# Loss reduction planning in electric distribution networks of IRAN until 2025

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***Abstract:*** *In this paper, a loss reduction planning in electric distribution networks is presented based on the successful experiences in distribution utilities of IRAN and some developed countries. The necessary technical and economical parameters of planning are calculated from related projects in IRAN. Cost, time, and benefits of every sub-program including seven loss reduction approaches are determined. Finally, the loss reduction program, the benefit per cost, and the return of investment in optimistic and pessimistic conditions are introduced.*

**Keywords:** Loss reduction, Energy loss, distribution networks, planning, 2025.

## 1. Introduction

In recent decades, different planning and efforts have been carried out in order to increase the efficiency of electric devices and power distribution networks. The generation and delivery of electric power, the electric loss in distribution networks, and loss reduction projects are costly acts. Therefore, loss reduction is an economic approach whose benefits are related to electric devices, cost rate of loss reduction, and other economic parameters.

In this paper, the increase of energy loss in Iran's distribution networks is investigated and estimated until 2025. Then, loss reduction planning and its components are introduced. Furthermore, loss reduction approaches applicable in specific period are clarified. This part includes seven loss reduction approaches and their cost and benefits. Finally, the total cost, benefits, and return of investment are calculated and analyzed. As the policy of the country is organized in order to reach 9% loss for distribution and transmission in 2025, and on the other hand, there is about 75% to 80% of total loss in distribution networks, the goal of planning is considers as 7% energy loss rate at 2025.

## 2. Loss reduction in Electric Distribution Networks of IRAN

In recent years, energy loss rate has considerably increased in electric distribution networks of IRAN. In Table 1, energy loss in different years, its growth and the prediction until 2025 are presented. The average increase of the energy loss rate, from 2001 to 2009, is equal to 1.4%. The energy loss rate in 2025 is linearly predictable that it would be 20.05% in 2025.

TABLE I: Energy loss rate, increasing rate, and predicted amount in 2025

| year | Loss (%) | Loss growth (%) | Average of Loss growth |
|---|---|---|---|
| 2025 | 20.05 | --- | 1.4 |
| 2009 | 16.05 | -8.3 | 1.4 |
| 2008 | 17.50 | -2.2 | 3.1 |
| 2007 | 17.90 | -0.6 | 4.0 |
| 2006 | 19.01 | -0.2 | 5.0 |
| 2005 | 18.10 | 8.9 | 6.3 |
| 2004 | 16.60 | 3.1 | 5.0 |
| 2003 | 16.10 | 7.5 | 5.8 |
| 2002 | 14.97 | 3.8 | 3.8 |
| 2001 | 14.42 | --- | --- |

It should be considered that the predicted energy loss is optimistic due to the real rate of loss growth. In fact, this amount of loss would increase every year due to the below reasons:

1. Demand growth: if the distribution network were not expanded, the loss growth would be almost two times of demand growth.
2. Depreciation of distribution network: according to the financial documents in Tavanir, longevity of distribution networks is almost 20 years. The loss of devices in the networks is increased because of the exhaustion due to their longevity.

As it is presented, the energy loss would be almost 20% in 2025 which is approximately one fifth of delivery power to the distribution companies. This amount is assumed to reach 7% in 2025. Considering this assumption, deviation of loss in different years is presented in Fig.1. The curve is based on proposed loss reduction planning.

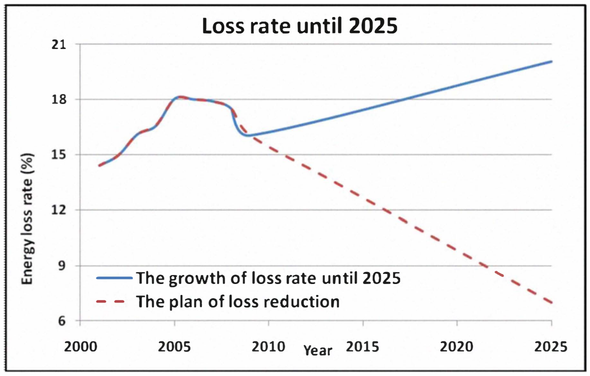


Fig. 1: Loss deviation in different years until 2025.

Based on studies in IRAN [6] and USA [1], different component of energy loss for distribution networks is shown in Table 2, assuming of 7% for total cost.

TABLE 2: Components of energy loss in distribution network.

| System area | Loss per total input power |
|---|---|
| MV lines and regulators | 1.2 |
| Distribution transformers | 2.8 |
| LV lines and service cables | 3.0 |
| Total distribution network | 7.0 |

## 3. Loss Reduction Approaches

After loss determination, loss reduction projects are prioritized based on their effectiveness, economic calculation, and return of investment. Since the loss scheduled in distribution network is equal to 7 % and this amount was 16.05 % in the beginning year, loss reduction approaches should reduced losses almost 56%. Loss reduction and peak shaving can be assumed to be the same in per cent. So approaches should be selected in order to make 56% reduction in load peak.

Some of the loss reduction approaches are shown in Table 3 based on studies carried out in IRAN, USA, and CANADA [1]-[6].

It is assumed that the longevity of the loss reduction approaches is about 20 years. The cost of loss is calculated in a 20 years period, converted to present value. Assuming interest and inflation rate at 15% and 10% respectively, profitability coefficient is calculated as:

$$\text{Profitability coefficient} = \frac{\text{Present value of benefits of loss reduction over 20 year period}}{\text{Present value of project cost}} \quad (1)$$

TABLE 3: selected loss reduction approaches and their effectiveness.

| Loss reduction approach | Average of power or energy loss reduction | Average of reduction in loss cost | Profitability coefficient | |
|---|---|---|---|---|
| | | | minimum | maximum |
| Phase load balance | 2 | 1.6 | 5 | 10 |
| Reactive power compensation | 4 | 3.2 | 6 | 20 |
| Conductor sizing | 11 | 15 | 4 | 14 |
| Distribution Transformers Locating and Sizing | 2 | 4.1 | 2 | 10 |
| High-efficient Transformers | 12 | 15 | 2 | 7 |
| Reconfiguration of Distribution Networks | 10 | 8 | 7 | 25 |
| Increasing MV and Decreasing LV Networks | 15 | 15 | 5 | 10 |
| Total | 56 | 61.9 | --- | |

## 4. Determination of Loss Reduction Approaches Cost and benefits

In this section, according to the benefits stated in Table 3 for each of the approaches, the estimated activity of them is determined.

### 4.1 Phase Load Balance

In this section, it is assumed that low voltage feeders are in balance. Since phase load balancing is a short-term approach, it should be carried out in short period [7]. Here, the maximum five years, until 2015, for phase load balancing is considered. In addition, it is assumed that 80 per cents of low voltage feeders are needed to be balanced. It is notable that the balanced and constructed feeders should stay in balance state due to prepared instructions, appropriate design and continuous monitoring. The cost of these activities is stated in Table 4. According to stated coefficient in Table 3, the benefits of this planning are summarized in Table 5.

### 4.2 Reactive Power Compensation

In this section, reactive power compensation is carried out with capacitor placement due to its better effectiveness than MV compensation and its side effects [8]. Assumptions of this strategy are as follows:

- Length of LV feeders is selected based on reactive power consumption with capacitor placement of 80% of total feeders.
- The average amount of reactive compensation for each feeder is estimated as 25 kVar.
- 80% of constructed feeders are needed to have compensator capacitors in 5 years. In other words, based on new standards, there is no need for capacitor placement in LV feeders until 2015.

Given the assumption, Table 6 represents cost resulting from this action. According to stated coefficient in Table 3, the benefits of this strategy are summarized in Table 7.

### 4.3 Conductor sizing

Conductor sizing should be done in both LV and MV levels [9]. In order to estimate the cost and benefits of this action, below assumptions are considered.

- The size of 95% of total MV feeders should be modified until 2025.
- The size of 100% of total LV feeders should be modified until 2025.
- Constructed feeders from 2011 until 2025 do not need to be modified due to their appropriate design.

Cost of this action is stated in Table 8, considering the aforementioned assumption. According to the coefficient stated in Table 3, the benefits of this project are summarized in Table 9.

TABLE 4: Cost of load balancing in LV feeders

| Loss reduction approach | Length of LV distribution feeders in 2009 (km) | Feeders considering for balancing (%) | Balancing cost for every kilometer of LV feeder in 2009 (tomans[1]) | LV feeders considering for balancing until 2015 | Recent cost of balancing (million (tomans) |
|---|---|---|---|---|---|
| Phase load balance | 287,708 | 80 | 500,000 | 230,166 | 115,083 |

TABLE 5: Benefits of load balancing in LV feeders

| Loss reduction approach | Profitability coefficient | | Loss reduction cost due to imbalance during 20 years (million tomans) | |
|---|---|---|---|---|
| | minimum | maximum | minimum | maximum |
| Phase load balance | 5.0 | 10.0 | 575,416 | 1,150,832 |

TABLE 6: Cost of reactive power compensation with capacitor placement in LV feeders

| Loss reduction approach | Length of LV distribution feeders in 2015 (km) | Percentage of feeders for reactive power compensation (%) | Reactive power compensation per km (kVAR) | Cost of 1 kVAR capacitor in 2009 (tomans) | Length of LV feeders for capacitor placement (km) | Recent cost of reactive compensation (million tomans) |
|---|---|---|---|---|---|---|
| Reactive power compensation | 403,525 | 80 | 25 | 6,000 | 1,091,111 | 163,667 |

TABLE 7: Benefits of reactive power compensation with capacitor placement in LV feeders

| Loss reduction approach | Profitability coefficient | | Loss reduction cost due to reactive compensation during 20 years (million tomans) | |
|---|---|---|---|---|
| | minimum | maximum | minimum | maximum |
| Reactive power compensation | 6.0 | 20.0 | 982,000 | 3,273,332 |

TABLE 8: cost of conductor sizing in LV and MV

| Loss reduction approach | Length of MV distribution feeders in 2009 (km) | Length of LV distributio n feeders in 2009 (km) | Percentage of MV for sizing until 2025 (%) | Percentage of LV for sizing until 2025 (%) | Average cost of the 1 km of MV sizing in 2009 (tomans) | Average cost of the 1 km of LV sizing in 2009 (tomans) | Length of MV for sizing until 2025 (km) | Length of LV for sizing until 2025 (km) | Recent cost of conductor sizing (million tomans) |
|---|---|---|---|---|---|---|---|---|---|
| Conductor sizing | 350,583 | 287,708 | 90 | 100 | 18,000,000 | 20,000,000 | 315,525 | 287,708 | 11,433,605 |

[1] 1 US$ = 1000 tomans

TABLE 9: benefits of conductor sizing in LV and MV

| Loss reduction approach | Profitability coefficient | | Loss reduction cost due to conductor sizing during 20 years (million tomans) | |
|---|---|---|---|---|
| | minimum | maximum | minimum | maximum |
| Conductor sizing | 4.0 | 14.0 | 45,734,418 | 160,070,464 |

### 4.4 Distribution Transformers Locating and Sizing

For this purpose, it is assumed that 20% of distribution transformers should be replaced [10, 11]. Therefore, the cost of this approach is presented in Table 10. According to the coefficient stated in Table 3, the benefits of this project are summarized in Table 11. Remaining transformers are considered to be used in new or profitable designs or to be converted to smaller transformers (expanding LV and MV network approach) which all of the new transformers have high efficiency. It is notable that the cost of discarding devices is considered in this case.

### 4.5 High-efficient Transformers

It is assumed in this project, that 100% of distribution transformers have become high-efficient [12]. The cost of this strategy is presented in Table 12. It is assumed that all of the existed transformers in the network would be high-efficient after 2011. According to the coefficient stated in Table 3, the benefits of this project are summarized in Table 13.

### 4.6 Reconfiguration of Distribution Networks

The reconfiguration should be done in both LV and MV networks. In order to estimate the cost and the benefits of the strategy, below assumptions are considered [13]. Reconfiguration is employed to 90% of total MV feeders and 70% of LV feeders. The networks constructed after 2011 do not need extra cost for reconfiguration of distribution networks due to appropriate design and continuous monitoring. Table 14 states the cost of this strategy. According to the coefficient stated in Table 3, the benefits of this project are summarized in Table 15.

### 4.7 Increasing MV and Decreasing LV Networks

In 2009, the ratio of MV network size to LV has been equal to 1.22. Based on economic studies, this ratio should be equal to 2.0 until 2025 [14]. Therefore, the length of 30% of LV feeders should be reduced. According to these assumptions, the cost of this approach is presented in Table 16. It is assumed that the constructed networks should be in a way that the size of LV network should be less than the half of MV in average after 2011. According to the coefficient stated in Table 3, the benefits of this project are summarized in Table 17.

TABLE 10: Cost of Distribution Transformers Locating and Sizing

| Loss reduction approach | Number of distribution transformers in 2009 | Number of distribution transformers for locating and sizing (%) | Cost of one distribution transformer sizing in 2009 (tomans) | Number of distribution transformers for locating and sizing | Recent cost of transformers locating and sizing (million tomans) |
|---|---|---|---|---|---|
| Distribution Transformers Locating and Sizing | 445,521 | 20 | 1,000,000 | 89,104 | 89,104 |

TABLE 11: Benefits of Distribution Transformers Locating and Sizing

| Loss reduction approach | Profitability coefficient | | Loss reduction cost due to Distribution Transformers Locating and Sizing during 20 years (million tomans) | |
|---|---|---|---|---|
| | minimum | maximum | minimum | maximum |
| Distribution Transformers Locating and Sizing | 2.0 | 10.0 | 178,208 | 891,042 |

TABLE 12: Cost of the usage of high-efficient transformers

| Loss reduction approach | Number of distribution transformers in 2009 | Number of distribution transformers for being high-efficient (%) | Cost of changing to a high-efficient transformer (tomans) | Number of distribution transformers for changing to high efficient ones until 2025 | Recent cost of the usage of high-efficient transformers |
|---|---|---|---|---|---|
| usage of high-efficient transformers | 445,521 | 100 | 2,500,000 | 445,521 | 1,113,803 |

TABLE 13: Benefits of the usage of high-efficient transformers

| Loss reduction approach | Profitability coefficient | | Loss reduction cost due to high-efficient transformers during 20 years (million tomans) | |
|---|---|---|---|---|
| | minimum | maximum | minimum | maximum |
| usage of high-efficient transformers | 2.0 | 7.0 | 2,227,605 | 7,796,618 |

TABLE 14: Cost of Reconfiguration of Distribution Networks

| Loss reduction approach | Length of MV distribution feeders in 2009 (km) | Length of LV distribution feeders in 2009 (km) | Percentage of MV for reconfiguration until 2025 (%) | Percentage of LV for reconfiguration until 2025 (%) | Average cost of the 1 km of MV reconfiguration in 2009 (tomans) | Average cost of the 1 km of LV reconfiguration in 2009 (tomans) | Length of MV for reconfiguration until 2025 (km) | Length of LV for reconfiguration until 2025 (km) | Recent cost of reconfiguration (million tomans) |
|---|---|---|---|---|---|---|---|---|---|
| Reconfiguration of Networks | 350,583 | 287,708 | 90 | 70 | 80,000 | 100,000 | 315,525 | 201,396 | 45,382 |

TABLE 15: Benefits of Reconfiguration of Distribution Networks

| Loss reduction approach | Profitability coefficient | | Loss reduction cost due to Reconfiguration of Distribution Networks during 20 years (million tomans) | |
|---|---|---|---|---|
| | minimum | maximum | minimum | maximum |
| Reconfiguration of Networks | 7.0 | 25.0 | 317,671 | 1,134,538 |

## 5. Summary of Proposed Loss Reduction Approaches

According to the previous sections, the cost and the benefits of proposed loss reduction approaches are summarized in Table 18.

As it is presented, in the pessimistic point of view, 3.93 times of the application cost of the approaches can be returned in 20 years. In other words, investment return of the approaches is about 5 years in this case. Furthermore, in the optimistic point of view, 13 times of this cost can be returned in 20 years and the investment return of loss reduction approaches is less than 2 years.

## 6. Conclusion

In this paper, planning on loss determination and reduction is scheduled based on successful experiences in IRN, USA, and CANADA. The application of 7 selected approaches of loss reduction is analyzed in 14 years, from 2011 to 2025. Cost and benefits of every stage and application of approaches is determined and presented. In a pessimistic condition, the benefits would be 3.93 times of the cost in 20 years and in an optimistic condition, it would be 13 times of the cost in this period.

TABLE 16: Cost of Increasing MV and Decreasing LV Networks

| Loss reduction approach | Length of LV distribution feeders in 2009 (km) | Percentage of LV feeder for decreasing (%) | Average converting cost of 1 km of LV to MV in 2009 (tomans) | Length of LV feeders for converting the voltage level until 2025 | Recent cost of the LV to MV converting (million tomans) |
|---|---|---|---|---|---|
| Increasing MV and Decreasing LV Networks | 287,708 | 30 | 10,000,000 | 86,312 | 863,124 |

TABLE 17: Cost of Increasing MV and Decreasing LV Networks

| Loss reduction approach | Profitability coefficient | | Loss reduction cost due to Increasing MV and Decreasing LV Networks during 20 years (million tomans) | |
|---|---|---|---|---|
| | minimum | maximum | minimum | maximum |
| Increasing MV and Decreasing LV Networks | 5.0 | 10.0 | 4,315,620 | 8,631,240 |

TABLE 18: Summary of proposed loss reduction approaches

| Loss reduction approach | Average of peak shaving (%) | Loss reduction cost from 2011 to 2025 (million tomans) | Profitability coefficient | | Loss reduction cost during 20 years (million tomans) | |
|---|---|---|---|---|---|---|
| | | | minimum | maximum | minimum | maximum |
| Phase load balance | 2 | 115,083 | 5 | 10 | 575,416 | 1,150,832 |
| Reactive power compensation | 4 | 163,667 | 6 | 20 | 982,000 | 3,273,332 |
| Conductor sizing | 11 | 11,433,605 | 4 | 14 | 45,734,418 | 160,070,464 |
| Distribution Transformers Locating and Sizing | 2 | 89,104 | 2 | 10 | 178,208 | 891,042 |
| usage of high-efficient transformers | 12 | 1,113,803 | 2 | 7 | 2,227,605 | 7,796,618 |
| Reconfiguration of Networks | 10 | 45,382 | 7 | 25 | 317,671 | 1,134,538 |
| Increasing MV and Decreasing LV Networks | 15 | 863,124 | 5 | 10 | 4,315,620 | 8,631,240 |
| Total | 56 | 13,823,767 | | | 54,330,938 | 182,948,066 |
| **Benefits per cost of loss reduction approaches** | | | | | **3.93 : 1** | **13.23 : 1** |

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