

A novel approach to assess radial distribution system for optimal sizing of microgrid

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ABSTRACT

The performance of Radial Distribution System (RDS) is enhanced by maintaining the appropriate Penetration Ratio (PR) of Distributed generation. However, it has been observed that Penetration Ratio cannot be useful to analyze the impact of a Microgrid on the performance of RDS. Hence a new index 'Relief Factor' (RF) is defined in this paper and the impact of a Microgrid at different RF is studied. This paper presents an approach to compute daily energy losses variation when Microgrids of varying RF are connected to RDS having various maximum demands. A methodology has been proposed for finding optimal RF and location of a Microgrid. In addition, the impact of maximum demand of RDS on optimum RF is analyzed. This paper gives the novel concept of assessing RDS to integrate a Microgrid depending on maximum demand of RDS as well as of a Microgrid. It also predicts size of a Microgrid based on optimum Relief Factor.

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1. INTRODUCTION

Shortage of transmission system capacities and the need for reliable power supply is fostering the growth of various types of Distributed Generators (DG). In case of lack of reliable electricity infrastructure, introducing higher shares of renewable energy sources can help alleviate pressure on strained distribution systems, and offer better service to consumers. The growing adoption of renewable energy sources as distributed generators is challenging the planning, design and operation of distribution networks. It is widely accepted that inappropriate placement and capacity of DG may lead to greater system losses than losses without DG [1, 2]. Literature on Hybrid Renewable Energy Sources (HRES) is focused on minimization of cost of energy and loss of power supply probability [3-5]. Growth of renewable based distributed energy sources urged the need of storage devices. A coordinated operation of distributed generators and storage devices gave rise to the concept of Microgrid [6]. Microgrid is composed of energy sources, storage devices and loads. It is operated in two modes- grid connected mode and islanded mode [7]. Flexible modes of operation and use of storage devices in a Microgrid add complexity in its integration with RDS [8-10]. Many algorithms are proposed for sizing of components of a Microgrid [11-13]. The problem of sizing of sources in islanded Microgrid can be formulated as a minimization problem with the objective to reduce capital, operational and maintenance cost [14-16]. Proper selection and size of distributed sources is challenging and complicated task in islanded mode of Microgrid due to lack of infinite bus [17]. The operation of a Microgrid to manage its generation and demand dependent on price-based scheme leads to uncertain and unreliable supply of power towards the utility [18]. Various power management strategies of a Microgrid are developed to enhance the performance of distribution network [19-21].

The impact of different DG technologies on variation of distribution system losses was analyzed using penetration ratio (PR) [1]. Electricity tariff of the Maingrid, fuel cost, availability of renewable sources, efficiency of sources and nature of Microgrid load are important considerations in determining the demand supply balance in a Microgrid [22, 23]. These factors differentiate Microgrid integration from DG integration. Though steady state analysis of a distribution system is analyzed in the presence of a Microgrid, performance of distribution network is not evaluated according to demand supply balance in a Microgrid [24]. A Microgrid can absorb the excess power during off-peak hours of the Maingrid. Depending on the demand supply balance in a Microgrid, it may export power to the Maingrid. However, in case of a shortage of internal generation in a Microgrid, its demand is fulfilled by the Maingrid. In such case, PR of a Microgrid is zero. Also, in case of a fault in RDS, a Microgrid gets isolated from the Maingrid. In such events, PR is zero. Thus, PR fails to assess both the modes of a Microgrid. PR indicates working of a Microgrid as a source only from the Maingrid perspective. Ratio of Microgrid generation to Microgrid demand is a deciding factor while integrating it in a distribution system.

It is clear from the literature that the impact of demand supply balance in a Microgrid for its integration in an RDS is left untouched. This paper presents a novel term to assess the performance of RDS in the presence of a Microgrid. The term can be established as an equivalent term for PR. This innovative term is addressed as ‘Relief Factor’ (RF). It is the ratio of Microgrid generation to the maximum demand of a distribution system. The problem of the correlation of optimum Relief Factor with ratio of RDS demand to Microgrid demand is also attempted. In this paper, a new methodology is presented to determine viable Microgrid generation with respect to Microgrid demand at optimal Relief Factor. Proposed work is presented in two stages. The first stage analyses the impact of a Microgrid on RDS by an innovative index Relief Factor. A new algorithm is proposed for determining the relation between optimum Relief Factor and ratio of RDS demand to Microgrid demand in the second stage. The rest of the paper is organized as follows: Proposed method of analysis of Microgrid integration in a distribution network is explained in Section 2. Section 3 presents research method applied for Microgrid integration in an RDS. Results and discussions using the proposed methodology applied to two case studies is explained in Section 4. Section 5 outlines the conclusion.

2. PROPOSED METHOD

A new index ‘Relief Factor’ is introduced to analyze implications of the presence of a Microgrid in the Maingrid. Relief Factor considers the Microgrid generation and not just the power exported from the Microgrid to the Maingrid. Thus, ‘Relief Factor’ proves to be more appropriate than ‘Penetration Ratio’ while assessing implications of the presence of a Microgrid on the Maingrid performance. However, the ratio of Microgrid generation to the Microgrid demand plays a significant role while deciding feasibility of Relief Factor. Microgrid is operated in two modes: grid connected mode and islanded mode. Accordingly, Relief Factor (R.F.) is defined for two operational modes.

- 1) Islanded mode:

$$\begin{aligned}
 \text{Relief Factor} &= \frac{\text{Microgrid Demand (i.e. Microgrid generation)}}{\text{Maximum demand of radial distribution system}} \\
 \sigma &= \frac{P_{D\mu G}}{P_D} = \frac{P_{G\mu G}}{P_D}
 \end{aligned}
 \tag{1}$$

- 2) Grid connected mode:
 - a) Microgrid as a source

$$\begin{aligned}
 \text{Relief Factor} &= \frac{\text{Microgrid Demand} + \text{Power exported by Microgrid}}{\text{Maximum demand of radial distribution system}} \\
 &= \frac{\text{Microgrid generation}}{\text{Maximum demand of radial distribution system}} \\
 \sigma &= \frac{P_{D\mu G} + P_{\mu G}^{in}}{P_D} = \frac{P_{G\mu G}}{P_D}
 \end{aligned}
 \tag{2}$$

- b) Microgrid as a load

$$\begin{aligned}
 \text{Relief Factor} &= \frac{\text{Microgrid Demand} - \text{Power imported by Microgrid}}{\text{Maximum demand of radial distribution system}} \\
 &= \frac{\text{Microgrid generation}}{\text{Maximum demand of radial distribution system}} \\
 \sigma &= \frac{PD_{\mu G} - P_{\mu G}^{\text{in}}}{PD} = \frac{P_{G_{\mu G}}}{PD}
 \end{aligned} \tag{3}$$

Problem is formulated with an objective to minimize power losses in an RDS subject to various constraints. It determines optimum Relief Factor for grid connected Microgrid. Power flow analysis for grid connected Microgrid is performed using Backward Forward Sweep method (BFS) [25]. Particle Swarm Optimization (PSO) is applied to find minimum loss in an RDS by integration of a Microgrid [26]. Expression for total real power loss is as follows [2]:

$$P_{\text{loss}} = \sum_{i=1}^m (I_i)^2 R_i \tag{4}$$

Where,

m = Number of the sections

I_i = Current of ith section

R_i = Resistance of ith section

The constraints in the optimization problem are

a) Active and reactive power balance constraints-They are expressed as (5) and (6):

$$\sum_{t=1}^T (P_G(t)) \Delta t \pm \sum_{t=1}^T P_{\mu G}^{\text{in}}(t) \Delta t = \sum_{t=1}^T P_D(t) \Delta t + \sum_{t=1}^T P_{\text{loss}}(t) \Delta t \tag{5}$$

$$\sum_{t=1}^T (Q_G(t)) \Delta t \pm \sum_{t=1}^T Q_{\mu G}^{\text{in}}(t) \Delta t = \sum_{t=1}^T Q_D(t) \Delta t + \sum_{t=1}^T Q_{\text{loss}}(t) \Delta t \tag{6}$$

Where,

P_G = Total active power generation of RDS and Microgrid

Q_G = Total reactive power generation of RDS and Microgrid

P_D = Total active power demand of RDS including Microgrid demand

Q_D = Total reactive power demand of RDS including Microgrid demand

P_{loss} = Total real power loss in the system

- P_{μG}ⁱⁿ = Power supplied to Microgrid from RDS.

+ P_{μG}ⁱⁿ = Power supplied from Microgrid to RDS

Δt = Time interval (1 hour)

T = Total time (24 hrs)

b) Voltage constraints- These are given by (7):

$$V_{\text{bus_min}} \leq V_{\text{bus } i} \leq V_{\text{bus_max}} \tag{7}$$

Where,

V_{bus i} = ith bus voltage

V_{bus_min} and V_{bus_max} is minimum bus voltage and maximum bus voltage respectively. System voltage limits are ±6 % of the nominal voltage value.

c) Microgrid generation constraints- The constraints are imposed on the size of a Microgrid.

$$P_{G_{\mu G}(\text{min})} \leq P_{G_{\mu G}(t)} \leq P_{G_{\mu G}(\text{max})} \tag{8}$$

Where,

$P_{G \mu G(\min)}$ is the minimum active power generation of Microgrid and is set as the 10% of the total load on the distribution system.

$P_{G \mu G(\max)}$ is the maximum active power generation of Microgrid and is set as the 90% of the total load on the distribution system.

3. RESEARCH METHOD

The optimum Relief Factor where RDS losses are minimum is one of the important criteria in deciding the location and size of a Microgrid. However, the optimum Relief Factor varies with maximum demands of RDS. An attempt has been made to determine the size of Microgrid for various RDS demands and optimum Relief Factor. A new factor ‘‘Demand Ratio’’ is used which indicates ratio of RDS maximum demand to Microgrid maximum demand. An algorithm is proposed for determining the Microgrid size for various cases viz. Demand Ratio-1, 4 and 8. Figure 1 shows the flowchart for Microgrid sizing based on RF and Demand Ratio.

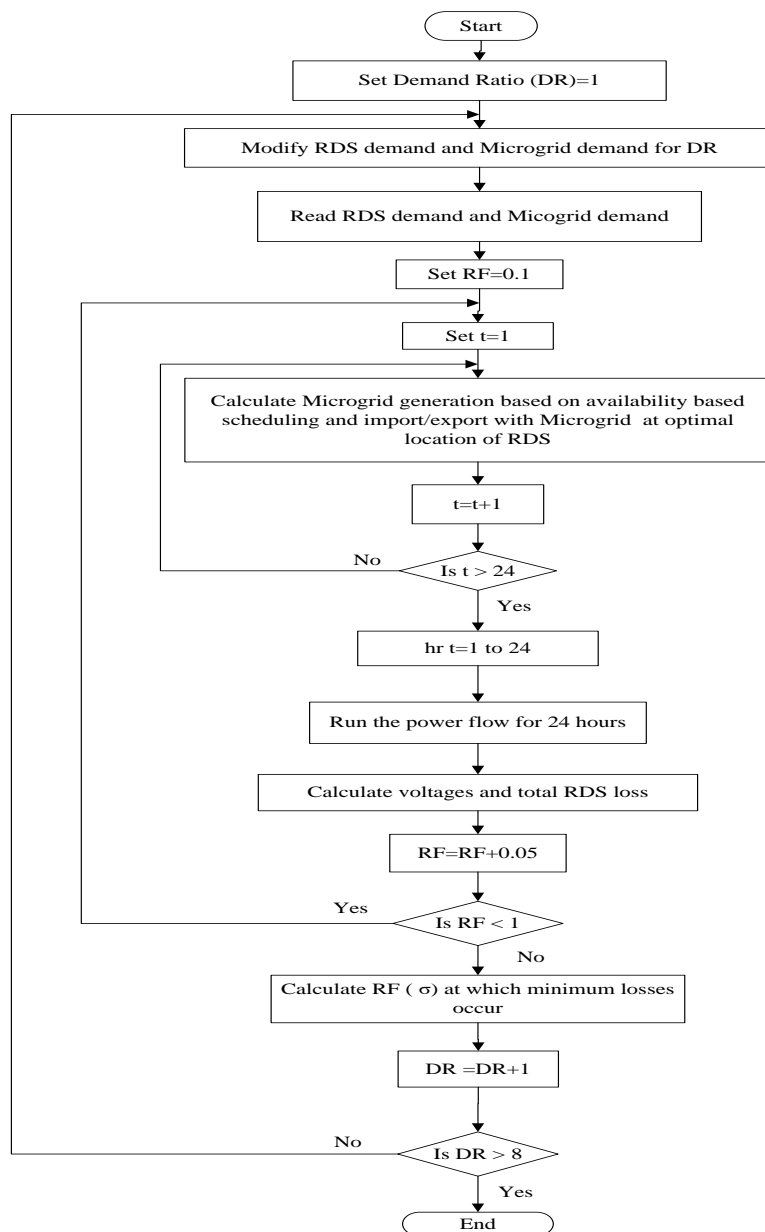


Figure 1. Flowchart for microgrid sizing based on RF and demand ratio

4. RESULTS AND DISCUSSION

Excessive burden of demands and/or long lengths of an RDS severely affect parameters of the farthest end of the RDS. Bus voltage and system losses are two performance indicators for assessment of an RDS. The location of a Microgrid is determined by selecting an approach based on the power injected by a Microgrid in an RDS. For this study, two systems-34 bus, 5.4 MVA, unity p. f., 11 kV RDS and 9 bus, 13 MVA, 23 kV are chosen for the analysis [27]. Demand supply balance of a Microgrid and load on a distribution system shows a variation over 24 hours' period. However, the demand is assumed to be constant over a period of one hour. The load demand of 34 bus system is modified to get load variation over 24-hour period. However, load demand of 9 bus system is kept constant for 24 hours. The two systems thus represent two different but realistic and practical scenario of hourly variation of load like in residential feeder and constant load like in 3 shift industrial feeder. The maximum demands and thus load pattern of both 34 bus and 9 bus RDS is modified with respect to Microgrid (MG) maximum demand to study the impact on Optimum Relief Factor and to assess the performance of the RDS. Accordingly, scenarios were created for Demand Ratios equal to 1, 4 and 8 in 34 bus and 9 bus RDS.

The impact of Relief Factor is first studied with respect to daily energy losses. Using Particle swarm optimization technique, the location of Microgrid was determined and it comes to be bus no. 25 in 34 bus system and bus no. 8 in 9 bus system. The study was further extended to see variation of Relief Factor with respect to maximum demand of RDS and impact on Microgrid generation. Figure 2(a) and 2(b) shows the variation of daily energy losses as a function of Relief Factor in 34 bus system and 9 bus system respectively.

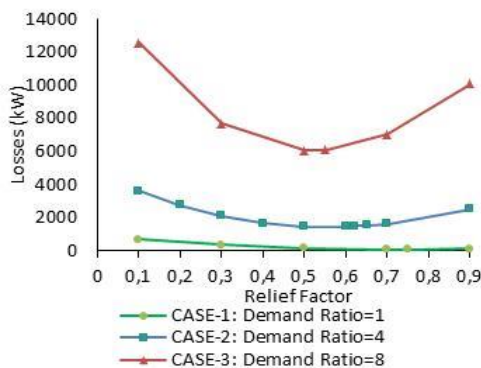


Figure 2 (a). Variation of losses for 34 bus system

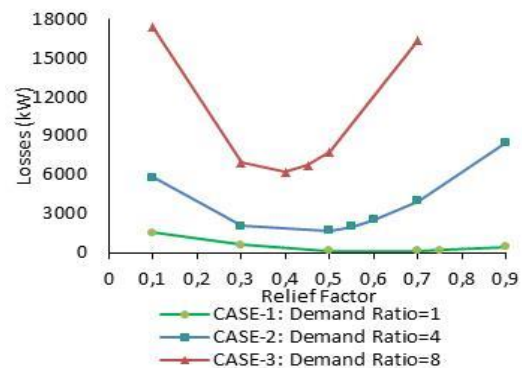


Figure 2 (b). Variation of losses for 9 bus system

It is observed that as Relief Factor increases, losses start decreasing. However, it is not always true. After a point even with increase in Relief Factor, losses also start increasing. The losses follow a U Shape trajectory with respect to Relief Factor. This type of shape has appeared in all the three cases studied for 34 bus system and 9 bus system. Regarding impact of RDS maximum demand, it is observed that as maximum demand of RDS goes on increasing the optimum Relief Factor (where losses are minimum) goes on reducing. The impact of increasing maximum demand and optimum Relief Factor is required to be studied in terms of Microgrid generation with respect to Microgrid maximum demand. This ratio also plays a significant role in deciding the size of a Microgrid.

Figure 3(a) and 3(b) shows the variation of Relief Factor and variation of Microgrid generation in terms of Demand Ratio for 34 bus system and 9 bus system respectively. The results indicate that though the impact of maximum demand of RDS is inversely proportional to optimum Relief Factor, it is directly proportional to maximum generation of a Microgrid. The case studies indicate that for higher RDS maximum demands, though optimum Relief Factor is lower, it requires higher Microgrid generation with respect to Microgrid maximum demand. Thus for a 34 bus system, if maximum demand of RDS is 8 times the Microgrid maximum demand, the maximum Microgrid generation required to achieve the optimum Relief Factor of 0.5, is around 4.45 times the Microgrid maximum demand. Similar trend is observed in 9 bus system. However, for Demand Ratio almost equals to one, it is observed that optimum Relief Factor of 0.7 results in Microgrid generation of 1.3 to 1.4 times Microgrid maximum demand in both 34 and 9 bus systems.

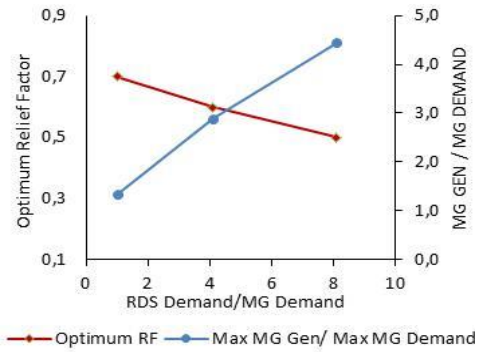


Figure 3(a). Effect of maximum demand of RDS in 34 bus System

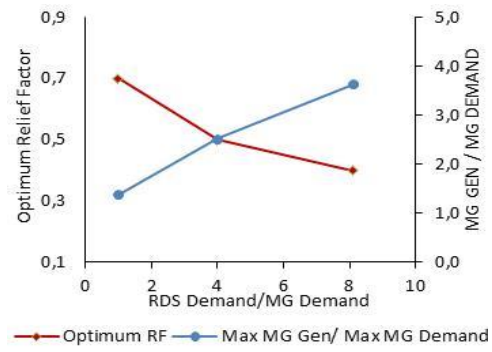


Figure 3(b). Effect of maximum demand of RDS in 9 bus System

The impact of Relief Factor on voltage profile of the RDS is also studied for three cases in 34 bus and 9 bus system. For 34 bus system, Figure 4(a) indicates effect of optimum Relief Factor on the voltage profile of bus 25, where the Microgrid is connected in 34 bus system. For 9 bus system, Figure 4(b) indicates the effect of optimum Relief Factor on the voltage profile of bus 8, where the Microgrid is connected.

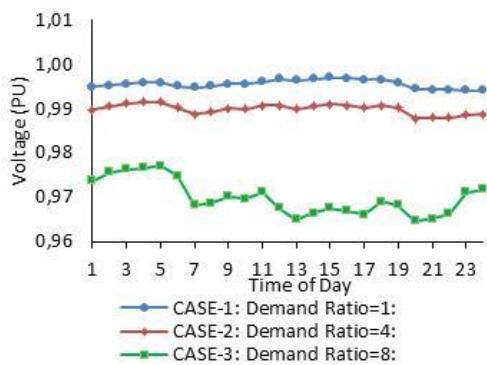


Figure 4(a). Voltage profile of MG Connected bus for 34 bus system for various DRs

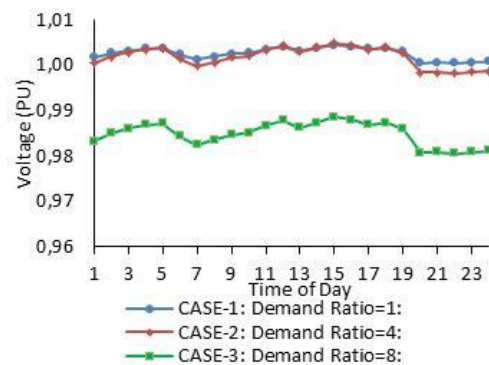


Figure 4(b). Voltage profile of MG Connected bus for 9 bus system for various DRs

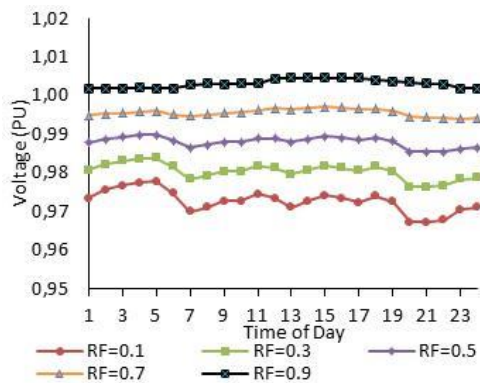


Figure 5(a). Voltage profile of MG connected bus in 34 bus system for viable case

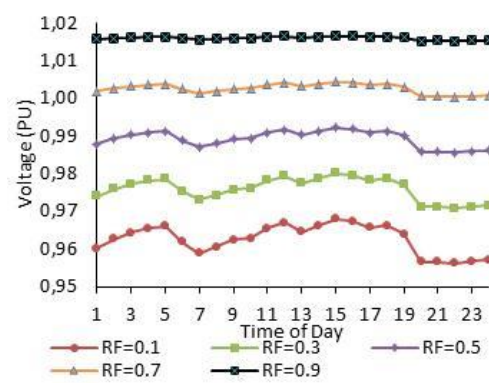


Figure 5(b). Voltage profile of MG connected bus in 9 bus system for viable case

It is observed in 34 bus and 9 bus systems, that voltage profile of the Microgrid connected bus is better for optimum Relief Factor where Demand Ratio is equal to one (Case-1). This substantiates the result that a

Microgrid is more viable in this case as system performance is most improved in terms of losses and voltage profile. The study was also done to see the impact of variation of Relief Factor on the voltage profile for most viable case, i. e Case-1. Figure 5 (a) and 5 (b) indicate variation of voltages at bus no. 25 in 34 bus system and bus no. 8 in 9 bus system for various Relief Factors. It is observed that voltage profile of the bus to which Microgrid is connected improves with increase in Relief Factor. The voltages at optimum Relief Factor comes closer to 0.99 to 1.0 p. u. As Relief Factor increases beyond optimum value, the voltages are observed in the range of 1.0 to 1.01. It is thus observed that at optimum Relief Factor, voltage profile improves significantly along with lowest losses leading to the best system performance.

5. CONCLUSION

The main contribution of this paper is the qualitative results that are applied to the most of distribution systems. The results presented help in deciding RDS for Microgrid integration to become viable operation in both grid connected and islanded mode. The study is also done to find out the optimum size of a Microgrid to improve system performance. In this paper, the assessment of RDS for integration of a Microgrid has been analysed for two systems. For each system, three different cases have been considered. In all cases, the daily energy losses variation as function of Relief Factor shows a U shape trajectory. Relief Factor indicates generation of Microgrid with respect to maximum RDS demand. Losses start to decrease with increase in Relief Factor but after a minimum value, losses start increasing with increase in Relief Factor. The minimum value is considered as Optimum Relief Factor for the RDS. The impact of variation of maximum demand of RDS on optimum Relief Factor is also studied. In both RDS, the optimum Relief Factor decreases with increase in maximum demand of RDS. Though lower Relief Factor means lower Microgrid generation, it can be interpreted that low optimum Relief Factor is better which is not always true. The optimum Relief Factor and Microgrid generation needs to be seen in context of Microgrid maximum demand and RDS maximum demand. Higher the maximum demand of RDS, Microgrid generation required with respect to the Microgrid maximum demand also increases.

Understanding the results, it is important to emphasise the effect of maximum demand of RDS and optimum Relief Factor. Microgrid is intended to use in two modes of operation- Grid connected and Islanded mode. Higher Microgrid generation with respect to its own maximum demand will result in higher installed capacity of DGs in a Microgrid. This installed capacity will remain unutilized when a Microgrid will operate in islanded mode of operation. This will result in Microgrid becoming inviable. The installed capacity of a Microgrid shall be so selected that it will improve the system performance and also becomes viable in both modes of its operation. It is thus always preferable to connect a Microgrid to RDS in which maximum demand of RDS is almost equal to Microgrid maximum demand. It can also be concluded that Microgrid integrated with such RDS shall be operated at optimum Relief Factor to improve the system performance.

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