response resources (DRRs), and energy storage systems (ESSs) which are connected through separate AC and DC links. The analytical modeling of the overall reliability (OR) and FR evaluation in distribution network is presented with its corresponding flowchart and a new index of FR. Finally, the effectiveness of the model is demonstrated in modified version of distribution network of bus four of Roy Billinton Test System (RBTS-bus4).

### D. Paper Organization

The reminder of the paper is organized as follows. Section 2 provides a required background on hybrid AC-DC microgrid and its advantages for future distribution systems. Section 3 represents FR concept and model. Section 4 employs the proposed model on modified distribution system of RBTS-Bus4. Finally, section 5 concludes the paper.

## 2. Hybrid AC-DC Microgrid

Most low-voltage resources (e.g. RERs, fuel cells and batteries) produce DC power which has to be converted to AC in order to be connected to the conventional AC grid, by DC/DC converters and additional DC/AC inverter. Meanwhile, many electricity consumers are using DC power such as inverter-based home appliances (e.g. TV, computer, stove, and air conditioner), light-emitting diode (LED) lights and electric vehicles (EVs). These loads should be connected to AC power systems through additional AC/DC rectifiers and DC/DC converters. Recently, DC distribution systems are taken into consideration due to the widespread development and deployment of DC power sources and loads [13, 14]. DC microgrids have been proposed to integrate various distributed generators. Conversely, in DC grids, AC sources have to be converted to DC for connecting to the DC microgrid. Moreover, additional DC/AC inverters are required for serving conventional AC loads. It can be concluded that, multiple reverse conversions is required in both individual AC or DC microgrids which may add additional cost and loss to the system [15]. Thus, it can be figured out that employment of hybrid grids will be highlighted in the future perspective of distribution networks.

Using smart grid technologies (i.e. communication, control, and computing technologies) enhances the operation of the grid and provides economical, reliable, and green operation through integration of the supply-side with the demand-side resources. Smart grids are predicted to move towards to an advanced topology that can facilitate the connections of various AC and DC resources, energy storage systems, and various AC and DC loads as a hybrid microgrid. Fig. 1 shows the general architecture of the hybrid microgrid. To achieve these goals, power electronic technology plays a vital role to connect different sources and loads to a hybrid microgrid. Hybrid AC-DC microgrid is proposed to reduce processes of multiple power conversions in an individual AC or DC grid and to facilitate the connection of various AC and DC sources and loads as a multi-energy career system.

The following advantages can be listed for such general architecture:

1) When AC link experiences contingency conditions, DC link can be disconnected from the failure section and continues supplying DC loads or vice versa.
2) Each DC generator can easily be deployed because it controls only the DC bus voltage.
3) The cost and loss of DC subgrid can be reduced because many power electronic converters are omitted from both DC resource units and end-use appliances and equipments.
4) RERs supply DC power. Therefore, the total cost and loss of the system can be reduced considerably. Regarding this matter, developing hybrid AC-DC microgrid enables high penetration of REDGs.
5) Although developing the DC subgrid has high investment cost, the total operation cost of the hybrid microgrid is satisfactory.

As shown in Fig. 1 in the hybrid microgrid both DC and AC resources are incorporated for electricity power generation. The extra/shortage of power is transmitted with sub-transmission substation to balance AC and DC loads and resources with the help of the intergrid inverter between AC and DC subgrids. The resources shown in Fig. 1 are highly distributed in all over the distribution network. Indeed, the interconnected architecture of AC and DC resources in a distribution network increase the complexity of their control strategy.

Since the share of DC resources and loads are usually low, the servicing capacity of the DC link is lower than AC link. Thus, the AC link may be taken into account as the main energy carrier of the system and the DC link plays the role of a supplemental energy carrier (or vice versa, depending on the network's special characteristics).

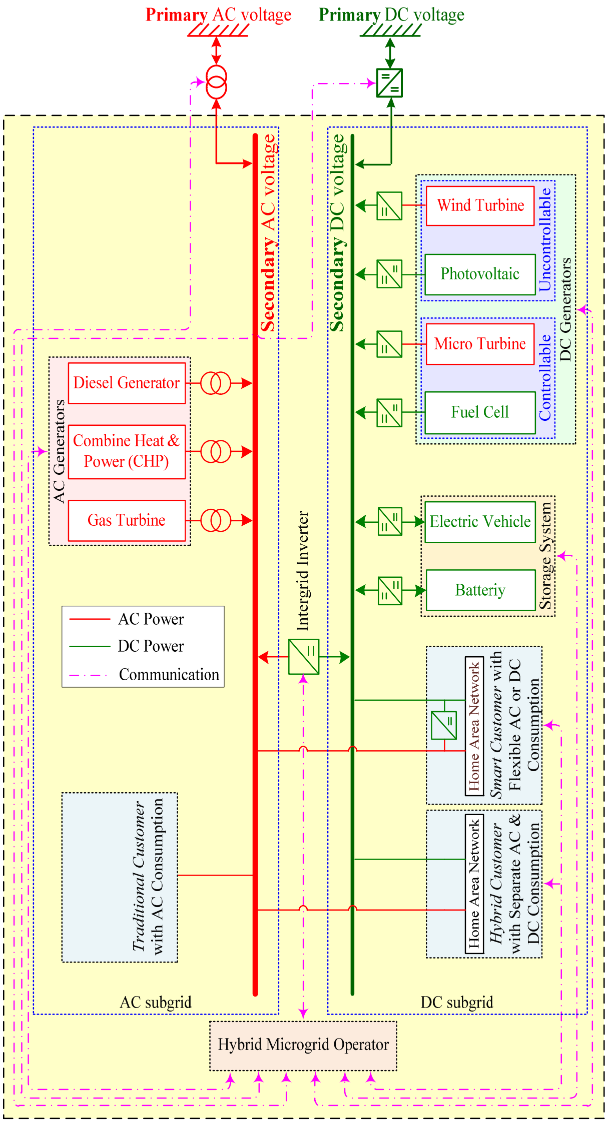

Fig. 1. General architecture of hybrid AC-DC microgrid.

Three customer types are considered in the proposed general grid's architecture namely; traditional customer that is connected to the AC link with merely AC consumption, hybrid customer that in addition to AC loads has some separate DC loads which should be supplied through separate AC and DC resources, and finally, smart customer that has both AC and DC loads, but as a result of its flexibility in power conversion, it could be supplied from both DC and AC links.

By employing the concept of FR, smart customers can possibly continue consuming electricity in contingency periods if their value of service reliability is high enough.

## 3. Flexible Reliability Concept and Modeling

The concept of FR is defined as the ability of a grid to continue serving electricity to the customers in contingency states. Enhancing OR of a system will lead to lower number or shorter duration of interruption by improving the averaged components' failure rate and repair time that consequently increases the investment cost of the system. However, enhancing FR of a system will not affect the components' characteristics and it is provided by technical opportunity of the grid. Moreover, in concept of FR enhancing the OR is not followed but it tries to enhance the reliability of selective customers that are known as high priority customers. Indeed, a high priority customer may be located in a system with low OR level, but with the high FR level. It can be concluded that adding the concept of FR beside the OR will optimize the grid's investment in long-run and will improve the grid's operation in short-run of the system.

Customers' priority is recognized based on their tendency for continuance of being supplied that represents their value of service reliability. Regarding this matter, the philosophy of designing distribution network architecture is presented in the previous section with the ability of offering an alternative resource for each individual smart customer in contingency states. In hybrid AC-DC microgrid the required backbone is practically provided for each smart customer to be supplied from two semi-separate sources; i.e. AC and DC sub-systems. Since both sub-systems are equipped with demand-side resources, the concept of FR is enabled by developments of such distribution system. Indeed, by support of RER and DRR, high priority smart customers can be secured against all type of contingencies, namely; AC and DC sub-system contingencies and upstream networks' contingencies.

Hybrid microgrid's operator estimates the customers' priority based on the customers willingness-to-pay to avoid and willingness-to-accept to compensate the interruption in a specified period. The desired reliability levels of customers are different in different times. For example, the desired reliability level for two neighbors may be different in different times. Thus, the priority of the customers shall not be same in different time and location. Providing FR changes based on customers' desires unlike the nodal reliability that is fixed based on the network characteristics.

It is possible that the OR of a grid be low to satisfy the most customers but its FR may be high enough to serve the high priority customers in critical periods. Thus, there will not be free-ride customers and the total investment of the grid could be planned in a minimum acceptable level. Free-riders are selfish customers with a tendency in misrepresenting their preferences, to minimize their contributions in providing a public good, but intend to enjoy the benefits of other users' contributions [10]. Free-riding may lead to inefficient levels of the public good and up to now, many solutions have been proposed for free-riding problem, such as implementing cost-sharing rules [16, 17] and penalizing free-riders [18, 19] and employing reliability insurance scheme [10].

### A. Overall Reliability Indices

The basic load-point (LP) reliability parameters are used to evaluate the reliability of the distribution system; i.e. the average LP failure rate (λ), the average load-point outage duration that known as repair time (r), and the average annual load-point time or unavailability (U) [20]. A wide range of system indices can be calculated with these three parameters. The system reliability indices may be customer-orientated such as SAIFI, SAIDI, customer average interruption frequency index (CAIFI), customer average interruption duration index (CAIDI), average service availability index (ASAI), Average Service unavailability index (ASUI) or load- and energy-orientated indices such as expected energy not supplied (EENS), average energy not supplied (AENS) and average customer curtailment index (ACCI). Required background for calculating these indices are addressed in [20].

In this paper, the following analytical approach is used for calculating the OR indices:

1) Get the $\lambda_j$, $r_j$ and $s_j$ for a failed element j.
2) Find the affected LPs and calculate the corresponding $\lambda_{ij}$ and $r_{ij}$ for an affected LP i using (1) and (2).

$$\lambda_{ij} = \lambda_j \prod_{k=1}^{N_{pr}} \left(1 - p_k\right) \tag{1}$$

$$r_{ij} = p_a s_j + \left(1 - p_a\right) r_j \tag{2}$$

3) Calculate the $EENS_{ij}$ using (3).

$$EENS_{ij} = L_i r_{ij} \lambda_{ij} \tag{3}$$

4) Repeat 1-3 for all elements in order to calculate the $EENS_i$ for LP i using the following equation:

$$EENS_i = \sum_{j=1}^{N_e} EENS_{ij} = L_i \sum_{j=1}^{N_e} r_{ij} \lambda_{ij} \tag{4}$$

5) Repeat 4 to evaluate the $EENS_i$ of all LPs.

6) Calculate the total system EENS using (5).

$$EENS = \sum_{i=1}^{N_p} EENS_i = \sum_{i=1}^{N_p} L_i \sum_{j=1}^{N_e} r_{ij} \lambda_{ij} \tag{5}$$

### B. Flexible Reliability Indices

For calculating FR indices in hybrid AC-DC microgrid the following assumption is carried out:

1) The operator of hybrid microgrid can fully monitor/control the RERs, DGs, DRRs, ESSs and inter-grid inverter of the system. Regarding this matter the servicing capacity of AC and DC sub-systems are observed.
2) Smart customers are assumed to be able to switch their load between AC and DC sub-systems, automatically and quickly (in less than one minute). Regarding this matter, no interruption time is considered for them in contingency states of the system and all or some part of their load is retrieved based on the alternative resource's servicing capacity.
3) The average load at each LP is used as the load model.
4) The substation is assumed highly reliable and this paper is considered the reliability models of distribution network.

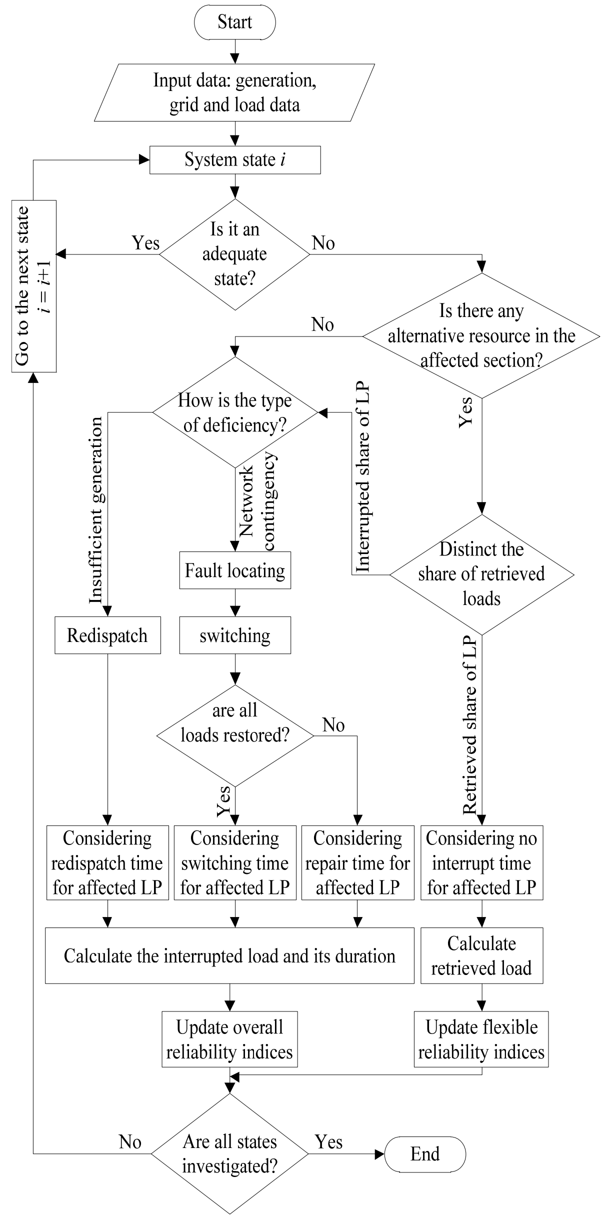

Fig. 2. Proposed flowchart for calculating OR and FR indices.

Fig. 2 indicates the proposed procedure of calculating FR indices beside OR indices. As it was stated before, the prerequisite of serving FR in the distribution network level is the existence of available alternative resource for each customer. Thus, in the failed state, it should be determined that "Is there any alternative resource in the interrupted part of the system, even before fault identification and reconfiguration of the system?". After distinction of the alternative resource servicing capacity in different LPs of the system, it should be determined that "How much of each LP can be retrieved by the alternative resources?". As it is shown in Fig. 2. firstly the contingency states are modeled and the system is analyzed in a specific contingency state. After finding the amount of available resources in the affected section, the share of retrieved load is calculated. Using remedial actions; i.e. redispatch and reconfiguration the interrupted (unsupplied) share of the load is tried to be served as soon as possible. If a LP be located in the fault section with no available alternative resource, it should be tolerant to pass the repair time.

The servicing capacity of the AC and DC sub-system can be formulated as (6) and (7), respectively. Since all terms of (7) are time-dependent values; $SC^{DC}$ should be updated in each time interval in time-dependent studies or be considered as the worst-case in the worst-case studies. Regarding this matter, the servicing capacity of AC sub-system is a constant value but the servicing capacity of DC sub-system may vary in time.

$$SC^{AC} = \bar{P}^{AC} \tag{6}$$

$$SC^{DC} = \sum_{l=1}^{N_{RER}} P_l^{RER} + \sum_{m=1}^{N_{DG}} P_m^{DG} + \sum_{n=1}^{N_{DRR}} P_n^{DRR} + \sum_{o=1}^{N_{ESS}} P_o^{ESS} + P^{inv} \tag{7}$$

In the failure state of AC or DC sub-system, the DC or AC sub-system provides the alternative resource for the interrupted section, respectively. Therefore, their servicing capacity represents their adequacy. The servicing capacities of AC sub-system is assumed to be equal in all LPs and is considered same as the feeder's capacity. This assumption is rooted in the nature of conventional AC distribution system due to the absence of adequacy problem. Equation (8) presents the LP servicing capacity of AC sub-system.

$$SC_i^{AC} = SC^{AC} \tag{8}$$

Unlike $SC_i^{AC}$, calculating $SC_i^{DC}$ depends on two parameters; i.e. the feeder's capacity in the DC sub-system and the adequacy of DC resources. The total adequacy of the DC resource can be calculated by summation of all available resources (including all DC generators, and the inter-grid converter) in the DC sub-system, as addressed in (7). Moreover, the summation of all $SC_i^{DC}$ is equal to the total servicing capacity, as addressed in the second equation of (9). Considering the mentioned constraints, the maximum achievable LP servicing capacity in DC sub-system is limited by the smaller value of $SC_i^{DC}$ or the feeder's capacity, as addressed in the first equation of (9).

$$\begin{cases} SC_i^{DC} = \min\left\{\bar{P}^{DC} \ \& \ SC^{DC}\right\} \\ SC^{DC} = \sum_{i=1}^{N_p} SC_i^{DC} \end{cases} \tag{9}$$

Finally, the available alternative resource at LP i is addressed in (10).

$$AR_i = \begin{cases} SC_i^{AC} & \text{if DC sub-system failed} \\ SC_i^{DC} & \text{if AC sub-system failed} \end{cases} \tag{10}$$

It should be noted that the $AR_i$ is the maximum possible amount of alternative resource in LP i and its potential capacity may be employed based on the customers' desires or priorities.

The proposed procedure of FR reliability indices is similar to the procedure of calculating OR indices that was addressed in the previous sub-section. Therefore, the following analytical approach is presented for calculating the FR indices:

1) Get the $\lambda_j$, $r_j$ and $s_j$ for a failed element j.
2) Find the affected LPs and calculate the corresponding $\lambda_{ij}$ and $r_{ij}$ for an affected LP i using (1) and (2).
3) The new FR index is introduced as the expected energy retrieved $EER_{ij}$ and is calculated as follows:

$$EER_{ij} = AR_i r_{ij} \lambda_{ij} \tag{11}$$

4) Repeat 1-3 for all elements in order to calculate the $EER_i$ for LP i using the following equation:

$$EER_i = \sum_{j=1}^{N_e} EER_{ij} = AR_i \sum_{j=1}^{N_e} r_{ij} \lambda_{ij}^{\sim} \tag{12}$$

5) Repeat 4 to evaluate the $EER_i$ of all LPs.
6) Calculate the total system EER using (13).

$$EER = \sum_{i=1}^{N_p} EER_i = \sum_{i=1}^{N_p} AR_i \sum_{j=1}^{N_e} r_{ij} \lambda_{ij} \tag{13}$$

## 4. Numerical Study

The Roy Billinton test system (RBTS) has 5 load busbars and it is extended to include distribution systems, which is appropriate for reliability evaluation studies. The distribution system of bus 4 is selected for the numerical study.

Fig. 3 shows the single line diagram of RBTS-Bus4.It is a rural network with a loading level of 40 MW, 38 LPs and 4779 customers; comprising 4700 residential (19.00 MW), 9 small user (16.30 MW), and 70 commercial (4.70 MW) customers. This distribution network is designed to deliver electricity with high reliability through a 33 kV ring linking three supply points (SP1, SP2 and SP3) [21]. Thus, it can be an appropriate distribution network for FR analysis. All the 11 kV feeders and laterals are considered as overhead lines. The required data for running reliability analysis is provided in [21].

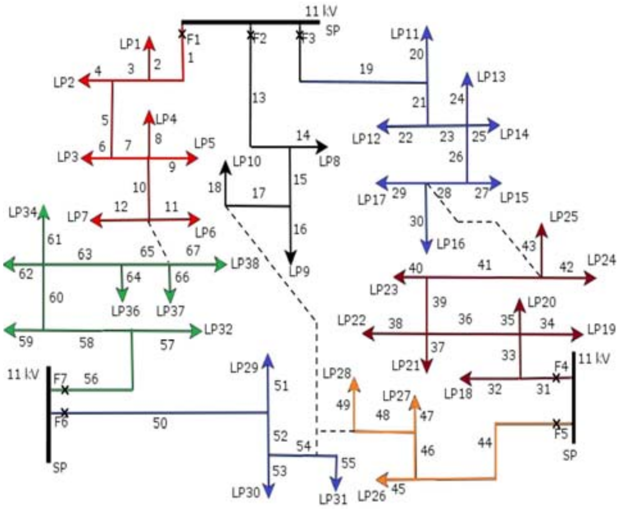

Fig. 3. Single line diagram of distribution network for RBTS-Bus4.

EENS of each feeder is calculated using the proposed analytical procedure of OR indices and is compared withthe results of [21] for validation of the proposed methodology.

Table 1 shows the results and the relative error in percent. As it can be seen from the Table 1, the relative error is so small and the calculated results are validated.

Table 1. Validation of Calculated Overall Reliability Indices with [21].

| **Feeder no.** | ***EENS* of feeder (kWh/yr)** | | **Relative Error (%)** |
|---|---|---|---|
| | **Calculated** | **[21]** | |
| F1 | 12205 | 12196 | + 0.07 |
| F2 | 1325 | 1323 | + 0.15 |
| F3 | 12017.9 | 12007 | + 0.09 |
| F4 | 13921.9 | 13930 | – 0.06 |
| F5 | 1130 | 1120 | + 0.89 |
| F6 | 1275 | 1268 | + 0.55 |
| F7 | 12480.3 | 12469 | + 0.09 |
| Total | 54355.1 | 54313 | + 0.08 |

Fig. 4 shows the single line diagram of the modified distribution network for bus 4 of RBTS. Three local DC feeders are added to construct the hybrid AC-DC microgrid in the end of F1, F4 and F7, which are labeled as F1DC, F4DC and F7DC, respectively. The length and reliability data (λ, r) of added DC feeders are considered same as the corresponding AC feeders. The servicing capacity of the added DC feeders are assumed as one fifth of servicing capacity of AC feeders. The demand-side resources of DC feeders are not shown in Fig. 4. for simplicity. All RERs, DGs, DRRs and ESSs are considered highly reliable without failure operation.

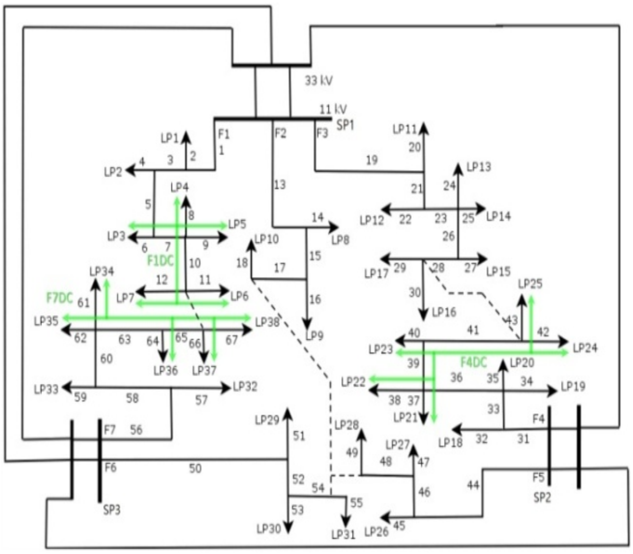

Fig. 4. Single line diagram of modified distribution network for RBTS-Bus4.

Table 2 shows the assumed characteristics of the equipments in the added DC feeders. Table 3 addresses the LP indices of OR and FR assessment; i.e. $EENS_i$ and $EER_i$. It can be seen that the $EER_i$ index for the LPs, which can be serviced by both DC and AC sub-systems is not zero. For better evaluating the impacts of FR on the system, the EENS and EER of feeders are compared and the percentage of improvement is reported in the Table 4. As it can be seen in this table by adding 3 DC feeders about 15% of the total grid's EENS is retrieved.

## 5. Conclusion

In this paper, the concept of flexible reliability (FR) and its approach of implementation in the hybrid AC-DC microgrid using demand-side resources (i.e. renewable energy resources, controllable distributed generators, demand response resource and energy storage system) was presented. The analytical method for calculating the new index of FR, expected energy retrieved (EER), was proposed. Implementing FR, a minimum acceptable reliability level (which is usually settled by regulatory authorities) will be provided for all customers in the distribution network. However, high priority customers are able to continue being supplied in contingency states, if they pay the corresponding cost. Investigating the economical effectiveness beside the provided technical opportunities for serving FR and defining an index for modeling the free-riders' benefit is considered as our future works.

Table 2. EENS and EER of the Case Study.

| **Feeder no.** | **EENS of feeder (kWhr/yr)** | **EER of feeder (kWhr/yr)** | $\frac{EER}{EENS}\times 100$ |
|---|---|---|---|
| F1 | 12205 | 2739 | 22.44 |
| F2 | 1325 | 0 | 0 |
| F3 | 12017.9 | 0 | 0 |
| F4 | 13921.9 | 2677 | 19.23 |
| F5 | 1130 | 0 | 0 |
| F6 | 1275 | 0 | 0 |
| F7 | 12480.3 | 2817 | 22.57 |
| Total | 54355.1 | 8232 | 15.14 |

Table 3. Rated Capacity of Demand-Side Resources of Added DC Feeder (kW).

| **Feeder no.** | **Wind** | **PV** | **DG** | **DRR** | **ESS** | **Total** |
|---|---|---|---|---|---|---|
| F1DC | 250 | 50 | 400 | 60 | 50 | 810 |
| F4DC | 200 | 100 | 350 | 70 | 60 | 780 |
| F7DC | 350 | 50 | 250 | 50 | 100 | 800 |

Table 4. Load-Point Indices of Overall and Flexible Reliability.

| **Feeder no** | **LP** | $EENS_i$ **(kWhr/yr)** | $EER_i$ **(kWhr/yr)** |
|---|---|---|---|
| F1 | LP1 | 1874.8 | 0.0 |
| | LP2 | 1902.1 | 0.0 |
| | LP3 | 1874.8 | 540.8 |
| | LP4 | 1907.5 | 550.2 |
| | LP5 | 1745.0 | 548.7 |
| | LP6 | 1452.5 | 550.2 |
| | LP7 | 1448.4 | 548.7 |
| F2 | LP8 | 340.0 | 0.0 |
| | LP9 | 585.0 | 0.0 |
| | LP10 | 400.0 | 0.0 |
| F3 | LP11 | 1902.1 | 0.0 |
| | LP12 | 1896.6 | 0.0 |
| | LP13 | 1896.6 | 0.0 |
| | LP14 | 1715.0 | 0.0 |
| | LP15 | 1740.0 | 0.0 |
| | LP16 | 1423.5 | 0.0 |
| | LP17 | 1444.2 | 0.0 |
| F4 | LP18 | 1902.1 | 0.0 |
| | LP19 | 1874.8 | 0.0 |
| | LP20 | 1902.1 | 0.0 |
| | LP21 | 1902.1 | 538.5 |
| | LP22 | 1720.0 | 530.7 |
| | LP23 | 1745.0 | 538.5 |
| | LP24 | 1448.4 | 538.5 |
| | LP25 | 1427.6 | 530.7 |
| F5 | LP26 | 390.0 | 0.0 |
| | LP27 | 400.0 | 0.0 |
| | LP28 | 340.0 | 0.0 |
| F6 | LP29 | 350.0 | 0.0 |
| | LP30 | 400.0 | 0.0 |
| | LP31 | 525.0 | 0.0 |
| F7 | LP32 | 1907.5 | 0.0 |
| | LP33 | 1907.5 | 0.0 |
| | LP34 | 1869.4 | 558.8 |
| | LP35 | 1907.5 | 570.2 |
| | LP36 | 1715.0 | 558.8 |
| | LP37 | 1750.0 | 570.2 |
| | LP38 | 1423.5 | 558.8 |

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