# Designing Medium Voltage Distribution Networks Based on Probabilistic Risk Criteria to Improve Network Reliability – Part II: A Study on Load Uncertainty and Distributed Generation

S.Najafi Ravadanegh, H.Mohammadian-Alirezachaei

**Abstract--This study presents the optimal placement of automatic power switches in the distribution network of Tabriz city, considering distributed generation sources and uncertainties arising from load forecasting and renewable energy generation. Given the urban context of the design scope, photovoltaic source penetration is prioritized. The design focuses on optimally positioning remote control switches (RCS) to enhance network reliability and meet automation objectives. For this purpose, an interface has been created to use the optimization force of MATLAB software and the technical computing force of DIgSILENT software. In this case, system index's are calculated in DIgSILENT software for each scenario in MATLAB, and by calculating the cost probability distribution function, the level of riskiness of the system is evaluated according to the number of installed switches. Due to the large volume of study results, a part of the studies and research results will be presented in this article.**

**Keywords: Reliability; design; automatic switches; automation; renewable resources; Risk.**

## I. INTRODUCTION

A medium-voltage distribution network is considered the backbone of modern distribution systems. Principled, optimal design based on electrical, geographical and financial limitations can play a significant role in reducing the costs of distribution companies and prevent unscientific assumptions, and on the other hand, respond to the needs of consumers in an efficient method [1-3].

The purpose of this research is to provide a methodology for the optimal design of medium voltage distribution networks to increase the reliability of the network in the presence of important uncertainties and to evaluate the risk values of important network variables in the presence of these uncertainties.

The basic issue raised in this research is a new approach to the medium voltage distribution network from the point of view of design. The progress of new technologies in the field of operation equipment, measurement, as well as the rules governing distribution companies, new topics have also entered the studies of distributed networks [4-6]. It is also important to note that current design studies target future networks, and over the coming years, numerous emerging technologies will integrate into distribution systems. Paying attention to the electricity market and smart distribution grids has made it necessary to create new attitudes in the future distribution networks. As examples of research in this area, reference [7] proposes a hybrid AC/DC distribution network in which the use of existing elements in the network structure is considered to improve the system reliability. In reference [8], an operational planning framework is proposed to evaluate the optimal design for multiple microgrids with the aim of increasing the security and reliability of power supply. In a different direction, research conducted in [9] developed a cyber-physical laboratory platform for distribution networks in which remote access tools were used to model and analyze security and reliability issues in power systems. Also, in another study presented in reference [10], an integrated approach is proposed to evaluate the performance of the distribution network from the perspective of self-resilience and identifying vulnerable points. The above-mentioned cases show that presenting new methods in the design and operation of future distribution networks will not only help distribution companies in advancing their current goals, but will also prepare them in planning to face new future events. In the conducted studies, many of the existing uncertainties have not been taken into consideration, but this issue is important in the mid-term and long-term design. Most studies have been conducted in an algebraic and non-probabilistic environment. In short, it can be said that the aim of this project is to provide

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a suitable framework to solve the problem of optimal design of medium voltage distribution by considering the uncertainty of the important input parameters and assessing the risk caused by them in a probabilistic environment [11-14].

## II. Study System and Regional AUtomation Stations

Fig. 1 illustrates the locations of automation stations within the study area. With this assumption, out of the total number of 1288 switches, 58 switches are RCS type and the rest are manual switches. Additionally, since some parts of the network include overhead feeders, switches are included along these feeders; in this study, there are 114 such switches.

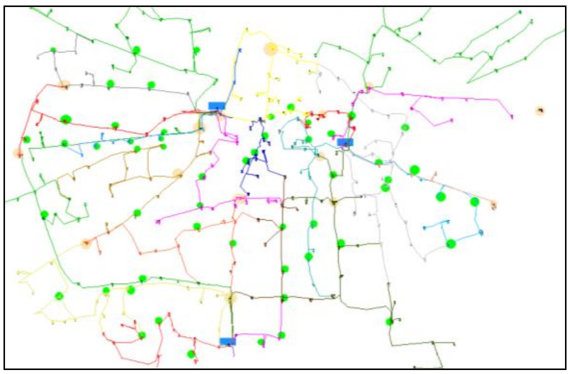

Fig. 1. The location of sub-distribution, automated substations and medium voltage feeders in the study area

For the design of the network in the year of horizon, it has been assumed that there is no remote-control switches in the network, and with this assumption, the type and number of switches necessary to improve the reliability of the network and increase its level of automation have been studied. In this study, according to the investigations, the level of network reliability for different scenarios after installing a certain number of remote-control switches has not improved much and remains almost constant. In the current study and for the studied network, the maximum number of switches that can be selected for each feeder is 8 switches. According to the conditions of each feeder, the remote-control switches may be selected between 0 and 8. The selection conditions depend on the study conditions, including the amount of load, the amount of penetration of PVs, the arrangement of the medium voltage network in each scenario.

## III. Increasing the Burden of the Pilot Area

According to the growth of the load of the region, the amount of load of each substation has been calculated and calculated as the last load point for the year of horizon 1400. It should be noted that a simultaneous increase in substation loads does not affect switch placement; therefore, attention should be focused on potential variations in load forecasting.

### *A. Probable Modeling of Distributed Generation Sources in the Pilot Area [3].*

Since the rate of growth of distributed generation sources (including photovoltaic cells) in the area under study is not known as a point, therefore, the penetration rate of distributed generation sources should be studied in the form of surface growth within the study area and up to 20% maximum. Based on this, the studied area was divided into regular blocks with dimensions of 100 meters by 100 meters using GIS software. For each block, the probability of the presence of photovoltaic distributed generation sources was calculated using the normal distribution function between zero and 20% of the block's consumption load and entered into the calculations. After this step, by using the spatial attachment of photovoltaic cell blocks to each substation, the amount of power of the photovoltaic cell connected to each substation is calculated and entered into the optimization software. In this project, the studied area is divided into 4366 square blocks. Figure (2) shows the overview of this zoning in the GIS software environment.

As an example, table (1) shows the coordinates and the amount of distributed generation resources of the blocks attached to substation No. SB020034 on feeder No. 5 of Golestan. Also, in figure (3), the supply range of this substation is calculated and shown by using spatial attachment of the closest distance of each block to a certain substation.

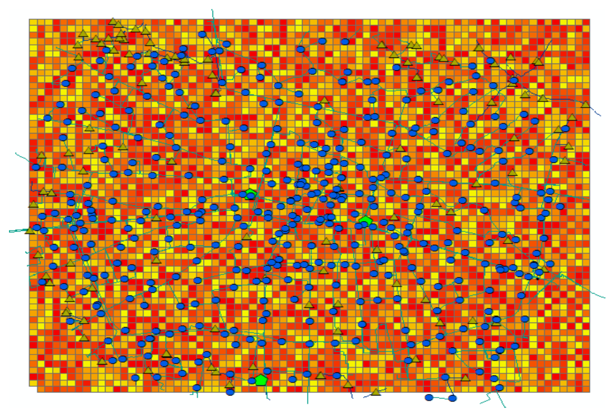

Fig. 2. Possible penetration values of distributed generation sources between 0 and 20% load

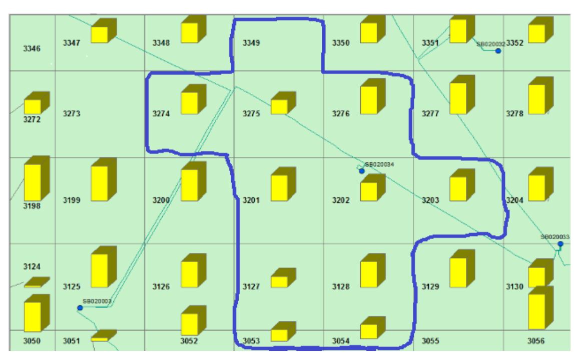


Fig. 3. The supply range of substation SB020034 by blocks of distributed generation resources on feeder No. 5 of Golestan

TABLE I
BLOCKS ATTACHED TO SUBSTATION NO. SB020034 ON GOLESTAN FEEDER NO. 5

| Substation Code | Substation Capacity | Feeder | Substation X | Substation Y | Block Num | Block X | Block Y |
|---|---|---|---|---|---|---|---|
| SB020034 | 1000 | F5 Golestan | 611517.69 | 4216518 | 3127 | 611423.8 | 4216383 |
| | | | | | 3128 | 611523.8 | 4216383 |
| | | | | | 3201 | 611423.8 | 4216483 |
| | | | | | 3202 | 611523.8 | 4216483 |
| | | | | | 3203 | 611623.8 | 4216483 |
| | | | | | 3274 | 611323.8 | 4216583 |
| | | | | | 3275 | 611423.8 | 4216583 |
| | | | | | 3276 | 611523.8 | 4216583 |
| | | | | | 3349 | 611423.8 | 4216683 |

## IV. RISK MODELING IN THE PROBLEM OF LOCATING AUTOMATIC SWITCHES

The final goal of this project is the optimal design of medium voltage distribution networks based on possible risk criteria to increase reliability by finding the right place to install remote control switches (RCS) with the aim of improving the reliability index at the lowest possible cost. For this purpose, in the above problem, risk modeling has been done by taking into account the uncertainties caused by load demand and penetration of Photovoltaic renewable energy sources.

As previously stated, energy not supplied (ENS) is critical for distribution network operations, though its level of importance varies among different operators. Risk-taking companies give less importance to lost energy, but more risk-averse companies are trying to reduce this risk with higher investments. Hence, accurate risk modeling is essential. In order to control the related risk in an environment with load uncertainty and penetration of Photovoltaic resources, as detailed in the previous chapters, a function to measure the risk related to the reliability gain is included in the objective function. CVaR (Conditional Value at Risk) is one of the most effective risk measures used in statistical planning. CVaR evaluation is able to quantify the risk potential beyond VaR (value at risk) and represents a suitable approach to manage the inherent problem of risk. Based on the above definition and considering the level of certain probability α, VaR is a sample of the lowest cost that, with the probability α, the cost does not exceed a certain value. Considering that the conditional expected cost CVaR is higher than that value, this parameter as a function of the decision variables is convex CVaR, so it can be effectively controlled or optimized using linear or convex programming. For a given α ($\alpha \in (0,1)$), VaR represents the lowest cost, with the assurance that the probability of obtaining an overall cost above this value is less than ($1-\alpha$).

CVaR can be modeled as the following linear equation:

$$CVaR(\alpha, x) = \max\{\eta - \frac{1}{1-\alpha} E_s\{\max\{\eta - f(x,s), 0\}\}\},\ \forall \alpha \in (0,1) \quad (1)$$

$$s(s) \geq (\eta - f(x,s)),\ \mathrm{s(s)} \geq 0 \quad (2)$$

$f(x,s)$ is the profit function in scenario s.

There is always a possibility of error and interruption of energy supply in power networks. When there is a power outage in the distribution system based on the occurrence of a fault, the supply of a number of loads is interrupted. On the other hand, profitability increases by feeding loads with higher reliability. Therefore, in order to show the importance of the energy not supplied of the system, $C_{ENS}(s)$ is assumed as a function of $f(x,s)$ in CVaR calculation. Therefore, the value of CVaR is calculated based on relations (1) and (2) and can finally be entered into the objective function as follows:

$$\begin{aligned}&\textit{Risk}\text{ based Cost Function} \approx \\ &\text{minimize }((1\text{-}\beta) * \text{cost}_{RCS} + \beta * CVaR)\end{aligned} \quad (3)$$

It should be noted that the cost of installing RCS switches is $\cos t_{RCS}$ .

The purpose of the above function is to minimize the system costs for risk aversion through the parameter β. Entering the weighted correction factor β indicates the balance between risk and expected costs. β values vary from 0 to 1. Therefore, considering zero value for the β parameter, the problem becomes a risk-free problem. As long as the value of β increases, the expected profit becomes less important and becomes a risk aversion problem.

It is clear that for a risk-averse company, $\cos t_{RCS}$ increases in proportion to its risk aversion. Because by adjusting the level of risk aversion, the optimal result will change and due to the higher importance of energy not supplied and the decrease of CVaR, the number of installed Switches will increase and, as a result, the installation cost will increase.

According to the explanations provided, the mentioned problem should be solved for several βs. In the following, the results obtained from the optimization of the above problem will be presented by setting β to different numbers.

Figure (4) shows the relationship between CVaR and Cost in several examples of different BBBs. It should be noted that by analyzing the obtained results, a part of the results that were of great importance has been presented. As it can be seen from the figure, the cost of the system has increased with the increase of β value. In this regard, the value of CVaR, which is considered here in line with the amount of energy not supplied for the sake of simplification, has been further reduced for risk-averse companies and according to the level of risk aversion of the company.

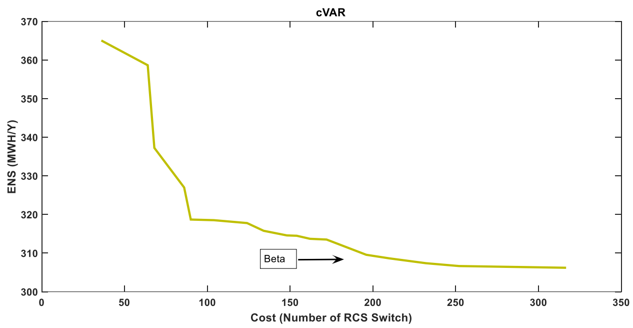


Fig. 4. CVaR diagram in terms of Cost in different βs

Here, the cost of the company is the same as the cost of purchasing RCS switches, and the benefit of reducing the energy not supplied of the system is expressed by installing these Switches. Table (2) shows the numerical representation of the relationship between the amount of energy not supplied and the cost of the system for different βs. In simpler terms, the table below shows that assuming the company's risk aversion is equal to $\beta_i$, this company needs capital equal to Total $\mathrm{Cost}_i$ so that the amount of energy not supplied is equal to Total $\mathrm{ENS}_i$.

TABLE II
COMMUNICATION BETWEEN TOTAL ENS AND COST IN DIFFERENT βs

| Total Cost (Number of RCS ) | Total ENS | $\beta$ | Risk No |
|---|---|---|---|
| 36 | 365.0549 | 1 | 1 |
| 64 | 358.6485 | 2 | 2 |
| 68 | 337.2431 | 3 | 3 |
| 86 | 326.9911 | 6 | 4 |
| 90 | 318.6936 | 7 | 5 |
| 104 | 318.5283 | 8 | 6 |
| 124 | 317.7828 | 10 | 7 |
| 134 | 315.7829 | 12 | 8 |
| 148 | 314.5882 | 15 | 9 |
| 154 | 314.4962 | 16 | 10 |
| 162 | 313.7086 | 18 | 11 |
| 172 | 313.5171 | 20 | 12 |
| 196 | 309.5673 | 21 | 13 |
| 210 | 308.6393 | 22 | 14 |
| 232 | 307.39 | 23 | 15 |
| 252 | 306.6529 | 24 | 16 |
| 316 | 306.2133 | 25 | 17 |

In order to show the details of the obtained results, the information about the RCS Switches installed in the network for some β values is presented in Table (3).

If we assume that the network is assumed to be a completely risk-averse company with a risk aversion index of BBB, and if you do not have an RCS type Switches, it is assumed to be a completely risk-averse company with a BBB index. In this case, according to the obtained results and the statistics of the total number of Switches in the network, the company's risk-taking index for this number and location of RCS Switches will be as shown in Table (3). Also, in table (4), the calculation of the company's risk tolerance for the best acceptable scenario based on profit (reduction of energy not supplied) is shown. The results of the calculations according to the two tables below show that increasing the number of Switches and decreasing the amount of energy not supplied present almost equal risk indicators. Finally, according to the calculations, the probability distribution function of the values exposed to risk is presented in Figure (5). In this figure, the probability density function of company costs is presented and can be used in CVaR calculation.

TABLE III
CALCULATION OF THE COMPANY'S RISK TOLERANCE FOR THE BEST ACCEPTABLE SCENARIO BASED ON COST (NUMBER OF SWITCHES)

| available RCS Switches | Chosen RCS Switches | Total | |
|---|---|---|---|
| 58 | 186 | Statistics of Switches contributing to the design | Statistics of Switches contributing to the design |
| | | 1288 | Total number of candidate Switches |
| | | 0.19 | Maximum risk tolerance |

TABLE IV
CALCULATION OF THE COMPANY'S RISK TOLERANCE FOR THE BEST ACCEPTABLE SCENARIO BASED ON PROFIT (REDUCTION OF ENERGY NOT SUPPLIED)

| Network RCS Switches | Amount of lost energy (MWH/a) | Reduction of lost energy (MWH/a) | risk index (β) |
|---|---|---|---|
| 0 | 365 | --- | $\beta = 0$ |
| 244 | 306 | 59 | $\beta = 0.224$ |
| 1288 | 105 | 260 | $\beta = 1$ |

Table (5) presents all the selected switches. Also, in this table, the substations in which automatic switches are placed are shown. According to this table, it can be seen that in some substations several switches have been selected simultaneously for network automation.

TABLE V
THE FINAL LOCATION OF THE AUTOMATIC SWITCHES IN THE BEST ANSWER AND THE SUBSTATION CORRESPONDING TO IT

| RCS Switch | Substation | RCS Switch | Substation | RCS Switch | Substation | RCS Switch | Substation |
|---|---|---|---|---|---|---|---|
| 1-CBK1131835-RCS | SB010053 | 7-DCS1592047 | SB020094 | 21-CBK1133215- | SB020056 | 25-DCS1590401 | SB010125 |
| 1-CBK1132327-RCS | SB010053 | 7-DCS1592153 | SB020108 | 21-DCS1589685 | SB020049 | 25-DCS1593321 | SB020113 |
| 1-CBK1132887-RCS | SB010036 | 8-CBK1131745-RCS | SB020068 | 21-DCS1590269 | SB020053 | 25-DCS1593453 | SB020090 |
| 1-CBK1134169-RCS | SB010036 | 8-DCS1591791 | SB020096 | 21-DCS1590329 | SB020069 | 25-DCS1593525 | SB010122 |
| 1-DCS1589583 | SB010048 | 8-DCS1592095 | SB020099 | 21-DCS1591617 | SB020131 | 25-DCS1593665 | SB020158 |
| 1-DCS1590053 | SB010070 | 8-DCS1598185 | SB020117 | 21-DCS1592949 | SB020066 | 25-DCS1593943 | SB020071 |
| 1-DCS1590709 | SB010076 | 8-DCS1598461 | SB020107 | 21-DCS1593309 | SB020064 | 25-DCS1594083 | SB010076 |
| 1-DCS1591641 | SB020133 | 8-DCS1598565 | SB020113 | 21-DCS1594003 | SB020086 | 25-DCS1594679 | SB020048 |
| 1-DCS1592375 | SB020088 | 8-DCS1601315 | SB020098 | 21-DCS1598979 | SB020126 | 25-DCS1595423 | SB020094 |
| 1-DCS1594187 | SB020106 | 9-DCS1593641 | SB020049 | 21-DCS1599739 | SB020092 | 25-DCS1596005 | SB010129 |
| 1-DCS1597671 | SB020095 | 9-DCS1599309 | SB020118 | 21-DCS1601137 | SB020153 | 25-DCS1596155 | SB020070 |
| 1-DCS1600107 | SB020038 | 9-DCS1600639 | SB010130 | 21-DCS1610480 | SB020012 | 25-DCS1596293 | SB010136 |
| 1-DCS1600247 | SB020060 | 9-DCS1608322 | SB010009 | 22-DCS1594315 | SB020127 | 25-DCS1596679 | SB020140 |
| 1-DCS1600363 | SB020112 | 9-DCS1608358 | SB010008 | 22-DCS1594585 | SB020066 | 25-DCS1597749 | SB010119 |
| 1-DCS1600985 | SB010038 | 10-CBK1133393-RCS | SB020040 | 22-DCS1594703 | SB020107 | 25-DCS1597933 | SB020050 |
| 1-DCS1602173 | SB010044 | 10-DCS1596143 | SB020120 | 22-DCS1598321 | SB020067 | 25-DCS1598333 | SB020158 |
| 1-DCS1604707 | SB010046 | 10-DCS1600177 | SB010044 | 22-DCS1598659 | SB020086 | 25-DCS1598613 | SB020072 |
| 2-DCS1589997 | SB010074 | 10-DCS1600411 | SB020064 | 22-DCS1599027 | SB020093 | 25-DCS1598637 | SB020096 |
| 2-DCS1590245 | SB020105 | 10-DCS1609488 | SB010006 | 22-DCS1602101 | SB020130 | 25-DCS1599085 | SB020120 |
| 2-DCS1590481 | SB020072 | 11-DCS1591363 | SB020143 | 23-DCS1589709 | SB020109 | 25-DCS1599935 | SB020105 |
| 2-DCS1591071 | SB010033 | 11-DCS1595579 | SB020122 | 23-DCS1590305 | SB010148 | 25-DCS1600165 | SB020057 |
| 2-DCS1592913 | SB010054 | 11-DCS1600447 | SB010020 | 23-DCS1592881 | SB020119 | 25-DCS1600223 | SB010071 |
| 2-DCS1593369 | SB020106 | 12-DCS1594071 | SB020135 | 23-DCS1593779 | SB020110 | 25-DCS1600495 | SB010147 |
| 2-DCS1595493 | SB010068 | 12-DCS1599773 | SB010136 | 23-DCS1596281 | SB020159 | 25-DCS1600591 | SB020106 |
| 2-DCS1597007 | SB010075 | 13-CBK1131439-RCS | SB020154 | 23-DCS1597231 | SB020088 | 25-DCS1600827 | SB020046 |
| 2-DCS1597993 | SB020071 | 13-CBK1133813-RCS | SB020111 | 23-DCS1600949 | SB020126 | 25-DCS1601363 | SB010008 |
| 2-DCS1598991 | SB020059 | 13-DCS1594843 | SB020073 | 23-DCS1601009 | --- | 25-DCS1601653 | SB010054 |
| 2-DCS1599715 | SB020046 | 13-DCS1599061 | SB020092 | 23-DCS1601279 | SB020112 | 25-DCS1601905 | SB010017 |
| 2-CBK1134089 | SB010127 | 14-DCS1600973 | SB010129 | 23-DCS1607834 | SB020123 | 25-DCS1601985 | SB020093 |
| 2-DCS1599819 | SB020096 | 15-DCS1591665 | SB020135 | 24-51737AB100001 | SB020178 | 51336AB100043 | |
| 2-DCS1605668 | SB020010 | 15-DCS1595075 | SB020134 | 24-CBK1135279- | --- | 51336AB100044 | |
| 3-DCS1598729 | SB020163 | 16-DCS1591115 | SB020141 | 24-DCS1591849 | SB010120 | 51336CB100019 | |
| 3-DCS1600131 | SB020074 | 16-DCS1596937 | SB010147 | 24-DCS1594175 | SB020114 | 51347AB100004 | |
| 4-DCS1591433 | SB020110 | 16-DCS1601961 | SB020148 | 24-DCS1596553 | SB010020 | 51737AB100002 | |
| 4-DCS1594443 | SB020078 | 17-DCS1590733 | SB020139 | 24-DCS1598505 | SB020163 | 51737CB100003 | |
| 4-DCS1596865 | SB020108 | 17-DCS1595507 | SB010119 | 24-DCS1599415 | SB020119 | 51738AB100005 | |
| 5-DCS1593837 | SB020118 | 17-DCS1597365 | SB020091 | 24-DCS1601291 | SB020124 | 51738AB100006 | |
| 5-DCS1599109 | SB020127 | 18-DCS1595543 | SB020109 | 24-DCS1602041 | SB020130 | 51738CB100017 | |
| 5-DCS1599553 | SB020050 | 19-DCS1593967 | SB020098 | 24-DCS1608370 | SB010122 | 51747CF100006 | |
| 6-DCS1591351 | SB020159 | 19-DCS1600687 | SB020099 | 24-DCS1609464 | SB010006 | 51747CF100007 | |
| 6-DCS1593093 | SB020131 | 20-DCS1595637 | SB020065 | 24-DCS1609476 | SB010006 | 51749AB100001 | |
| 6-DCS1601399 | SB010063 | 20-DCS1596901 | SB010118 | 24-DCS1629130 | SB020013 | | |
| | | 20-DCS1608346 | SB010008 | | | | |

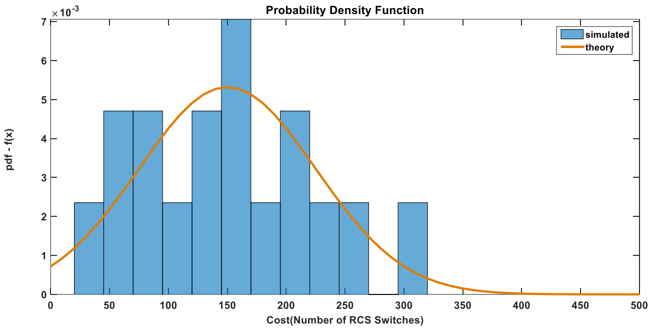


Fig. 5. Probability density function of company costs

## V. Conclusion

This research has investigated the design of a medium-voltage distribution network in terms of reliability and based on probabilistic risk criteria. The studied network is a large part of the medium voltage network of Tabriz city, including the affairs of Golestan, Roshanayi and Emamiye. In this study, the maximum reliability values that can be obtained are calculated and corresponding to those optimal values that can be obtained at an acceptable cost. As an important part of the research, the impact of the influence of distributed generation resources with a probable nature and also some distributed generation resources with a deterministic and focused nature on the design of the network has been evaluated in index of reliability and the numerical values of the reliability index have been calculated and compared in the definite and probable space. The location of selected automatic Switches is also provided. Based on the results of the research, the risk aversion and risk tolerance of the company in terms of the cost of installing the switch and reducing the amount of energy not supplied has been calculated and compared with the ideal state.

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