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Full Length Research Paper

Effects of gas service on the electricity distribution system assets

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This paper investigates the effect of gas outage on the assets of electricity distribution systems as well as the effects of load growth. Owing to the fact that electricity and gas distribution systems supply energy demand independently, in this paper, gas and electricity consumption is analyzed and the overload of electricity distribution systems when cutting off gas current is considered. The findings of this research revealed that overload is a consequence of changes in consumption behavior and leads to casualties in electricity distribution systems. Numerical studies on real information of Tehran Distribution Company at the time of gas pressure fall in 2005 are also provided in this study.

Key words: Gas outage, distribution system, Tehran electricity, casualty, asset management.

INTRODUCTION

Gas and electricity distribution systems are considered as energy carriers from the production site to the consumption point. Based on the energy price, consumers choose an energy type for lighting, heating, cooling, etc. Energy consumption growth leads to many challenges in power system. The rapid expansion of energy production and consumption has brought with it a wide range of environmental issues at the local, regional and global levels. With respect to global environmental issues, Turkey's carbon dioxide (CO_2) emissions have grown along with its energy-consumption (Kaygusuz, 2010). The aim of Balat (2010) is to identify the main challenges concerning the security of energy supply in Turkey and to offer solutions.

One of the main challenges is distribution system planning. The distribution system of each energy type is designed and developed with regard to the corresponding load demand. Load demand prediction for mid or long-term horizons is important for the development of any model for electric power system planning.

The aim of Pedregal and Trapero (2010) is to develop a general multi-rate methodology in order to forecast optimally load demand series sampled at an hourly rate for a mid-term horizon. Kavvadias et al. (2010) addresses the problem of optimal design of trigeneration plants and discusses the factors that affect the operation and the feasibility of investment. The aim of Fernández and Márquez (2009) is the study of specific characteristics of maintenance in these types' service providers. Farsi and Filippini (2009) present an empirical analysis of the cost efficiency of a sample of Swiss multi-utilities operating in the distribution of electricity, natural gas and water.

Andre et al. (2009) presents techniques for solving the problem of minimizing investment costs on an existing gas transportation network. Mehrdad et al. (2009) presents a novel approach for optimal electric distribution system expansion planning using a hybrid energy hub concept. In Li et al. (2010), a multistage interval-stochastic regional-scale energy model is developed for supporting electric power system planning under uncertainty that is based on a multistage interval-stochastic integer linear programming method. However, the effects of load growth resulted by cutting off other energy carriers has never been considered in studies.

When the predicted load exceeds the basic amount considered in system design, difficulties such as outage,

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quality decline and change of economic indicators appear. An attempt is made in Rakhshani and Sadeh (2010) to present feasible and practical methods to improve dynamic response of load frequency control problem in a deregulated power system.

Aggelos et al. (2010) examines the implementation of an artificial intelligence system in an urban distribution network, capable to locate and isolate short circuit faults in the feeder, thus accomplishing immediate restoration of electric supply to the customers. A fuzzy logic-based direct load control scheme of large air conditioning loads, which considers the reliability characteristics of nodes where the air conditioning loads are connected, is proposed for restructured power systems in Goel et al. (2010).

Trebolle et al. (2010) proposes a market mechanism, referred to as reliability options for distributed generation, which provides DSOs with an alternative to the investment in new distribution facilities. Nevertheless, the influence of gas on electricity indicators has not been considered.

Gas is an energy carrier, the outage or quality decrease of which can affect the efficiency of gas and electricity distribution systems. In Pelletier and Wortmann (2009), a multi-stage linear program is used to simulate the repartition of the natural gas flow in an interconnected grid system on a succession of contracting periods. Costs and complexities associated with a centralized planning approach may be too great to justify a strong interventionist approach, in view of scant evidence showing that consumers generally make poor decisions in selecting an energy supplier for specific end uses (Costello, 2009).

Some research present energy management in buildings. Reducing operational energy must also mean economic gain to households to encourage their participation (Mohd et al., 2010). Lee (2010) attempted to evaluate and rank the energy performance of buildings from the perspective of multiple objective outputs. Figueiredo and Martins (2010) presents a building automation system where the demand-side management is fully integrated with the building's energy production system, which incorporates a complete set of renewable energy production and storage systems. An automated mixed-integer linear programming (MILP) optimization model has been developed to quantify the economic benefit of the projects independently and in combinations (Cakembergh-Mas et al., 2010). The influence of consumer's change of gas consumption behavior on electricity consumption has never been studied.

The increase of electricity load resulted by gas outage or change of consumers' choice leads to the alteration of sociological behaviors and the indicators of system casualties and reliability. Electricity load growth resulted by gas outage or quality decrease is considered in this paper. Having an area of over 3 hectares, supplying 5 million customers and being responsible for Tehran as a capital city, Tehran Distribution Company is of the most sensitive electricity regions of Iran. Thus, controlling the consistency of this system and considering the factors affecting its operation are of crucial importance.

Factors influencing electricity supply include climatic conditions, cultural effects, social consequences, etc, during all of which the system has to consistently meet consumers' demands. Gas outage or pressure decrease is of the factors influencing electricity load and distribution system. Gas outage or pressure decrease forces the consumers to use electric heaters instead of gaseous ones. This results in significant increase of electricity consumption. Therefore, many of distribution system equipment working with full load are exposed to damages. For each of the damaged equipment, an extra cost is imposed to eliminate the fault. In addition, the unsupplied energy wasted due to the damages imposed to the equipment and the costs of substituted equipment and also the time spent by the workers lead to irreparable casualties for distribution companies.

Subsequently, this paper describes asset management in electricity and gas systems. Thereafter, it covers the effects of gas outage on electricity distribution systems. Numerical studies in Tehran Power Distribution Company at the time of gas pressure decline are then covered. Finally, the paper concludes.

ASSET MANAGEMENT IN POWER AND GAS DISTRIBUTION COMPANIES

Distribution system assets are considered as a part of a wide and integrated system. Therefore, asset management in distribution systems is much more complicated compared to financial management. Asset management actually means compromising the risk and outcome. Distribution system planning, designing infrastructures, forecasting, maintenance and repair are of the activities that have always played a crucial role in distribution system. The different aspect of asset management is the change of targets, constraints and the methods of achieving goals and facing the limitations. Thus, plans of distribution companies for asset management when the targets change are based on the following factors:

1. Cautious operation.
2. Acceptable risk management.
3. Justification of the costs by optimizing the operation and balancing the risks.

The life-cycle of the costs of an asset starts with planning and designing and continues with purchasing, conformity, operation, maintenance, repair and substitution. The target of asset management is to optimize the costs in each stage of this cycle. Using available capacities in this cycle is of crucial importance. Asset management

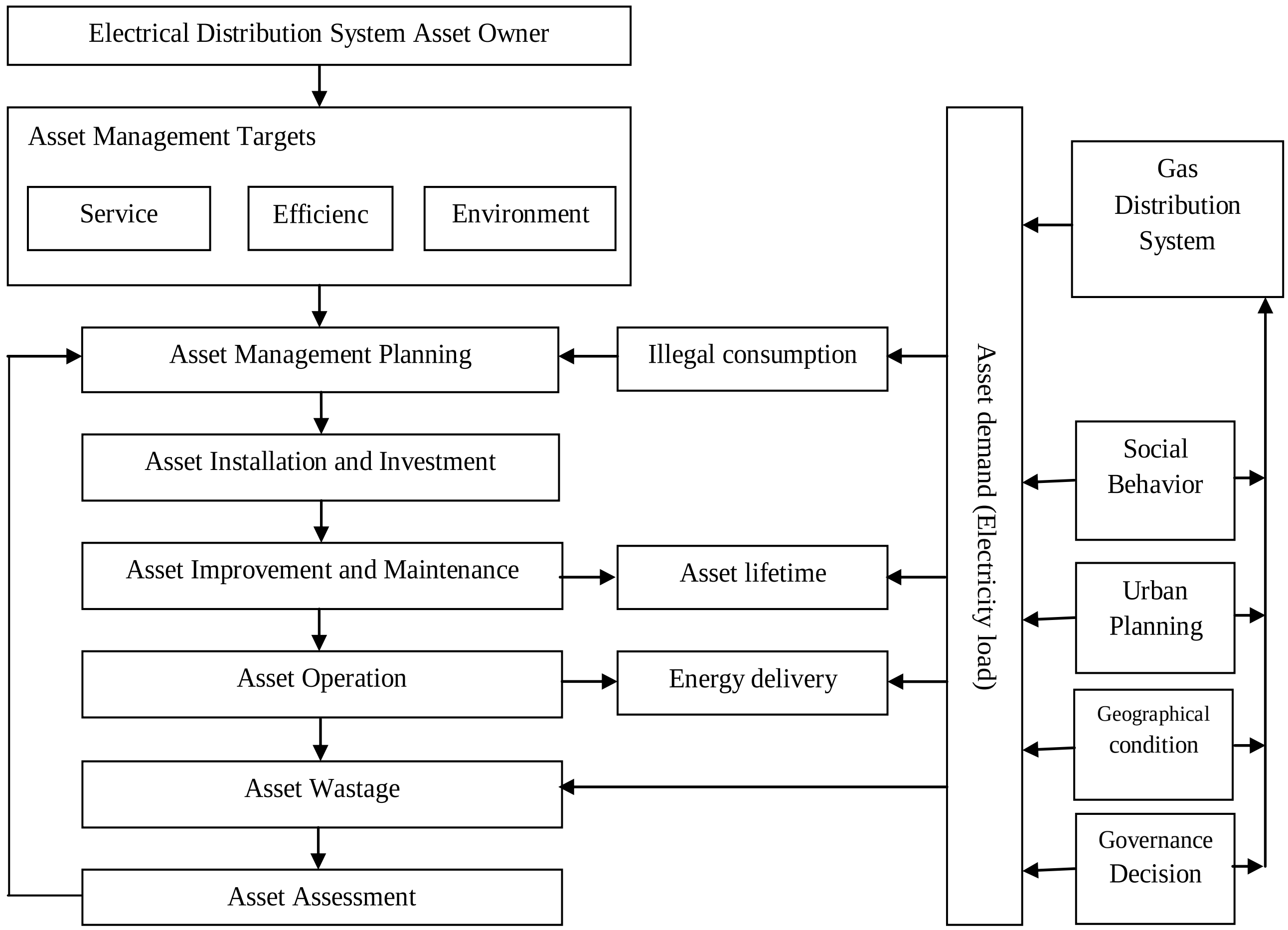

Figure 1. Asset management process.

consists of three periods described as follows:

1. Short-term (real time): includes operation management activities.
2. Mid-term: Management of maintenance and repair of available assets belongs to this set of activities.
3. Long-term: planning, system development and installing new capacities are placed in this group.

The process of asset management aimed at achieving predefined goals is shown in Figure 1. As one can see, design and planning of system development is of the most important activities in asset management and is conducted based on load demand in each of gas or electricity distribution systems. When the system load exceeds the maximum predicted amount, some of network equipments will be damaged. By analyzing the damages imposed to electricity distribution system by load growth (resulted by gas pressure decline), the influence of gas and electricity assets on each other are considered in this paper. The effects of load growth on distribution system can be classified as follows:

1. Load growth lead to overload equipment: When load growth exceeds the maximum predicted amount, some distribution equipment such as protective elements is demolished. These effects are explicit load effects on the system.
2. Equipment lifetime reduction: When the load increases, the temperature of electric equipments like transformers and cables will increase proportionally to square load growth. These are implicit load effects on the system.

In addition to damaging distribution equipment and the resulting casualties, load growth exposes outage to customers. This results the dissatisfaction of customers and the economic loss arising from electricity outage (the unsupplied energy). This is one of the effects of distribution system on electricity load. As one can see, distribution system and load have a mutual effect on each other.

As it can be seen in Figure 1 asset demand affects on illegal consumption, asset lifetime, energy delivery and asset wastages. In subsequently, we investigate effect of asset demand on mentioned parameters. Asset demand determine by variety factors such as social behavior, urban planning, geographical condition, governance decision and quality of gas services to its customers as shown in Figure 1. In this paper, quality of gas services is discussed.

CONSIDERATION OF GAS OUTAGE EFFECTS ON ELECTRICAL DISTRIBUTION SYSTEM ASSET MANAGEMENT PROCESS

Asset demand investigation

As mentioned before, gas outage and pressure decline are of the most important external factors affecting load and distribution system. When gas is cut out, consumers use electric heaters instead of gaseous ones and thereby, electricity consumption increases. This leads to two changes in system load.

1. Increase of simultaneity factor: The increase of simultaneity factor to more than the basic amount considered in system design leads to overload the equipment load, decrease of their lifetime and the demolition of some equipment and protective elements.
2. Increase of illegal connection: Higher electricity demand leads to the increase of illegal consumption.

Overload on equipments damages them and decreases their lifetime. Both of these events destroy or reduce the worth of distribution assets.

Asset wastage investigation

The costs of damages imposed to electricity distribution system resulted from gas outage can be classified as follows. Outage costs can be divided to three categories:

1. The costs of demolished equipment and their substitution.
2. The costs of workers required to eliminate the faults.
3. The costs of unsupplied energy.

The cost of equipment is calculated by multiplying the number of outages in the corresponding costs that is calculated from cost list. The workers cost is also obtained by calculating the average duration of each outage in the costs of each minute. For each kilowatt hour (kWh), the cost of unsupplied energy related to the number of outages is considered to be 0.055 dollars compared to days before gas pressure decline. After separating the outages, the average of past days is compared with days of gas pressure decline and therefore, the difference cost is obtained. Therefore, low pressure accidents are divided to normal and accidental outages.

A. Normal outages: These outages happened every day and therefore, their growth is considered in this paper. These outages are as follows:

1. Fuse burning.
2. Burning of connection box.
3. Connection snap.
4. Burning of connection cables (like jumper, customer connection cable, etc.).

B. Accidental outages: Accidental outages occur due to load growth to over the predicted amount or decrease of insulation lifetime. These outages include:

1. Cable short circuit.
2. Wire snap.
3. Connection damage.
4. Cable head damage.
5. Damaging board.
6. Damaging transformer.

As one can see, all the damages arise from load growth and the resulting heat. Thus, the factor leading to load growth (gas pressure decline) is held responsible for the costs of these events. Reliability indices are used here. We consider life management indices to model asset wastage and reliability together, because when assets are damaged, outages are occurred and then SAIFI, SAIDI and other reliability indices are valued. Therefore, these indices (Reliability and life management) discuss common concepts.

Using illegal consumption costs

Having the average of last months, the cost of illegal energy consumption in days of gas pressure decline is considered as 0.055 dollars for each kwh. It should be noted that here, the ratio of invalid energy consumption in days with low gas pressure to the number of monthly illegal connections is considered to be constant.

Asset lifetime investigation

In this part of the paper, the cost of equipment’s lifetime decrease arising from the overload is calculated. As mentioned before, overload leads to the increase of loss and the heat. If it exceeds a marginal value, the heat amounts the threshold of the insulator and thereby, the insulator’s lifetime is decreased. To calculate implicit effects, one must do the following:

Load growth imposed to the distribution company at the time of gas pressure decline is calculated using relation (1):

$$K = \frac{L_m}{L_{av}} \quad (1)$$

where *K*, L_m and L_{av} are load growth factor, load peak at the time of gas pressure decline and average load peak in the last week in turn. In addition, loss and temperature increase can be calculated using relation (2):

$$LOSS \propto \Delta\theta \propto L_m^2 \propto K^2 \quad (2)$$

where *LOSS* and $\Delta\theta$ are the loss of electricity system and the amount of temperature increase in turn. Transformer insulator is a Class "A" type and is designed for a maximum temperature of 40 ($\Delta\theta_{MAX} = 40$). Therefore, increase of critical temperature ($\Delta\theta_C$), which leads to the reduction of insulator lifetime is calculated using relation (3).

$$\Delta\theta_C = \Delta\theta - \Delta\theta_{MAX} = \Delta\theta - 40 \quad (3)$$

The increase of critical temperature will subtract WL days from transformer's lifetime. Here, WL can be obtained using relation (4).

$$WL = 4 \times \left(2^{\frac{40(K^2-1)}{6}} \times FLD - 1\right) \quad (4)$$

where FLD is the number of days with load growth. WL, which is the decreased lifetime of the cables and transformers in terms of days, can be considered as the number of days, when distribution insulated equipment (cables and transformers) are rented and utilized by Gas Company. Thus, lifetime decrease of insulated equipment can be calculated using relations (5) and (6):

$$CC = LC \times WL \times PC \quad (5)$$

$$TC = S \times WL \times PT \quad (6)$$

where CC, LC, PC, TC, S and PT are the cost of cable lifetime decrease, cable length, the price of each meter of cable per day, the cost of transformer's lifetime decrease, the installed capacity and the price of each kVA of capacity per day.

Energy delivery investigation

The amount of extra loss is calculated by considering the electric energy wasted due to load growth and is considered as 0.055 dollars per kWh. The amount of loss is relative to the square of load growth factor. Thus, the factor of loss increase resulted by gas outage can be calculated using relation (7):

$$f_{loss} = K^2 \quad (7)$$

where floss is the loss increase factor. Therefore, the amount of loss increase can be obtained using relation (8):

$$\Delta LOSS = FLD \times (f_{loss} - 1) \times LOSS \quad (8)$$

where ΔLOSS and LOSS are the amount of increased loss and the amount of normal loss in turn.

NUMERICAL STUDIES

Here, the number of days when the distribution company is affected by the load growth resulted from gas pressure decline are determined by considering the number of Tehran Distribution Company's outages and their behavior in days of gas pressure decline compared to normal days. 6^{th} to 10^{th} of January in 2005 are the understudy days of gas pressure decline.

Consumption growth of illegal connections

As reported by Tehran Distribution Company, the number of illegal connections in January is described as shown in Table 1. If the ratio of the amount of illegal consumption in days of gas pressure decline to the total illegal consumption is considered to be constant, it will be equal to 142.18 per invalid connection as reported by Tehran Distribution Company. Therefore, illegal consumption in each distribution company and the cost of total illegal consumption is as demonstrated in Table 1. Total cost of illegal consumption growth in Tehran Distribution Company at the time of gas pressure decline is 62856 dollars.

Calculation of implicit effects imposed to distribution companies

According to the recent research conducted by Tehran Distribution Company, cable and transformer insulator lifetime in this company is equal to 24 years. In result, considering cable price to be 161 dollars per meter and transformer capacity to be 110 dollars per kVA, PC and PT can be calculated as follows: according to PC relation, cable price is equal to 0.0018379 dollars. With regard to relation PT, the price of 1 kVA is 0.0012557 dollars.

Table 2 represents load peak at the time of gas pressure decline, average load peak in the two last weeks, load growth factor, cables length and the installed

Table 1. Statistics of the number, consumption and growth cost of illegal connections in distribution companies.

Illegal consumption (kWh)	Cost ($)	No. of illegal connection
1142837	62856	7851

Table 2. Estimation of implicit casualties cost.

Load growth factor	Number of extra days	Cables length (KM)	Installed capacity	Cost of cables' lifetime decrease	Cost of transformer's lifetime decrease	Total cost (dollars)
1.011369	0.480673	15646	10131791	13.9037	8.1161	22.01946

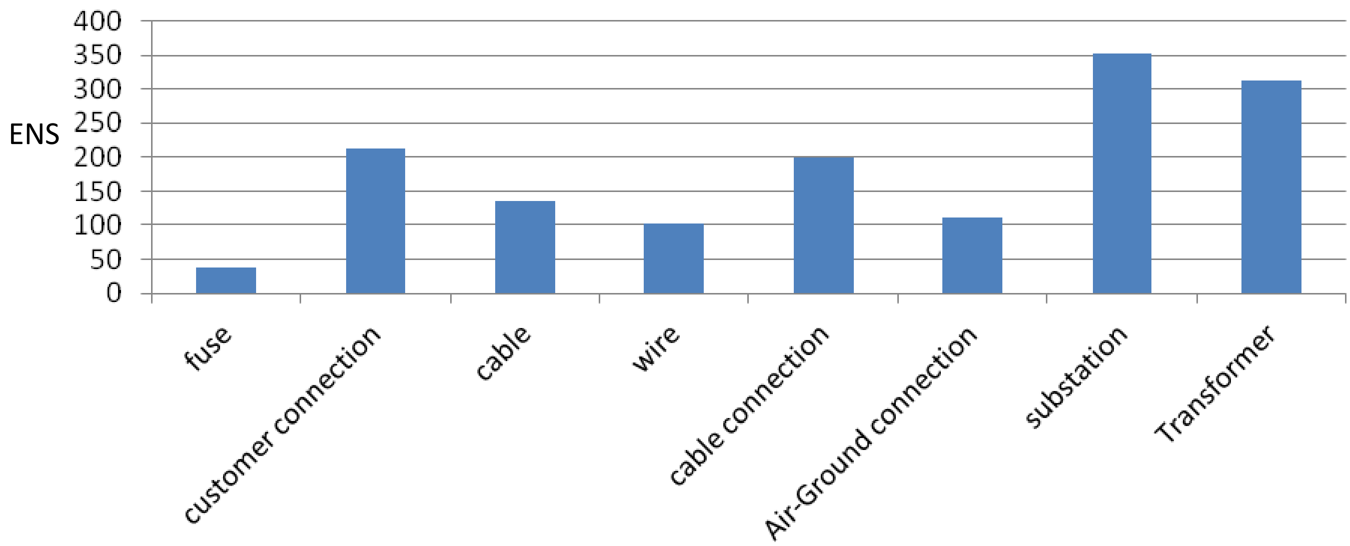

Figure 2. Unsupplied energy of each low voltage outage at the time of gas pressure outage.

capacity and the total casualty cost. According to this table, total implicit casualty cost is equal to 22019 dollars.

Calculation of electricity outage costs

Average duration and average unsupplied energy related to each low pressure outage at the time of gas pressure decline are shown in Figures 2 and 3. To calculate the costs of workers required to eliminate the fault, the following hypothesis are considered.

1. Each fault elimination group is composed of three workers.
2. The number of working days is 26 days a month and the number of working hours is 7 h a day. Thus, the number of working minutes is calculated as follows:

$$26 \times 7 \times 60 = 10920$$

3. The cost of each worker is 1.2 dollars per month.

Regarding previous hypothesis, the cost of each minute for a group is equal to 0.32967 dollars. In result, the calculated casualty cost is as shown in Table 3, in which costs, time and unsupplied energy are presented in terms of thousand dollars, minutes and kWh in turn.

Determination of extra loss cost arising from load growth

Regarding to the statistics of two years ago, average loss of Tehran Distribution System is equal to 11.55%, which is calculated as 3106000 MWH. Thus, 258833.33 MWH

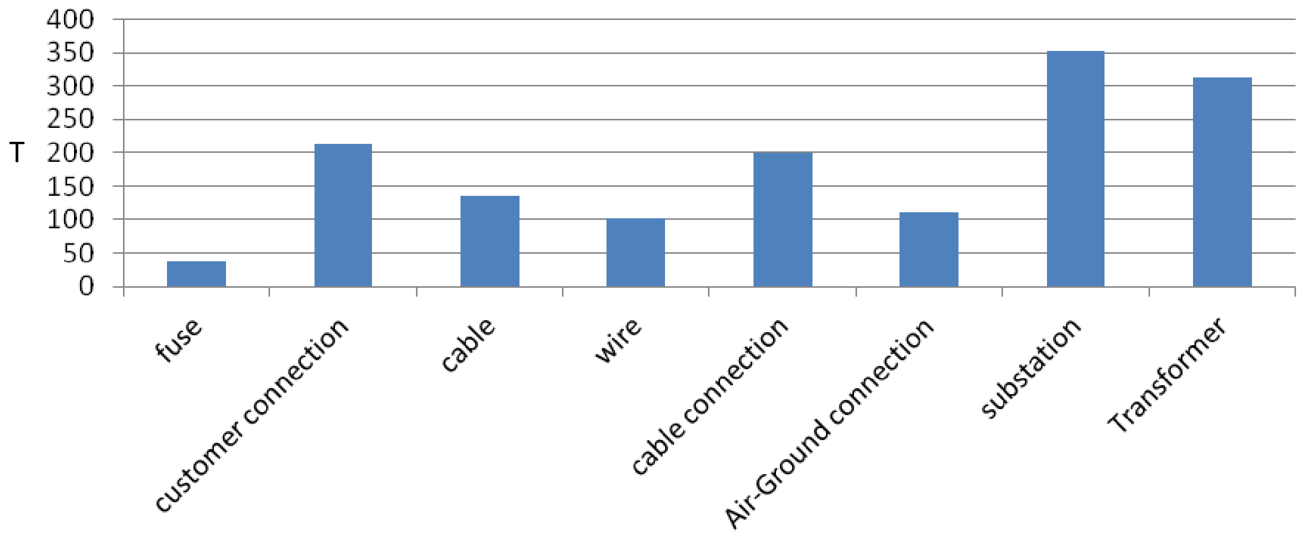

Figure 3. Average duration of each low voltage outage at the time of gas pressure outage.

Table 3. Casualty cost in regions with full information.

Information	Fuse	Connection box	Connection snap	Connections burning	Cable short circuit	Wire snap	Cable connection	Cable head	Board	Transformer
No. of outages	402	35	106	52	177	236	4	8	1	2
Time of outages	14874	1120	11872	3640	23895	24072	800	880	352	624
Energy not supplied	15477	899.5	805.6	5200	10620	23033.6	1204.8	2469.6	2521	4306
Equipment wastage cost	1.71	1.33	0.37	0.05	24.5	1.84	0.55	1.17	3.12	11.08
Worker cost	4.90	0.37	3.91	1.2	7.878	7.94	0.26	0.29	0.11	0.20
ENS cost	0.85	0.05	0.04	0.29	0.58	1.27	0.07	0.13	0.13	0.23

of energy is wasted in Tehran Distribution Company every month.

Electricity peak load in Tehran at the time of gas pressure decline is equal to 5965.7 A while this amount is calculated as 5911.9 for weeks before gas pressure decline. Therefore, load growth and loss increase factors are equal to:

$$K = 1.0091 \ , \quad f_{loss} = 1.0183$$

In result, the amount of loss increase is equal to:

$$\Delta LOSS = 631553 \ kWH$$

Thus, the loss resulted from loss increase is equal to 34.735433 dollars. Table 4 is obtained after conducting all cost calculations. All costs are

Table 4. The cost of final loss.

Cost of illegal connections	62.85604
Implicit loss	22.01984
Wastages cost	54.42658
Workers cost	31.496265
Unsupplied energy cost	8.641487
Added amount loss cost	34.735433
Total casualty cost	214.175645

represented in terms of thousand dollars. Therefore, final loss cost is equal to 214175 dollars.

CONCLUSION

In this paper, we suggest to consider gas and electricity distribution systems together for planning and operation. Thus, asset management of each system must be performed by considering outage risk and low-quality supplement of the other energy carrier. This affects the design and development of energy distribution systems of both carriers and their operation.

When designing each distribution system, it is essential to consider the risks to be able to install extra capacity in distribution systems so that special operation of the system at the time of load growth to more than a certain amount is feasible. In this paper, we considered the effect of gas outage or change of customer behavior due to gas pressure decline on electricity distribution system. We also covered the weak points and the amount of vulnerability in a particular region. As shown in the paper, vulnerability of electricity distribution systems is much higher than gas systems.

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