Research Journal of Applied Sciences Engineering and Technology 4(7): 813-818, 2012
ISSN: 2040-7467

Submitted: November 15, 2011 Accepted: December 09, 2011 Published: April 01, 2012

Decreasing Length of Distribution Network for Loss Reduction: Technical and Economical Analysis

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Abstract: Nowadays reduction of distribution system losses is the most important priority in design and operation of electrical networks. In an electrical network a significant percentage of power and energy produced in power plants is wasted in the path of generation to distribution system. Losses may appear in all levels of power system, i.e. generation, transmission, and distribution system. High current levels, low voltage levels, and radial structure of distribution system lead to a high percentage of losses. For instance, in 2010, approximately 75% of losses occurred in distribution systems in IRAN. Several methods have been proposed to reduce losses, such as capacitor placement in medium and low voltage levels, reconfiguration in networks, increasing cross section in conductors, etc. In recent years, the approach of decreasing or eliminating low voltage distribution networks has been proposed. In this study, at first, the origins of losses in distribution system are reviewed and then strategies for loss reduction are investigated. Then, by decreasing of length of low voltage distribution system in a sample feeder in Mazandaran province power Distribution Company, losses and voltage drop is calculated. Finally, the economic justification of the proposed solution is presented.

Key words: Distribution network, economic analysis, electrical loss, network length

INTRODUCTION

According to validity of available statistics on total losses in power system, including generation, transmission and distribution system, distribution system has the highest amount of total losses. The rates of losses in transmission and generation systems are almost inevitable. Ideally, losses in an electric system should be around 3 to 6%. In developed countries, it is not greater than 10%. However, in developing countries, the power losses percentage is around 20%; for this reason, utilities in the electric sector are currently interested in reducing power losses in order to be more competitive, since the electricity prices in deregulated markets are related to the system losses. In "Mazandaran province power-distribution" company in IRAN, in 2010 the technical and non-technical losses were accounted as 16% of the total input energy. Such percentage means that, considering total amount of energy, about 686753 MWh energy losses is occurred due to these losses (www.maztozie.ir). Main reasons of the high loss level are aged networks and, consequently, bad technical state of networks, as well as shortcomings in customer management processes. Detriment resulting from the losses with the average price of energy, i.e., 0.1 $/kWh, is about 68675300 Dollars. Thus the value of 1% reduction in energy loss is about 686753 Dollars. This can be achieved by appropriate investment and by practical strategies. Thus by reducing losses in distribution system the investment can be compensated within future years.

In recent years, several methods such as capacitor placement in medium and low voltage levels, reconfiguration of networks, and increasing cross section of conductors, using DGs and etc, have been proposed. The worldwide experience shows that in utilities with high network loss level, 1 $ investment on loss reduction saves 10.15 $ for the utility (Munasinghe and Engineering, 1984).

Capacitors are widely used in distribution systems for reactive power compensation to achieve power and energy loss reduction, system capacity release and acceptable voltage profile (Ng *et al*., 2000; Delfanti *et al*., 2000; Hsiao and Chien, 2001).

Selecting the optimum type and size of conductors for planning and optimization of distribution networks is one of the essential parts of the design process. Some papers have been published dealing with optimal conductor selection for distribution networks. In general

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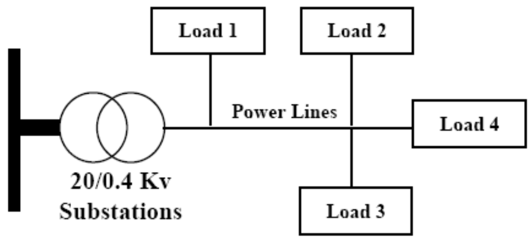

Fig. 1: A single diagram of radial distribution system

Fig.2:Geographical location of mazandaran

attention has focused on reducing cost through optimizing the conductor profile (Sivanagaraju *et al*., 2002; Wang *et al*., 2000)

In (Taleski and Rajicic, 1997), a method was proposed to determine the configuration with minimum energy loss for a given period. In (Chiang and Jean-Jameau, 1990a; Chiang and Jean-Jameau, 1990b; Cheng and Kuo, 1994; Jeaon *et al*., 2002), solution strategies have been proposed for feeder reconfiguration using simulated annealing.

In (Salman, 1996), the effect of distributed generation on voltage regulation and power losses in distribution systems is discussed. Reference (Borges and Falcao, 2003) has presented a technique to evaluate the impact of DG size and placement on losses, reliability and voltage profile of distribution networks. Reference (Davidson and Ijumba, 2002) has presented an optimization model for loss minimization in a distribution network with DG.

In Iranian distribution system, due to the radial structure, length of low voltage network is very high, so that in some feeders its length is about 2 km. Thus in this feeder, percent of voltage drop and losses is outside of allowable limit. In recent years, the approach of decreasing or eliminating low voltage distribution networks is considered by many researchers. In this paper, the target is to realize critical areas of a sample network, i.e. nodes that suffer a high level of voltage drop and losses. Then, the effect of reducing low voltage network or reducing feeding radius of transformers on compensating voltage drops and losses have been investigated.

Distribution networks connection: There are three general classifications of electrical power distribution systems, which are known as radial, ring and network systems. Radial systems are the simplest supply type since the power comes from one power source. A generation system supplies power from the substation through radial lines which are extended to the various areas of a community. Radial systems are the least reliable in terms of continuous service, since there is no back-up distribution system connected to the single power source. If any power line opens, one or more loads are interrupted. Therefore, there is more probability of power outages. However, the radial system is the least expensive. This system is used in remote areas where other distribution systems are not economically feasible. Most distribution systems in IRAN are radial. In some of these networks, due to the length of the radius fed, non-standard voltage drop occurs, especially at the end of line. This voltage drop can cause high losses in distribution lines; a 5% voltage drop causes losses to increase about 11%. Figure 1 shows a radial network. (Seelye, 1930; Willis, 1997)

Geographical location of Mazandaran: The nature of Mazandaran province is under the influence of geographical latitude, Albroz heights, elevation from sea level, and distance from the sea, southern wildernesses of Turkmenistan, local and regional wind currents, and diverse vegetation cover. From geographical point of view Mazandaran province is divided into two parts; coastal plain and Alborz mountainous area. Alborz mountain range has surrounded the coastal strip and coastal plains of the Caspian Sea like a high wall. Due to permanent breeze of the sea and local winds in southern and eastern coasts of the Caspian Sea, sandy hills have been formed that have caused the appearance of a low natural barrier between the sea and plain. High and low average temperature in these two weather regions are about: 10.9ºC in winter, 26ºC in summer and the annual average temperature is 17.7 ºC. Annual average humidity is about 75.5%. There are 13 cities in Mazandaran province that Sari is the center of it. Figure 2 illustrates the geographical location of Mazandaran province.

Mazandaran Distribution company: Mazandaran Distribution Company is located in Sari. Also, the company has an office in each city of Mazandaran province. Table 1 shows the statistics of Mazandaran distribution network from 2007 to 2010. According to

Table 1: Situation of network in mazandaran Distribution Company

Situation of network	2007	2008	2009	2010
Length of low voltage Line (Km) (400 v)	12491	12861	13207	13559
Length of medium voltage line (Km) (20 Kv)	9013	9301	9639	9944
Number of transformers	17958	19230	20911	2258
Capacity of transformers (MVA)	2490	2641	2839	3035
Number of customers	863093	912784	966758	1026758
Percent of losses (%)	18.4 (%)	17.3 (%)	16.8 (%)	17.4 (%)

Table 2: calculation of existing network

	T_1 (Name of transformer)		
Name of feeder	1	2	3
Main length (m)	285.5	88	10
Voltage drop (%)	8.7	0.94	0.41
Losses (KW)	5.93	0.16	0.11
Total length (m)	526	88	10
Number of customer	76	13	1
Input power (KW)	93	20	40
Losses of energy (Mwh)	94.51	1.40	0.96

Table 1, by increasing in number of customers, length of low and medium voltage lines are increased. This is one of the most important factors for increasing losses in Mazandaran distribution network.

Electrical losses component: In electrical networks, energy is wasted in various forms. Losses in power distribution system have different component. Therefore, identifying different components of losses is a prerequisite to evaluate and reduce losses in each network. Analysis of losses in electrical networks shows that several factors cause losses; but generally they can be divided into three major categories: technical losses, non-technical losses (management losses), and technical-management losses. Each of the three categories is divided into various components.

Technical losses: This part of losses is dependent to technical specification of equipment in power distribution system. In a system with appropriate operating condition, most losses in the system are caused by technical losses. Reduction of these losses is difficult and almost impractical, unless there are problems in operation management; in this situation, eliminating these problems can lead to mitigation of losses. These losses are composed of several components, through which the most important components are listed below:

- Ohmic losses in power distribution system
- Losses caused by leakage current
- Losses of distribution transformers
- Losses due to weak connections
- Losses of metering device
- Losses caused by incorrect designing
- Losses caused by harmonics in power distribution network

Non-technical losses: Incorrect operation, lack of inspection and care, lack of repairs, lack of proper equipment replacement and delay in development of electrical network have an important role in in network losses. These losses are not dependent to technical specification of equipment. Therefore, they are called non-technical or management losses. Most important factors which lead to non-technical losses are as follows:

- Unauthorized use of electricity
- Errors in calculations
- Errors in metering device
- using improper transformers
- Streets and parks lighting
- Lack of attention to improve network

Technical and non-technical losses: Although significant part of energy losses in electrical networks has technical origin, there are losses in the network that are originated from incorrect operation (management and scheduling) and can be called technical-management losses. The components which can be listed in this category are so diverse. Some of the most important components are listed below:

- Abnormal active power flow in power distribution system
- Abnormal reactive power flow in power distribution system
- Low power factor in power distribution system
- High capacity of capacitors
- Lack of scheduled service for lines or equipment
- Lack of scheduled development for networks
- Unbalance load in the network

In (Sarfia and Salamaa, 1994; Lisa, 2006; Narong and Nittaya, 2007; dos Santos, 2006) more details about each of these sections are explained.

Strategies to reduce losses in distribution system: Several strategies have been introduced and experienced so far to reduce losses in the network. These strategies lead to reduce in one or more loss origins. By access to technology and new scientific innovations and the discovery of new phenomena or properties of materials, etc, these solutions are broadening. Since some losses are caused by combination of two or more factors, using two or more strategies could be more effective for reducing losses. Most losses in electrical networks are due to line resistance and resistances of equipments in the network. With respect to the fact that resistance is dependent to current, heat, environment temperature and other factors, one of the main methods of reducing losses is to reduce the resistance of conductor lines. Reducing feeding radius of distribution trans formers (low voltage reduction) can

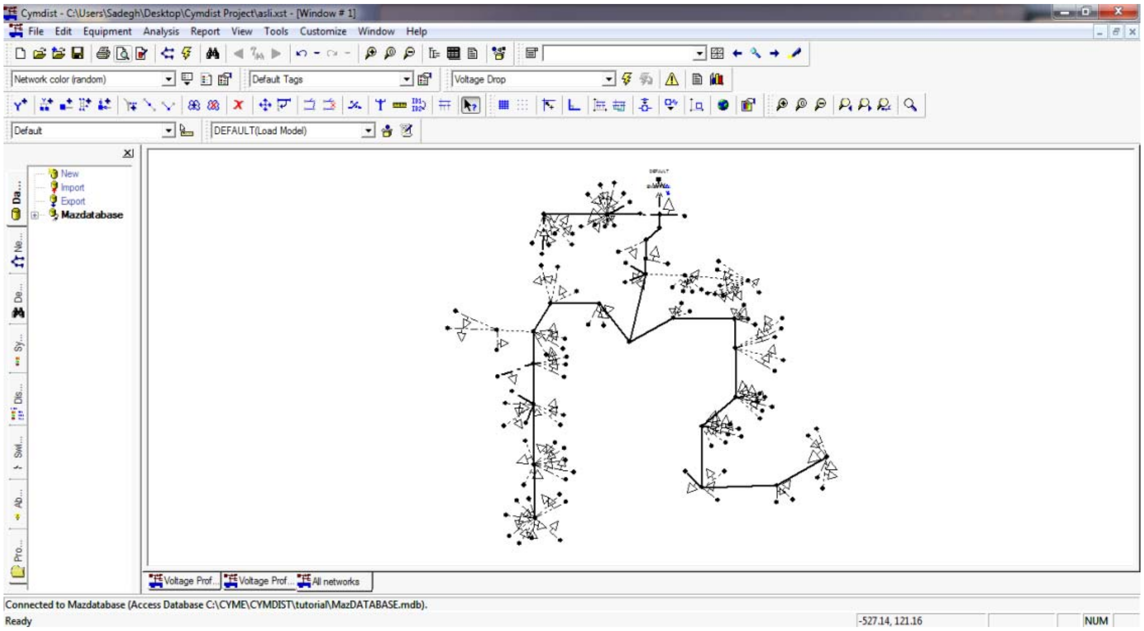

Fig. 3: schematic of network in Cymedist software package

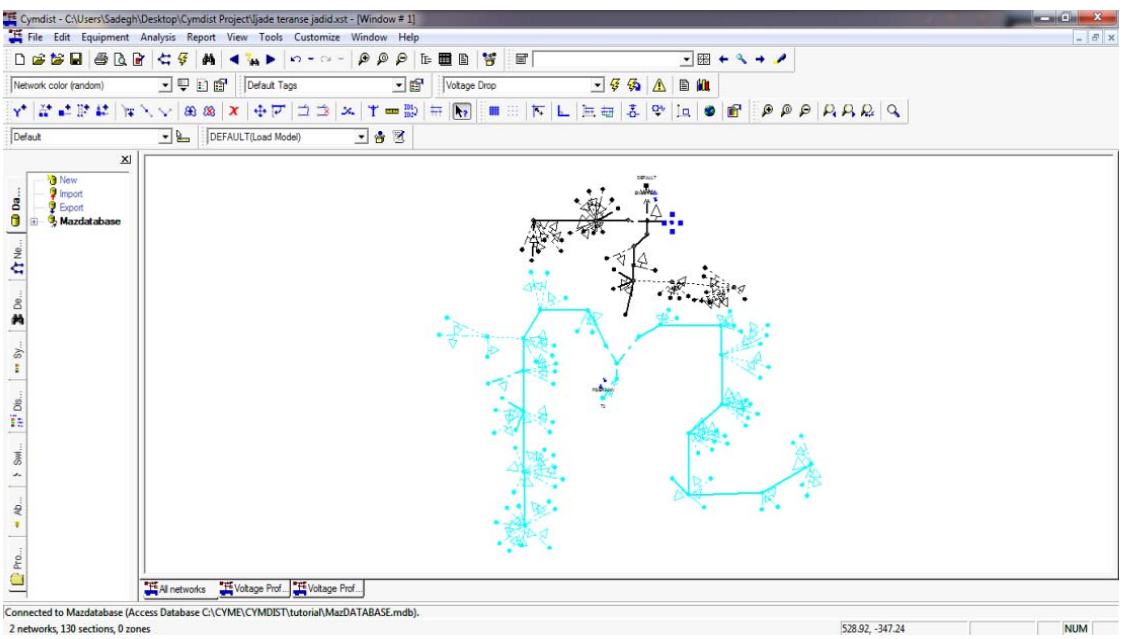

Fig. 4: Schematic of new network with adding transformer (Decreasing length of distribution network)

also be considered as an important strategy for reducing losses. Important strategies of reducing losses are listed below:

- Reducing phase and neutral conductor resistance (modified cross section)
- Capacitors placements in medium and low voltage networks
- Reducing length of low voltage networks
- Reducing the harmonics by active or passive filter
- Ring the medium voltage network
- Capacitors placements on electrical motors
- Reducing leakage losses caused by leaves of trees in streets
- Reducing leakage losses due to the insulators
- Reducing iron and copper losses of transformers
- Reducing losses due to decrease or increase in customer voltage

Table 3: calculation of new network

	Name of transformer				
	T_1			T_2	
Name of feeder	1	2	3	1	2
Main length (m)	63	88	10	164.5	222.5
Voltage drop (%)	3.05	0.92	0.3	2.6	3
Losses (Kw)	0.3	0.61	0.11	0.87	0.64
Total length (m)	121	88	10	182.5	222.5
Number of customer	15	13	1	31	30
Input Power (Kw)	15	20	40	44	34
Losses of energy (Mwh)	2.59	5.27	0.96	7.51	5.53

Table 4: Cost of new 20 Kv network designs

Length of new 20 Kv network	63 Meter
Cost of new 20 Kv network ($)	1312.5
Cost of transformer ($)	4416.66
Cost of new plan ($)	5729.16

- Reducing Ohmic losses of electricity network equipment
- Reducing metering device errors
- Using high-efficiency and low-consumption light bulbs

Sample area selection: This section mentions network problems with analytical methods and simulation. The objective is to find out the viability of reducing network length for solving network's non-standard voltage drop. A sample area is chosen to implement analyses and simulation. Customers' complaints about voltage drop are our criterion for selecting sample area.

Sample area in Sari is selected to reduce losses and to improve its voltage drop. Figure 3 shows the area in software package. Software used for calculation is "Cymedist" software, which is known as powerful software for analysis of power distribution networks. Table 2 shows the calculation of existing network. As can be seen, Feeder 1 is out of standard limit because of overloading and long length of feeders, which consequently impose a total 54.3 MWh energy losses in distribution network.

In order to reduce losses and to compensate voltage drop in sample feeder, different scenarios, such as reducing the length of low voltage network and adding low-capacity transformers, will be considered. In fact, a 20 KV network is suggested to replace low voltage network. In order to find optimal position of low-capacity power distribution transformers in sample feeders, 5 important factors are considered:

- Reducing feeder losses
- Installing a low- capacity transformer in load-center
- Determining maximum of feeding radius in order to keep voltage drop in allowable limit
- Regarding field constraints and line safety zone in designing distribution network
- Growth of load during the next 5 year

Different modes have been noticed with respect to these hypotheses. Calculations and software simulation proved 5 suggestions as acceptable plans. Through these plans, 3 plans have been chosen as applicable plans. One of these practical projects is presented below.

In this plan, the length of feeders is reduced by adding one power distribution transformer with 200 KVA rated power in parts A. Figure 4 shows the new design of network. Also, Table 3 shows the calculation for the existing network while its length is reduced. Table 4 shows the cost of new designs.

According to Table 1 and 2, implementing the plan causes losses to reduce about 32.45 MWh. Also, the percentage of voltage drop has reached to standard limit.

Economic analysis of suggested project: In economic justification of project, investment cost and the rate of return on investment in a given period of time, with respect to facilities lifetime, must be investigated. The aim of this paper is to reduce losses in order to provide continuous and reliable electricity and to improve power quality.

Also, the price of each KWh of energy has been studied with respect to prices of losses. The amount of energy loss can be calculated according to Eq. (1):

$$E_{L\text{-}av} = T \times P_{L\text{-}max} \times L_{SF} \tag{1}$$

$E_{L\text{-}av}$, T, $P_{L\text{-}max,}$ and L_{SF} are energy loss, period of study, power losses in peak times, and losses factor, respectively. Losses factor can be calculated via Eq. (2):

$$L_{SF} = 0.3 \times L_F + 0.7 \times L_F^2 \tag{2}$$

Where L_F is load factor. This factor is obtained from division of average power to maximum power. The average power is also obtained from the average of measurements in different feeders and in different times by power analyzer. Considering Eq. (2) and regarding information of loading, the losses factor is equal to 0.79. Also, with respect to the data presented in Table 1 and 2, reduction in losses is about 32.45 MWh. So energy loss is:

$$E_{L\text{-}av} = 32450 \times 0.79$$
$$E_{L\text{-}av} = 25635.5 \text{ Kwh}$$

According to the price of energy losses announced by energy ministry, the cost of energy loss is:

Cost of losses energy = losses energy (KWh) × 0.13 $/KWh

So, the value of energy saved by reduction of energy losses is 3332.61 Dollars.

For calculating rate of return on investment (Payback Period), which is an approximate method for comparing economic projects, Eq. (3) is used:

$$N = P / CF \tag{3}$$

CF and P are the annual income and the initial investment cost, respectively. Considering the cost of projects, which is about 5729.16 Dollars, according to Eq. (3) the rate of return on investment is about 21 months. This indicates that the plan is viable.

CONCLUSION

Reducing energy loss in power networks has turned to a major concern for engineers in recent years. Different scenarios, such as using capacitors and increasing cross-section area of conductors, have been suggested so far to reduce network losses. Due to age of low voltage networks and their length, expanding medium voltage lines and limiting the length of low voltage networks has been suggested as a solution in recent years. Regarding its technical and economic matters, this scenario is being used in Iran distribution networks.

This study investigated the viability of the scenario for a sample network. The voltage drop and losses of sample network are out of standard range. Different plans have been investigated via software, as well as with calculations. The results have revealed one of plans as an optimum plan for test network. The optimum plan reduces energy losses, and its rate of return on investment about 21 months. Of course, it is possible to implement other scenarios simultaneously, such as using capacitors and increasing cross-section of conductors, to have more reduction of losses and to reduce rate of return on investments.

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