ASSESSING THE BENEFIT OF ISLAND OPERATION OF VARIABLE DISTRIBUTED GENERATION IN RELIABILITY IMPROVEMENT OF RADIAL DISTRIBUTION NETWORKS

Željko POPOVIĆ
Faculty of Technical Sciences, Serbia
zpopovic@uns.ac.rs

Stanko KNEZEVIĆ
Schneider Electric DMS NS, Serbia
stanko.knezevic@schneider-electric-dms.com

ABSTRACT

This paper presents an approach for assessing the benefit of island operation of variable distributed generation (DG) in improving reliability in radial distribution networks. The proposed approach employs the risk-based procedure to obtain the best network automation scenario in the presence of variability of loads and variability and uncertainty of distribution generation. The automation scenario defines the number, type and location of automation devices to be allocated in the network to enable optimal creation of islands and thus to minimize the expected reliability cost. This cost consists of the cost of interruptions to customers and the cost of automation devices. By varying the level of variability and uncertainty of DG production different automation scenarios and corresponding reliability costs are obtained using the risk procedure. Based on these results the value of island operation of DGs in improving reliability in radial distribution networks is assessed.

INTRODUCTION

Distribution system reliability is essential for customer satisfaction. Because of that, maintaining and improving service reliability becomes one of the major concerns for distribution utilities (DSOs). Beside the traditional approaches (e.g., network automation), distributed generators (DGs) can also improve the reliability in radial networks by reducing the duration of customer's interruptions [1]-[4]. Such improvement depends on DGs operating in island mode. An island (microgrid) can be formed when sufficient local generation exists to supply local load and the operational constraints (thermal and voltage) are satisfied in the island. However, due to the unpredictable nature of DGs (e.g., wind-based and solar-based DGs) and variability of demand not only one but various futures, i.e. various combinations of load and generation may occur. In this environment, reliability improvement achieved by creation of one or more DG islands (microgrids) in case of sustained faults in radial networks can only be assessed by employing risk analysis.

In this paper, triangular and trapezoidal fuzzy numbers are used to describe variability in demand and variability and uncertainty in DG production, respectively. The risk-based procedure is proposed that enables obtaining the best automation scenario in such environment. This procedure employs the MILP model [4] to analyze the variability and uncertainty of loads and DG production simultaneously for all possible intervals (α-cuts) of fuzzy numbers. For each interval, the MILP algorithm determines the number, type and location of remotely controlled switches (RCSs) (switches and reclosers) and fault passage indicators (FPI) in the network, i.e. the automation scenario that enable creation of island(s) for every sustained fault so that the total reliability cost is minimized. This cost consists of the cost of interruptions to customers and the cost of RCSs and FPIs. RCSs are used to create one or more islands in the case of a sustained fault as well as to enable load curtailment (e.g. in distribution substations) and thus ensure the optimal creation of island(s). In the proposed way, a number of high-quality automation scenarios are obtained. These scenarios, along with the corresponding outcomes, are evaluated and the best one is selected by employing maximal Expected Monetary Value (max EMV) criterion for measuring and managing risk. Using the proposed procedure, network automation scenarios and corresponding reliability costs are obtained for various levels of variability and uncertainty of DG production. Based on these results the value of island operation of DGs in improving reliability in radial distribution networks is assessed. The analyses are performed on the reliability test network Bus 4 of the RBTS and the obtained results are presented and discussed in details.

MODELING OF LOAD AND GENERATION VARIABILITY AND UNCERTAINTY

Variability in demand along with the variability and uncertainty in DG production are modeled here by introducing fuzzy concept. According to this concept, the values of load and generation are translated into a possibility distribution using the approach proposed in [5]. This process is discussed in the sequel.

A load duration curve (LDC) that describes the load variability is shown in Fig.1. This curve can be seen as the cumulative load probability distribution function (PDF). In Fig.2, T is the proportion of time the load is at or below a load level of K kilowatts. By applying the approach proposed in [5], the load duration curve, i.e. the load PDF, is transformed into the triangular membership function, shown in Fig. 2. Hence, the variability of load at the given node will be described by triangular fuzzy number $\widetilde{D}=(D_L, D_M, D_R)$.

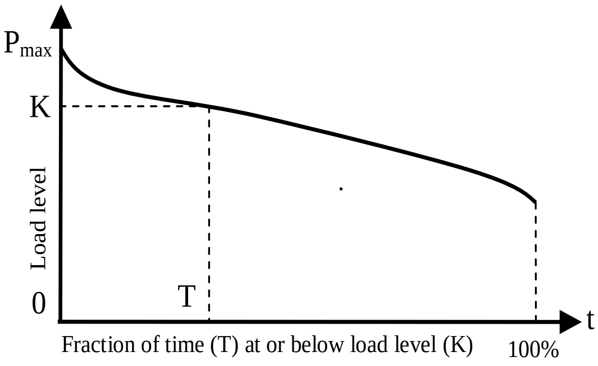

Fig.1. Load duration curve (LDC) representation

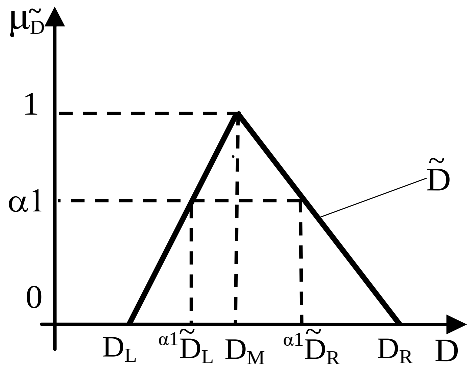

Fig.2. Fuzzy representation of LDC

Due to the random nature of renewable generators and unpredicted climate changes, power generated by distributed generation is unpredictable and subjected to high variability and uncertainty. This is shown in Fig. 3 where the cumulative power probability distribution of wind turbine for four average wind speeds is presented [6]. Probability distribution functions from Fig. 3 are transformed into triangular membership functions shown in Fig. 4 [5]. Each of triangular fuzzy numbers in Fig. 3 describes the variability in DG generation for the corresponding average wind speed. In order to assess the uncertainty in DG generation due to the uncertainty in future wind speed, the power output of a wind generator is described by trapezoidal fuzzy number $\tilde{G}=(G_1, G_2, G_3, G_4)$, as shown in Fig. 4. In this

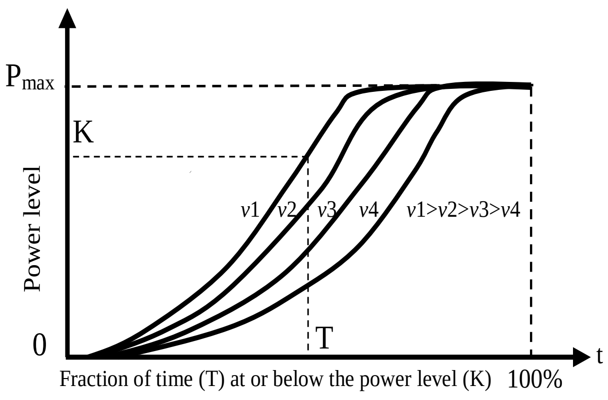

Fig.3. Power probability distribution of wind turbines

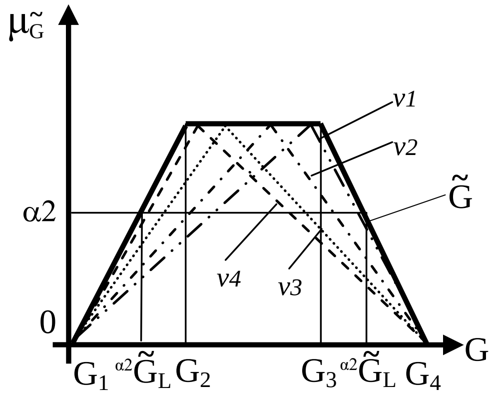

Fig.4. Fuzzy production representation

way, all possible power PDFs of a DG that corresponds to wind speeds between *v*1 and *v*4 are taken into account. That is, both the variability and the uncertainty of DG generation can be described in the proposed way. Here, it should bear in mind that the area under the trapezoidal membership function is greater than the area under any of individual triangular membership functions shown in Fig. 4. This implies that the fuzziness of trapezoidal number and thus the uncertainty/variability that this fuzzy number describes is greater than that described by any individual triangular fuzzy number.

RISK-BASED APPROACH FOR NETWORK AUTOMATION PLANNING

The procedure for obtaining the best network automation scenario in radial distribution networks with island operation of DGs, in the presence of variability and uncertainty of load and generation, respectively, consists of the following global steps:

1) Obtaining a set of network automation scenarios.
2) Evaluation of the obtained network automation scenarios and selection of the best scenario using risk-based approach.

The aforementioned steps are described in details hereafter.

<u>Obtaining a set of network automation scenarios</u>

The calculation procedure for obtaining a number of different automation scenarios in the network consist of the following steps:

1) Set the value of $\alpha1=0$.
2) For current value of $\alpha1$ determine left-hand side (LHS) crisp value ($^{\alpha1}\tilde{D}_L$) and right-hand side (RHS) crisp value ($^{\alpha1}\tilde{D}_R$) of fuzzy load from its membership function (see Fig. 2).
3) Set the value of $\alpha2=0$.
4) For current value of $\alpha2$ determine LHS ($^{\alpha2}\tilde{G}_L$) and RHS ($^{\alpha2}\tilde{G}_R$) crisp value of fuzzy generation from its membership function (see Fig. 4).
5) By using crisp values from previous steps solve the fuzzy MILP model presented in [4]. The MILP

model is solved for every combination of crisp values of fuzzy load and generation. In this way, the optimal automation scenarios (optimal number, type, and location of new ADs and optimal location of the existing ADs) are obtained for every combination of crisp values of current α-cuts of fuzzy load and fuzzy generation.

6) If α2=1 go to step 9).
7) Increase α2, for say Δα=0.1 and repeat steps 4)–5).
8) Repeat step 7 by gradually increasing α values until value α2=1 is reached.
9) After α2=1 is reached divide the interval [G2, G3] of trapezoidal fuzzy generation (see Fig. 4), into say 10 equal subintervals. For each subinterval obtain a value of fuzzy generation from its membership function and repeat step 5. Note that in this way only one crisp value of fuzzy generation is defined.
10) Increase α1, for say Δα=0.1, and repeat steps 3)–9) for this increased value of α1.
11) Repeat step 10) by gradually increasing α1 values until value α1=1 is reached.

Through steps 1)-11) a number of different network automation scenarios are obtained. These scenarios are evaluated as presented hereafter.

Evaluation of network automation scenarios

Each network automation scenario is evaluated for every fault in the network and for all combination of demand and generation. Evaluation and selection of the best automation scenario is done according to the maximal expected monetary value (max EMV) criterion for measuring risk [7] as decribed hereunder.

By applying automation scenario SCR_i in case of fault (k) in the considered network two possible cases (outcomes), O_1 and O_2, can occur with the corresponding probabilities:

- island can be created (O_1) with the probability $P_k(O_1,SCR_i)$,
- island cannot be created (O_2) with the probability $P_k(O_2,SCR_i)=(1- P_k(O_1, SCR_i))$.

The island cannot be created if load is greater than generation within the island, if the capacity constraint of branches is violated in the island, or if the voltage constraint is violated in the island. The probability of appearing of the aforementioned conditions is calculated as proposed in [7].

Now, the total expected (fuzzy) costs for an automation scenario SCR_i, $E(SCR_i)$, is obtained by summing up costs for all faults in the network [7]:

$$E(SCR_i) = \mathrm{CAD}_i + \mathrm{CRL}_i + \sum_k \sum_j P(O_j, SCR_i) \cdot CI\tilde{N}T(SCR_i, O_j), \quad (1)$$
$$k \in N_f, \quad j = 1,2, \quad i = 1,..,N$$

where:

CAD, CRL – cost of new ADs and cost of relocating the existing ADs, respectively,

CINT – annual fuzzy interruption cost due to short-term and long-term interruptions of fuzzy loads and fuzzy DG production considering the possibility of DG island operation,

N – number of obtained automation scenarios,

N_f – set of all faults in the network,

Evaluated automation scenarios are ranked and the best one is choosen ($d(SCR_{opt})$) by applying the maximal expected monetary value (max EMV) criterion for measuring risk. In the network automation planning problem, this criterion corresponds with the network automation scenario with the minimal total expected cost $E(SCR_i)$,

$$d(SCR_{opt}) = \min E(SCR_i), \quad i = 1, \ldots, N. \quad (2)$$

NUMERICAL RESULTS

The proposed approach is used to assess the benefit of the island operation of DGs in improving reliability in the modified Bus 4 of the RBTS [8] test system, shown in Fig. 5. For testing purposes the original network [8] is modified by adding 8 DGs of the same type, as shown in Fig. 5. The required data are given in [8] and in [9]. Fuzzy numbers quantifying the uncertainty in input quantities are as follows: $K\tilde{G} = (0, 0.2, 0.8, 1)$ and $K\tilde{D} = (0.3, 0.4, 1)$. Hence, fuzzy load and generation are obtained by multiplying the maximal load and generation values shown in Fig. 5 by fuzzy coefficients $K\tilde{D}$ and $K\tilde{G}$. Four cases (S1-S4) are analyzed and the results are shown in Table 1.

Cases S1 and S2 consider network with and without possibility of DG islanding, respectively. To assess the influence of island operation of DGs on reliability improvement, the budget spent (CAD) on network automation in S1 is considered to be the maximal available budget in S2. The comparison of S1 and S2 shows that island operation offers noticeably better reliability, i.e., significantly lower expected reliability cost (E(SCR)). It should be emphasized that number, type and location of automation devices differs noticeable in the considered cases. Further, the influence of the level of uncertainty of DG production is analyzed in cases S3 and S4. In case S3 lower degree of uncertainty of DG production is considered by decreasing the fuzziness of the trapezoidal fuzzy number. This is accomplished so that the uncertainty in

Table 1 Test results

Case	Automation devices locations			$E(SCR_l)$ [US$]	CAD [US$]
	Recloser	Switch	FPI		
S1	5,32,48,65, 66, 67, 76, 78, 87, 89, 91	6, 12, 13, 14, 39, 40, 41, 42, 56,57, 58, 59, 97, 98	17, 19, 21, 22, 23, 30, 34,46, 51, 61, 64, 72, 74, 77	1,452,508	181,544
S2	18, 20, 22, 64, 66, 67, 75, 77, 78, 88	-	2,4,6,8,17,19, 23,29,31,33,35, 44,46,48,50,61, 63,72,74,76,83, 86,90	1,996,998	100,850
S3	5,32,48,65,66, 67,76,77,78,87, 89,91	6,12,13,14,39, 40,41,42,56,57 ,58,60,97,98	17,19,21,22,23, 30,35,47,50,61, 64,72,74	1,407,356	189.260
S4	5,6,20,32,48,65, 66,67,76,77,78, 87,88,89,91	12,13,14,33,39 ,40,41,43,49,5 6,57,58,60,68, 79,97,98	7,17,19,22,23, 28,31,34,44,46, 51,61,64,72,74, 75	1,373,672	233,584

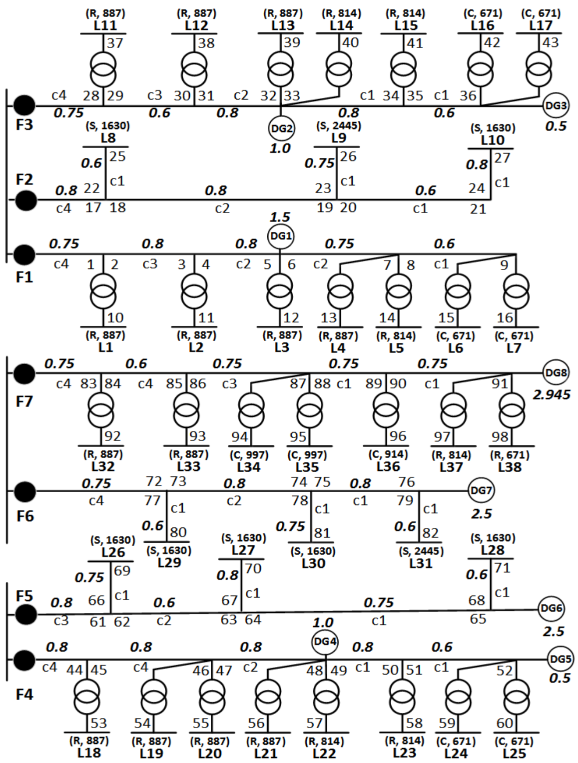

Fig. 5. Test network

DG production is described by triangular fuzzy number with the fuzzy coefficient $K\widetilde{G} = (0, 0.5, 1)$ instead of the original one. In this case expected reliability cost is lower than that in case S1. Note that budget requirement (CAD) in this case is higher than that in S1. In case S4 the degree of uncertainty is further decreased and the uncertainty in DG production is described using fuzzy coefficient $K\widetilde{G} = (0, 0.5, 0)$, i.e. the DG production is described by crisp number. In S4 expected reliability cost is lower than that in case S1 and in case S3. Note that budget requirement (CAD) in this case is higher than that in S1and in S3. The aforementioned results show that the degree of uncertainty of DG production has a noticeable influence on the possible benefit gained from the island operation of DGs. They also show that lower degree of uncertainty in DG production may lead to higher network automation budget requirements. This is because lower degree of DG uncertainty leads to lower possibility of unsuccessful islanding and thus increase the possible benefit of ADs used to create the islands. Hence, decrease in DG uncertainty leads to increase in the number of ADs which in turns decrease the risk of financial losses, i.e. the risk of significant reliability costs.

CONCLUSION

This paper proposes the risk-based approach for assessing the benefit of island operation of variable distributed generation (DG) in improving reliability in radial distribution networks. The proposed approach employs fuzzy sets to describe the variability in demand and variability and uncertainty in DG production. For different levels of variability and uncertainty in DG production the best network automation scenarios, which ensure minimal expected reliability cost considering island operation of DGs, are obtained using the MILP-based approach. By comparing these solutions the value of island operation of DGs in improving reliability is assessed. The obtained results show that island operation of DGs may have a significant effect on improving reliability in radial distribution networks. They also show that the degree of uncertainty of DG production influence noticeable the benefit that can be gained from island operation of DGs in improving reliability in radial distribution networks.

REFERENCES

[1] M. Raoofat, 2011, "Simultaneous allocation of dgs and remote controllable switches in distribution networks considering multilevel load model," *Int. Jrnl. Electr. Power Energy Syst*, vol. 33, 1429 – 1436.

[2] Y. M. Atwa, E. F. El-Saadany, 2009, "Reliability evaluation for distribution system with renewable distributed generation during islanded mode of operation", *IEEE Trans. Power Syst.*, vol. 24, 572-581

[3] A. Heidari, V. G. Agelidis, and M. Kia, 2015, "Considerations of sectionalizing switches in distribution networks with distributed generation," *IEEE Trans. Power Del*, vol. 30, 1401-1409.

[4] Z. N. Popovic, S. D. Knezevic, B. B. Brbaklic, 2018, "Optimal reliability improvement strategy in radial distribution networks with island operation of distributed generation", *IET Gener. Transm. Distrib.*, Vol. 12, No. 1, 78 – 87.

[5] M. Pota, M. Esposito, G. De Pietro, 2013, "Transforming probability distributions into membership functions of fuzzy classes: A hypothesis test approach", *Fuzzy Sets Syst.*, vol. 233, 52-73.

[6] L.J.S. Bradbury, 2013, "The probability density distribution for the power output from arrays of wind turbines and the intermittent nature of wind power", *J. Wind Eng. Ind. Aerodyn*, no. 123, 121–129.

[7] Z. N. Popovic, S. D. Knezevic, 2017, "Risk-based procedure for network automation planning in radial distribution networks with distributed generation", *Proceedings CIRED 2017*, vol.1, 2525 – 2528.

[8] R. N. Billinton and I. Sjarief, 1991, "A reliability test system for educational purposes-basic distribution system data and results", *IEEE Trans. Power Syst.*, vol. 6, 813–820.

[9] Z. N. Popovic, S. D. Knezevic, B. B. Brbaklic, 2016, „Optimal Number, Type and Location of Automation Devices in Distribution Networks with Distributed Generation", *Proceedings of the CIRED Workshop 2016*.