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Designing a regulatory framework for efficient integration of distributed generation technologies

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Abstract: This paper focuses on the designing procedure of a regulatory framework in distribution networks with the main goal being to facilitate the integration of distributed generation (DG) units. The proposed framework is based on the concept of the reward penalty scheme (RPS) and creates effective financial incentives for distribution companies (DISCOs) in improving the quality of their services by applying DG units. To achieve this goal, reliability indices and annual energy losses of a distribution network are considered as two significant measures used in designing the structure of several RPSs. Employing these schemes, the regulators can quantify the quality of services provided by DISCOs. In order to examine the abilities of the proposed method, a case study on a test distribution system connected to bus 6 of the RBTS is performed. The obtained results show that a well-designed regulatory scheme can motivate DISCOs to adopt higher penetration of DG in such a way that their technical criteria can be improved.

Key words: Distributed generation, incentive-based regulation, reliability, reward penalty scheme

1. Introduction

In both vertically integrated and restructured power systems, electricity distribution companies (DISCOs) have a natural monopoly [1]. In such an environment, companies have no tendency to employ new technologies and more efficient procedures to improve their economic efficiency and service quality unless an appealing rate of return is offered by regulators to recover the cost associated with the adoption of such technologies. These conditions become worse in cases where system regulations are designed based on performance-based regulation (PBR) [2]. In response, electricity distribution regulators try to provide some financial incentives with the main goal of adopting new technologies in the distribution sector. In the case of distributed generation (DG) resources (i.e. any kind of electricity generation units directly connected to the distribution network [3]), regulators around the world have proposed different incentive-based mechanisms to motivate both DISCOs and investors in installing these units in the distribution networks [4–6]. The main idea behind these supporting regulations is to guarantee an acceptable level of profit for DG investors. However, such regulations are insufficient in providing surety for different technical benefits of the DG units [7]. In other words, under these supporting regulations, the installation of DG units can have unpredictable (i.e. positive or negative) effects on the performance of distribution networks. For instance, inefficient integration of DG units can increase the required investment costs for network reinforcement and increase power losses at large penetration levels [8]. The economic regulation of

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DISCOs and network tariffs for grid users have been introduced as the main tools that can be used to address this problem [9]. In this paper, assuming that the DISCOs are under PBR, we tried to design indirect financial incentives based on performance measures that can be improved by an efficient integration of DG resources. As a result, it can be expected that employing such regulations will motivate the DISCOs to efficiently integrate DG units in order to improve the performance measures of their networks. To this end, we will take advantage of the reward penalty scheme (RPS) because distribution system regulators in many countries have adopted the RPS as an effective tool for regulating service quality [10].

There has been significant activity in the literature addressing the problem of RPS design. In [2], a risk assessment methodology was proposed to quantify the uncertainty associated with reliability indices. This methodology was then employed in designing the procedure of some fair RPSs. In [11] and [12], fuzzy C-means clustering was borrowed to effectively categorize similar DISCOs, and the RPSs were designed for each cluster to improve service reliability. In [13], the RPS was designed using data envelopment analysis (DEA). The authors in [14] proposed a design method to equalize the total rewards and penalties arising from implementation of the RPS in order to reduce the regulatory cost. None of these papers investigated the abilities of the RPS to facilitate the effective expansion of DG units. However, the impacts of economic and quality regulations of distribution systems on the integration of DG have been investigated in many publications. In [15], a method was proposed to quantify the incentives for DISCOs to integrate DG units into their grids. In [16], economic regulations on DISCOs in Spain and Portugal were reviewed and, after the identification of gaps in the regulatory tools and methodologies, several key alternatives were proposed. The analysis of traditional distribution system regulations and how to improve them to accommodate higher levels of DG was followed in [17]. State-of-the-art regulatory frameworks for integration of DG in some EU countries were reviewed in [18]. The authors in [19] proposed a second revenue stream based on the ability of DG units to reduce the outage risk of consumers to incentivize DG integration in distribution networks. Nonetheless, the above-mentioned studies only considered the DISCOs' perspectives and did not consider the potential of the regulatory framework to address the aforementioned issues. To the best of our knowledge, the incentives for DG integration have not been considered in the designing procedure of the RPS. Hence, this paper mainly focuses on a design procedure of the RPS with the main goal of motivating DISCOs to efficiently employ DG resources. Improving the reliability level of customers together with reducing energy losses in distribution networks are two technical criteria that are involved in the design of the RPS.

2. Reward penalty scheme

As mentioned before, the main goal of this paper is to propose an applicable and effective method for efficient integration of DG units using the RPS. The RPS is a regulatory tool that creates a link between a quality index (e.g., reliability indices) and a company's revenue [20]. In this scheme, regulators define an acceptable level of the quality index as a target value or benchmark. A company will be penalized if it cannot satisfy this target. Alternatively, it will receive a bonus for a performance that surpasses the target.

A general form of the RPS is depicted in Figure 1 [13]. This curve shows the relation between the level of quality index and the amount of reward or penalty. As shown in the figure, the main parameters of RPS curves are the benchmark, dead bandwidth, incentive rate, reward cap, and penalty cap. The dead band is a zone around the benchmark in which neither the penalty nor reward is exposed [10]. Beyond this zone, whether a DISCO receives a bonus or incurs a penalty depends on the value of its quality index [21]. It should be noted that the smaller values of most indices that are usually used in the RPS (e.g., reliability indices and energy losses) represent better performance and, therefore, in Figure 1, the direction of improvement in the quality index is considered to be right-to-left. The slope of the line between the reward point and reward cap point is known as the reward ramp. This parameter indicates the amount of change in the value of the reward per unit change in the quality index. In the same way, the slope of the line between the penalty point and penalty cap point is called the penalty ramp [12]. In many RPSs, the reward ramp and penalty ramp are equal, known as the incentive rate (IR) [10]. The value of the reward or penalty is also capped at a specific level in order to limit the financial risks associated with the RPS [12].

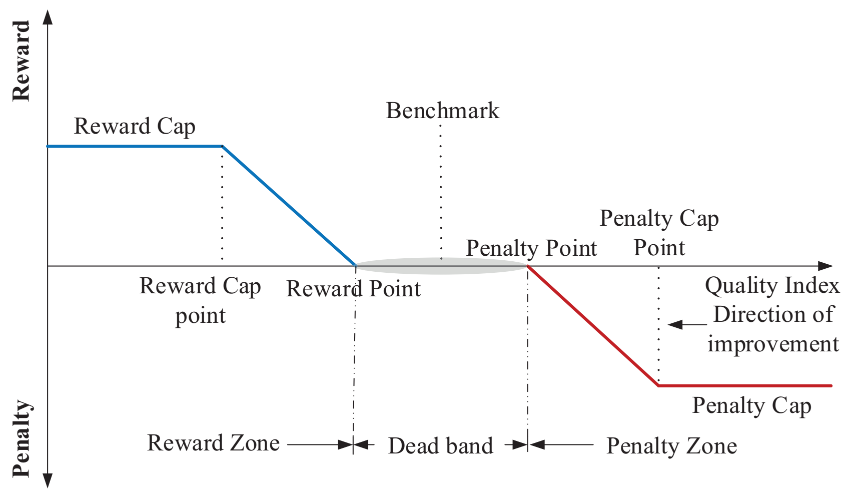

Figure 1. A general reward penalty scheme.

Once the values of the main parameters (e.g., benchmark, dead bandwidth, IR, reward, and penalty caps) are set, the designing procedure of the RPS is complete. Although the main idea behind the RPS is quite simple, there are many difficulties in designing and implementing a proper and fair RPS [20]. In the next section, the design process of the RPS will be addressed in detail.

3. Structure of the proposed incentive scheme

In this section, a step-by-step algorithm is proposed to design the RPS in a way that provides adequate incentives for a DISCO to effectively integrate DG in its distribution network. Accordingly, the general structure of the regulatory process associated with the RPS is shown in Figure 2. As presented in this figure, as the first step, a suitable quality index should be chosen that considers the available data and regulatory goals. The RPS can then be designed based on the selected quality indices. By designing the RPS, it can be applied to a DISCO for a specific period of time (e.g., 1 year). After this period, the regulatory agency evaluates the outcomes and, if necessary, modifies the RPSs for the next period.

In this paper, we emphasize the design process of the RPS. Hence, detailed information about the selection of indices and the design of the RPS are presented in the following section. It is worth noting that although choosing quality indices is done based on DG impacts on the distribution network, the RPS parameters are calculated from economical and technical system data, e.g., historical reliability data, network energy loss, customer interruption cost, and a DISCO's revenue.

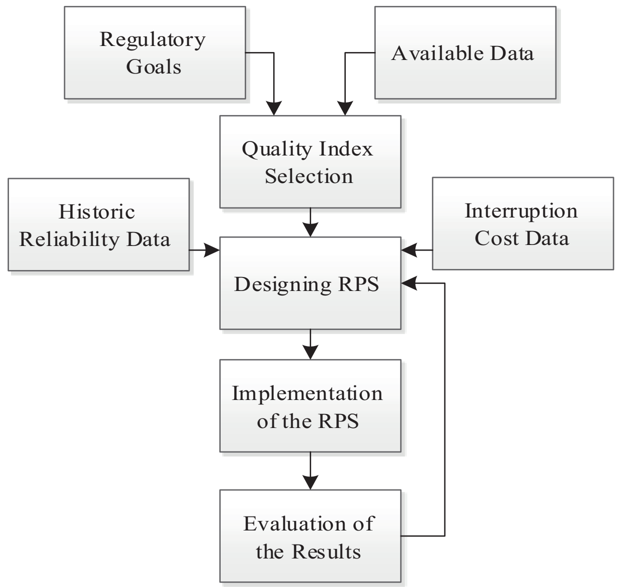

Figure 2. Flowchart of the regulatory process of the RPS.

3.1. Selection of the quality indices

As previously mentioned, the selected quality indices should satisfy the following constraints:

1) Sufficient data should be available to calculate them.

2) They should effectively reflect the regulatory goals.

This paper mainly focuses on designing a regulatory procedure to motivate DISCOs to effectively employ DG. Therefore, selected indices should properly reflect the major benefits of DG resources for the distribution network. Among the wide variety of benefits that can be expected from DG units, we consider their effects on distribution system reliability and energy losses. However, the proposed method is general and other benefits of DG can be applied, as well.

In order to quantify the reliability level of power delivered to customers in the distribution network, different reliability indices have been introduced. These indices can be divided into two main categories: load point and system indices [22]. The first group of indices illustrates the reliability level at an individual load point, and the system indices show the reliability level of the whole network. RPSs are usually applied to the average system reliability indices, e.g., the system average interruption duration index (SAIDI), system average interruption frequency index (SAIFI), and average energy not supplied (AENS) [4,20]. Although these fundamental indices are very important, there are some deficiencies associated with each of them [23,24]. Indeed, the system average indices cannot always give a complete representation of the system [24]. As an example, they do not provide any information about the load points whose reliability levels are significantly lower than the average. Since DG resources can effectively improve the reliability of such load points, it is essential to choose an index to reflect this important issue. The other important effect of DG on distribution system reliability is to supply a portion of loads while an interruption occurs due to a problem at higher voltage levels. Hence, on the basis of these observations, in this paper, the main effects of DG are considered as follows:

1) Supplying some distribution loads once the upstream network is interrupted.

2) Improving the average system reliability indices.

3) Providing higher reliability levels for the less reliable load points.

4) Reducing energy losses in the distribution network.

In order to quantify the above items, a set of appropriate indices should be used. Detailed information about these indices and the design procedure of the RPS is described in the following section.

3.2. Scheme 1: designing the RPS associated with upstream network interruption

Since DISCOs are not responsible for interruptions that occur due to any failure at higher voltage levels (i.e. generation and transmission outages), it is not fair to penalize them for this [21]. Hence, in this paper, an incentive scheme that only contains a reward zone is proposed. This scheme is presented in Figure 3. The index of this scheme is defined as the amount of load served by DG when the upstream network is unavailable. As shown in Figure 3, the proposed scheme has two main parameters: the incentive rate and the reward cap. The value of the reward cap is usually considered as a percentage of the DISCO's annual revenue [10]. The incentive rate of this scheme can also be determined using Eq. (1):

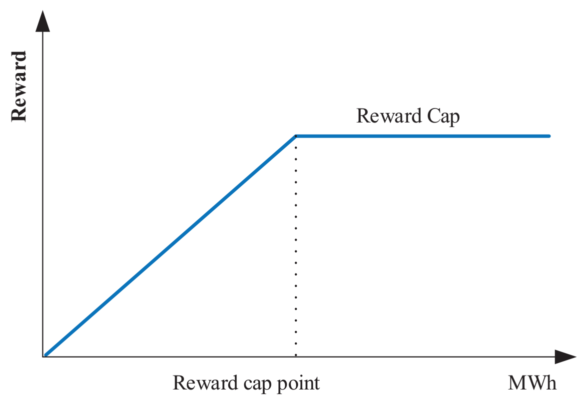

Figure 3. RPS proposed for Scheme 1.

$$IR_{Sc1} = \alpha \times (IC - EP) \tag{1}$$

where IR_{Sc1} is the incentive rate of Scheme 1, α is a correction coefficient with a value between 0 and 1, IC is the interruption cost, and EP is the electricity price.

The purpose of α is to realize the value of the interruption cost and to also provide a control to share the profits of this scheme between customers and the DISCO. In some extreme examples, if the value of α equals 0 or 1, the total profits of Scheme 1 are distributed to customers or the DISCO, respectively.

3.3. Scheme 2: designing the RPS based on the average system reliability index

As previously mentioned, the most popular average system reliability indices used in RPSs are the SAIFI, SAIDI, and AENS. For example, in Finland and Norway, the reliability index of the RPS is T-SAIDI and ENS, respectively [25,26]. In general, the RPS diagram of this scheme is similar to the one presented in Figure 1. However, it should be noted that in some countries, a variety of RPS graphs have been implemented to regulate the average system reliability index. For instance, there is neither a dead band zone nor a reward/penalty cap in the Norwegian scheme [25]. The benchmark value of this scheme is determined based on the historical reliability data of the DISCO [21]. The dead zone width is considered as a percentage of the benchmark (usually 3% to

5%). The IR is calculated based on the interruption cost survey, and the reward and penalty caps are also considered to be a percentage of the DISCO's annual revenue [11]. Such methods have been utilized in many countries such as Finland, Norway, and the UK [26].

3.4. Scheme 3: designing the RPS to consider less reliable load points

As mentioned earlier, the existence of an RPS based on the average system reliability index cannot necessarily ensure that consumers at all load points receive an acceptable level of service reliability. Hence, a reliability index based on the load point indices should be employed to take the effects of the DG on these load points into account. To this end, the reliability index of Eq. (2) is proposed in this paper:

$$RI_{Sc3} = \frac{\sum (N_i(U_i - Th) \times H_0(U_i - Th))}{\sum (N_i \times H_0(U_i - Th))} \tag{2}$$

where RI_{Sc3} is the reliability index of Scheme 3, N_i is the number of customers at load point i, U_i is the total annual interruption duration of the ith load point, Th is the threshold value, and H_0 is the Heaviside function. In other words, the quality index of Scheme 3 is defined based on the differences between total annual interruption duration of less reliable load points and a threshold value. The threshold value can be considered as a function of the mean and standard deviation of the historical SAIDI data using Eq. (3):

$$Th = mean(pdf(SAIDI)) + k \times SD(pdf(SAIDI)) \tag{3}$$

where $mean(pdf(SAIDI))$ and $SD(pdf(SAIDI))$ are the mean and standard deviation of the probability distribution function of the historical SAIDI, respectively, and k is a constant coefficient (usually between 2.5 and 3.5).

Since the quality index of this RPS represents the less reliable load points, it is not reasonable to consider a reward zone for this curve. As a result, the curve of this scheme can be developed, as shown in Figure 4. This curve has two main parameters: the penalty ramp and penalty cap. As previously mentioned, the penalty ramp is determined based on the interruption cost survey, and the penalty cap is considered to be a percentage of the total annual revenue of the DISCO.

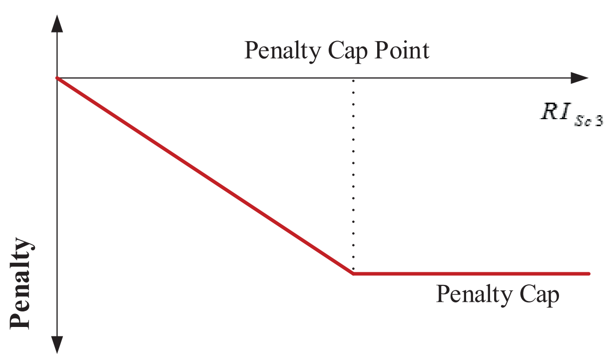

Figure 4. RPS diagram related to Scheme 3.

3.5. Scheme 4: designing the RPS based on energy losses in the distribution network

The fourth RPS of the proposed regulatory framework tries to control the losses of the distribution network. The index of this scheme is total annual energy losses of the distribution grid. The RPS curve of this scheme is similar to the one shown in Figure 1. The benchmark value can be determined from Eq. (4):

$$B_{Sc4} = L_r \times Load \times (1 + \beta) \quad (4)$$

where B_{Sc4} is the benchmark for Scheme 4, L_r is the target value of loss percentage, *Load* is the total annual load of the previous year, and β is the annual load growth. L_r is determined based on improvement in the historical data of network losses. As an example, in Iran, L_r is calculated using the data itemized in Table 1, where L_a is the percent of network losses associated with the previous year and E is the expected percent of annual reduction in loss. The dead bandwidth is also considered to be a percentage of the benchmark value.

Table 1. Calculation of the target value of electricity distribution losses in Iran.

L_a	$L_a \leq 10$	$10 \leq L_a \leq 12$	$12 \leq L_a \leq 14$	$14 \leq L_a \leq 16$	$16 \leq L_a \leq 18$	$18 \leq L_a \leq 20$	$20 \leq L_a \leq 22$	$22 \leq L_a \leq 24$	$24 \leq L_a$
E	0	2	3	4	5	6	7	8	10
L_r	8	$L_r = L_a \times (1 - E / 100)$							

The IR is determined based on average annual day-ahead market prices [15]. Finally, the reward and penalty caps are considered as percentages of the total annual revenue of the DISCO. In the following section, application of the proposed regulatory framework on the incentives for efficient integration of DG in a test distribution network is presented.

4. Case study

In order to investigate the effectiveness of the proposed RPSs, a case study is presented in this section. In this case study, the effects of the designed RPSs on the incentives for DG integration in a distribution network are evaluated. The study is conducted on the test distribution network connected to bus 6 of the RBTS. This network has 4 feeders and 40 load points that supply a variety of load types (e.g., residential, agricultural, and small industrial) [27]. Detailed information and data for this system can be found in [27]. In the following section, the design process of the proposed RPSs is carried out and then the annual revenue of the test DISCO affected by these schemes is analyzed.

4.1. Designing the RPSs

As previously described, four different RPSs are considered in the proposed method. In order to design each RPS, the values of the parameters mentioned in Section 3 should be assessed. Accordingly, the maximum value of total reward and penalty (i.e. the sum of the four schemes' caps) is assumed to be 3% of the DISCO's annual revenue. The reward and penalty caps for each scheme are considered as a percent of the total cap according to Table 2. Finally, the full database, including the test system data, DG energy price, network energy price, and other parameters of the proposed RPSs, is available from the authors upon request.

Table 2. Reward and penalty caps of the proposed RPSs.

Scheme	1	2	3	4
Reward cap (% of total cap)	15	45	0	40
Penalty cap (% of total cap)	0	45	15	40

4.2. Case I: evaluation of the DISCO's revenue without any DG integration plan

Values of the selected indices for the base case (i.e. without DG integration plans) and the reward or penalty associated with each scheme are presented in Table 3.

Table 3. Values of the indices and associated reward or penalty in the base case.

Scheme	1	2	3	4
Index value	0 kWh	22.70 kWh	2.85 min	12.23%
Reward or penalty (% of total revenue)	0	–1.0153	–0.1830	–0.3021

As shown in this table, in this case, the DISCO being studied experiences penalty zones in all of the schemes (except Scheme 1). According to Table 3, in this situation, the DISCO has to pay about 1.5% of its annual revenue as quality-related penalties. In the following subsection, it is investigated whether the proposed schemes can motivate the DISCO to consider the DG integration plans for addressing poor quality issues.

4.3. Case II: evaluation of the DISCO's revenue considering DG integration plans

In order to investigate the effects of the DG units on the DISCO's annual revenue, in this case, an optimization algorithm is presented to find the optimal expansion plans of the DG units. The formulation of this optimization problem is addressed in Eqs. (5)–(12). Running this problem, the optimal size and location of the DG can be found from the viewpoint of the DISCO. In this problem, it is assumed that the DISCO owns and operates the DG units. However, this assumption does not limit the proposed framework and, in the case that the DISCO is not allowed to own DG, this problem can be seen as a rough estimation that is made by the DISCO to indicate the optimum capacity and place of the DG units considering DG investor requirements. Based on the obtained results, the DISCO can then provide some incentives for DG investors to persuade them to optimally integrate DG units in its network.

$$\max(\Pi) = \max(Rev - Cost + RP) \tag{5}$$

$$Rev = E_{DG} \times Pr_E^{DG} \tag{6}$$

$$Cost = Inv_{DG} + Op_{DG} \tag{7}$$

$$Inv_{DG} = \sum_{i=1}^{N_{DG}} \frac{(1+r)^{UL_i} - 1}{r \times (1+r)^{UL_i - 1}} \times Inv_{DG}^i \times C_{DG}^i \tag{8}$$

$$Op_{DG} = \sum_{i=1}^{N_{DG}} Op_{DG}^i \times \sum_{l=1}^{N_{ll}} P_{DG}^{i,l} \times T^l \tag{9}$$

$$E_{DG} = \sum_{i=1}^{N_{DG}} \sum_{l=1}^{N_{ll}} P_{DG}^{i,l} \times T^l \tag{10}$$

$$RP = \sum_{i=1}^{4} RP_{SCi} \tag{11}$$

$$P_{DG}^{i,l} \leq C_{DG}^{i} \tag{12}$$

Here, Π is the annual profit associated with the DG integration projects; Rev is the annual revenue associated with the DG units; $Cost$ is the annual cost associated with the DG units; RP is the total costs due to implementation of the RPSs; E_{DG} is the annual energy produced by DG units; Pr_E^{DG} is the energy price of DG units; Inv_{DG} and Op_{DG} are the investment and operating cost of the DG; Inv_{DG}^i and Op_{DG}^i are the investment and operating cost of the ith DG; N_{DG} is the total number of DG units; r is the interest rate; UL_i is the useful lifetime of the ith DG; C_{DG}^i is the capacity of the ith DG; N_{ll} is the number of load levels; $P_{DG}^{i,l}$ is the power of the ith DG during load level l; T^l is the duration of the lth load level; and RP_{SCi} is the revenue from the ith RPS. In the simulation performed in this section, a single load level (annual average load) is considered, and the decision variable associated with the DG size (i.e. C_{DG}^i) is continuous. It is worth noting that in the presented DG placement optimization problem:

1. It is assumed that Inv_{DG} and Op_{DG} are only functions of the size and output energy of the DG, respectively, and do not depend on the installation location. The investment and operating costs of the DG is assumed to be 14,625 kRial/kW and 572 Rial/kWh, respectively. Furthermore, the decision variables associated with the size of the DG is continuous, and the DG units are assumed to have been installed in the medium-voltage network. It is worth noting that consumers who have their own DG are not modeled in the study.

2. Costs associated with the four introduced RPSs (i.e. RP) are a function of the performance indices of these RPSs. Since the value of these indices are influenced by the size and location of DG units, RP is also a function of the location and size of the DG. In order to calculate RP, the change of the regulatory framework is not taken into account.

This optimization problem is treated with the genetic algorithm (GA) and the optimal locations of the DG units for different penetration levels (i.e. DG total capacity/average load ratio) are obtained. The annual profit of the DISCO versus different penetration levels of the DG units is illustrated in Figure 5. As can be seen in this figure, the annual profit for low penetration levels (lower than 8%) is negative due to the penalties incurred from the RPSs. However, in the case of higher penetration levels, the penalties associated with the RPSs decrease and consequently the annual profit of the DISCO is positive. Moreover, once the penetration level of the DG increases more than 32%, the value of annual profits starts to decrease. Therefore, for the DISCO in question, a 30% penetration rate of DG can be a proper integration plan and the DISCO can effectively guide the company toward the reward zones of the RPSs.

In order to investigate the effect of each scheme on the annual profit function, different components of the profit function are shown in Figure 6 and Table 4. As can be seen, the profits from Scheme 1 and Scheme 4 monotonically increase as the penetration level increases and reaches a maximum value at 20% and 24%, respectively. The profit of Scheme 2 has an ascending trend with negative values in cases lower than a 32% penetration rate. This can be translated into a low reliability level of the network (in the penalty zone), and it gradually moves toward the dead zone, i.e. between 32% and 56% penetration rates. For penetration levels higher than 60%, the DISCO then gains rewards from Scheme 2. Thus, it can be concluded that the reduction in profit from 32% to 64% of the DG penetration level is caused by the dead zone of Scheme 2 and the reward cap of Schemes 1 and 4.

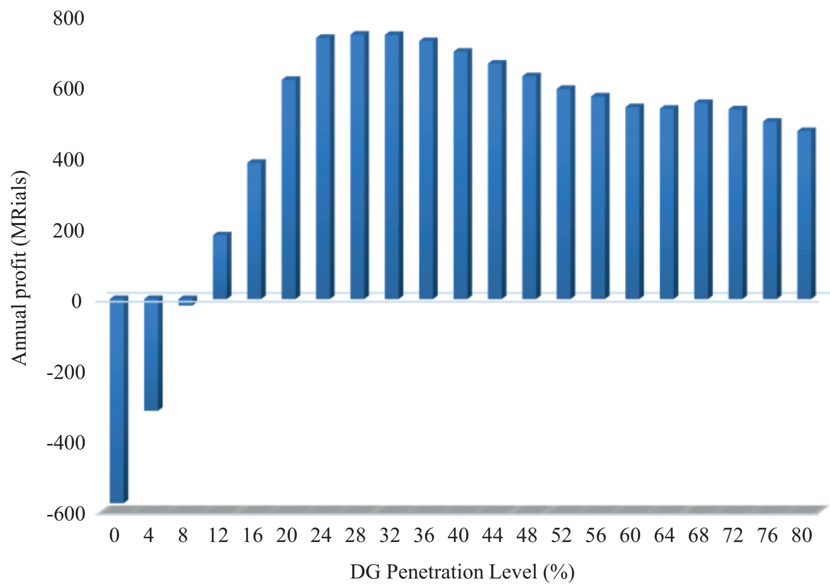

Figure 5. Annual profit of the DISCO for different DG penetration levels.

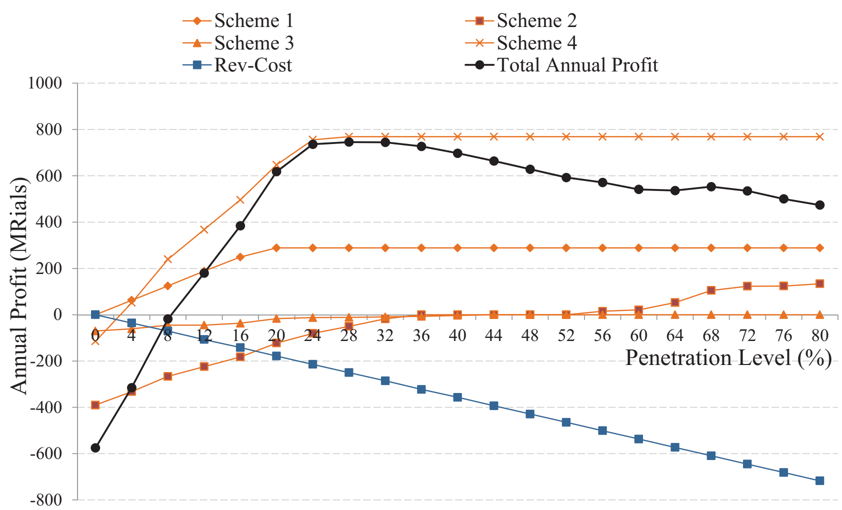

Figure 6. Components of the profit function.

Table 4. Components of the profit function.

	Penetration level (%)					
	0	16	32	48	64	80
Scheme 1	0	249.12	288.29	288.29	288.29	288.29
Scheme 2	–390.27	–182.44	–17.87	0	52.43	133.71
Scheme 3	–70.33	–36.96	–9.48	0	0	0
Scheme 4	–114.84	496.06	768.79	768.78	768.78	768.78
$Rev - Cost$	0	–141.79	–285.18	–428.90	–573.13	–717.27
Total	–575.44	383.99	744.55	628.17	536.37	473.51

4.4. Sensitivity analysis

As thoroughly discussed in the numerical results, the dead zone width of the second scheme and also the caps of Schemes 2 and 4 can significantly affect the effectiveness of the proposed regulatory framework. Thus, in the next part, a sensitivity analysis is performed on these parameters.

4.4.1. Dead zone width of the second scheme

In order to investigate the effect of this parameter on the profit function and the reliability level of the distribution network, four different values for this parameter are considered: 0%, 5%, 10%, and 15% of the benchmark associated with Scheme 2.

The company's profit associated with these values is illustrated in Figure 7. As can be seen in this figure, for the RPS without a dead zone (0% dead zone width), the rise of profit function continues until about 56% of the DG penetration level. However, beyond this value, the profit is decreased, which implies that for these values the cost of DG installation is more substantial than its benefits. Also, based on this figure, as the dead zone width is increased, the annual profit for lower (higher) penetration levels increases (decreases). This is because of the fact that as the dead zone is broadened, the reward and penalty zones of the second RPS move toward the left and right sides (see Figure 1). Hence, as can be seen in Figure 8, for higher values of the dead zone width, lower DG penetration will move the AENS from the penalty zone to the dead zone. Consequently, it can be concluded that as the dead zone width of the second RPS increases, incentives for improving the AENS decrease.

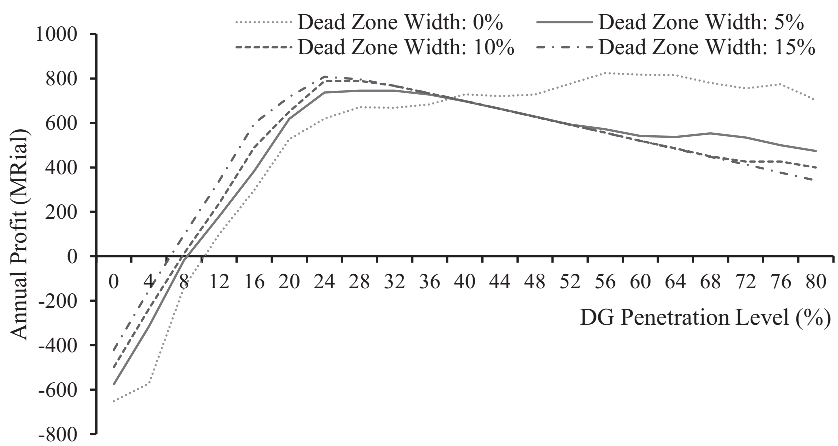

Figure 7. Annual profit for different values of dead zone width.

4.4.2. Caps of Schemes 2 and 4

As previously mentioned, the reward and penalty caps of the proposed schemes are considered as percentages of the total cap (e.g., 3% of the company's annual revenue). In this part, the impacts of the caps associated with Schemes 2 and 4 on the profit function are examined. To this end, the values of these caps are set at different levels listed in Table 5. These values are chosen in such a way that the sum of each pair is equal to 85% of the total cap. The company's annual profit functions correspond to these values and are depicted in Figure 9. It can be seen from this figure that for penetration levels below 16% the changes in the values of the caps have no effects on the annual profit. This is because neither Scheme 2 nor Scheme 4 reached its cap. However, for higher penetration levels, the value of the annual profit decreases as the caps of the fourth scheme decrease.

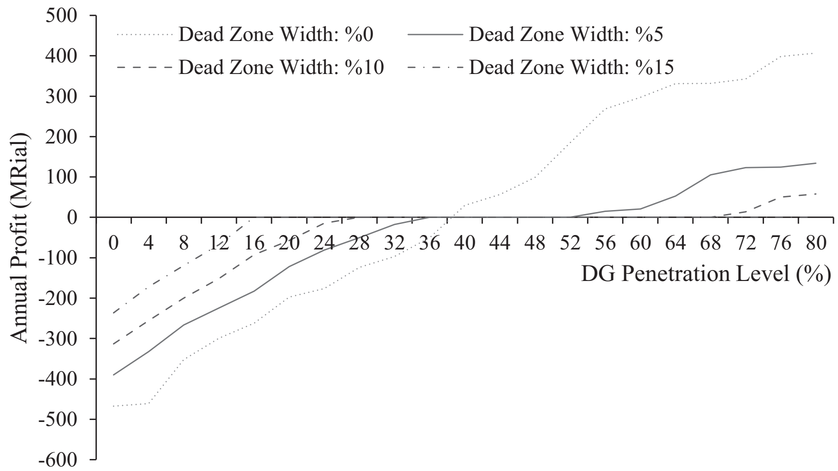

Figure 8. Annual profit of Scheme 2 for different values of dead zone width.

By referring to Figure 6, it can be inferred that this is caused by the significant effect of the reward cap of the fourth RPS on the profit function.

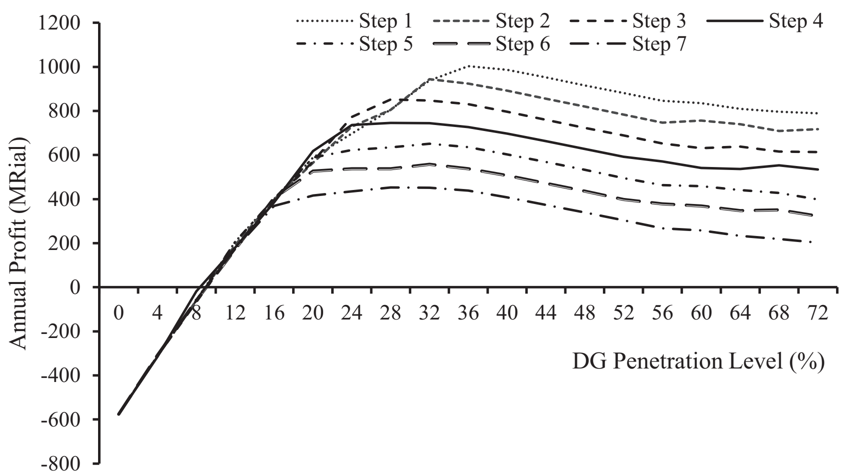

Figure 9. Annual profit for different caps of the second and fourth schemes.

Table 5. Values of the caps of Schemes 2 and 4 for performing sensitivity analysis.

	Reward and penalty caps (% of total cap)						
Step	1	2	3	4 (base case)	5	6	7
Scheme 2	30	35	40	45	50	55	60
Scheme 4	55	50	45	40	35	30	25

5. Conclusion

In this paper, a regulatory framework is presented to facilitate the integration of DG units in distribution networks. Improving the reliability level of a system together with minimizing distribution losses are introduced as criteria of this regulatory procedure. The proposed method is based on the RPSs and four different schemes are introduced to effectively quantify the main effects of DG on a distribution network. Several algorithms are then proposed to properly set the values of different parameters associated with these RPSs. Finally, in order to exemplify the proposed method, a case study on a test distribution system is performed. The obtained results show that this regulatory framework can motivate DISCOs to improve their service quality by employing DG resources. The study also shows that the values of some parameters associated with the RPSs (dead zone width and caps of the schemes) can significantly affect the effectiveness of these RPSs. Finally, it is worth noting that in the numerical study performed in this paper, only the investment in DG resources is considered to evaluate the effectiveness of the incentive schemes. However, in practice, a DISCO's managers have many options to reinforce their network and improve quality indices. Hence, investigation of the effects of the incentive-based regulatory framework on a DISCO's project selection is proposed as a good topic for future work.

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