Technical and Economic Investigation of the use of Aerial Bundled Cables in the Electricity Distribution Network

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ABSTRACT:
Nowadays, in modern and developing countries, it is very difficult to live without continuous and reliable electric energy. After realizing the high importance of energy resources and power generation in power plants, its transmission and distribution in a safe, sustainable and high-quality manner became very important. In the past, most of the electrical energy was carried out at the low voltage level through aerial networks with copper wires, but in recent years due to problems such as the greater importance of accessibility, the importance of improving power quality, theft of copper wires due to the increasing price of copper, electricity theft, etc., the implementation of aerial wire networks is prohibited except in special cases in distribution companies, and the use of aerial bundled cables has been replaced instead. In this article, first by introducing the merits and demerits of the implementation of aerial bundled cables, economic study (profit and loss) and also the return period of the capital in a system have been investigated and at the end its efficiency or inefficiency for distribution companies has been studied.

KEYWORDS: Aerial Bundled Cables, Conversion of Wire to Cable, Economic Study of Return on Capital, Distribution Network.

1. INTRODUCTION

Weak pressure networks are divided into two categories: air and ground. Each of the networks has its own advantages and disadvantages. Table 1 shows some of the advantages and disadvantages of such networks.

Table 1. Advantages and disadvantages of ground and air low pressure networks.

Network type	Advantages	Disadvantages
Ground	• High security and lack of privacy • Beautification • Increasing reliability • Reducing environmental effects	• High construction cost • Problem finding • Relatively high expertise • The need for modern and expensive troubleshooting equipment and devices • License to dig a canal, etc
Aerial	• Ease of network construction • Less cost to build • No need for a drilling permit • The possibility of developing the network at a lower cost • Ease of fault finding	• Relative lack of stability in conditions • unfavorable weather • privacy • Environmental effects • Creating transient errors and power cuts • The possibility of unauthorized use of electricity • Wire theft

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Considering the disadvantages mentioned for air wire networks, the use of aerial bundled cables is an alternative method for power transmission at the distribution level [1], and Isfahan Province Electricity Distribution Company is one of the pioneers in this field.

2. AERIAL BUNDLED CABLES

This type of cables was used for the first time in 1955 in France to replace low voltage networks with wire conductors [2] and due to their many advantages, they found a suitable application position. The history of using this type of cable in Iran is not very long and today most of the distribution companies are using this type of coated wire. In the beginning, the insulation used for these cables was materials called Polyvinyl Chloride (PVC) and although this material had many weaknesses due to its poor quality and lack of resistance in weather conditions, it was considered an important progress in this field. With the progress of petroleum and petrochemical industries, as well as the discovery of new petroleum products, new insulating materials were produced, but the basic progress in insulation occurred with the production of polyethylene crosslink (XLPE) insulation in the General Electric factory of America in 1953. This material quickly opened its place in the cable industry due to its very suitable properties. After that, in 1977, for the first time, polyethylene crosslink was used as insulation in low pressure aerial cables, and due to its very suitable properties, it is still used. Commonly used low pressure aerial bundled cables are divided into 4 categories [1]:

1. Cables with separate steel holding wires and neutral phase conductors for lighting passages that are made of aluminum.
2. Cables that are made of aluminum reinforced with steel, aluminum reinforced with alloy or aluminum alloy with a common neutral and holding wire, and the phase conductors for lighting passages that are made of aluminum.
3. Cables without holding wires (with phase, neutral and passageway lighting conductors)
4. Aluminum double stranded cables (only for street lighting)

2.1. The Advantages of using Aerial Bundled Cables

The use of aerial bundled cables in the network has its advantages and disadvantages, some of which can be briefly mentioned [3].

1. Increasing the reliability of the network against weather conditions and events caused by the collision of foreign objects
2. Significant reduction of undistributed energy
3. Reducing the cost of pruning in forested areas
4. Reducing losses by eliminating the leakage current in trees and equipment
5. Reducing the risk of fire in forested areas and preventing the destruction of the environment and the death of animals
6. More freedom of action in designing the lines due to the reduction of the distance between aerial bundled cables
7. The possibility of installing a new line of aerial bundled cable next to the previous line on a beam
8. The possibility of installing low pressure aerial bundled cable on the existing foundations of 20 kV lines
9. The possibility of installing telephone and optical fiber lines on a common base while maintaining the privacy of 0.5 meters
10. It is easier to repair broken beams in aerial bundled cable lines compared to regular aerial lines and continuity in providing service to subscribers.
11. The possibility of beautifying the city by hiding the aerial bundled cables from public view by passing the cable over the wall or hiding it in special channels.
12. Being resistant to corrosion and as a result reducing the rupture of low-pressure lines
13. Reducing the amount of unauthorized use of electricity
14. The difference in cost is small and compensable from the place of saving in the damage of blackouts
15. The possibility of maintenance and service when the line is energized
16. Reducing maintenance costs (systematic reduction of tree pruning and replacement of broken insulators, etc.)
17. Increasing safety while working on lines and reducing damages and losses caused by electrocution
18. Possibility of use in narrow passages
19. Reducing the possibility of overvoltage caused by lightning
20. Reducing the vibrations of the transmission line due to phenomena such as wind and the possibility of making spans longer
21. The use of low class bases due to the lightness of the cable
22. Reducing the running time of aerial bundled cables compared to the wired network
23. The possibility of using short bases due to the insulation of the conductors
24. The possibility of increasing the capacity of the line and installing a new circuit on the bases

3. CALCULATION OF BENEFITS AND REDUCTION OF ECONOMIC COSTS OF USING AERIAL BUNDLED CABLES

3.1. Reducing Uncertainties and Undistributed Energy

Today, the most important goal of distribution companies is to provide electric energy to consumers at a low cost with the least uncertainty. Therefore, an interruption in the continuity of energy, regardless of the factors that cause it, causes a decrease in the level of network reliability. Therefore, one of the duties of distribution companies is to use methods to reduce accidents and blackout hours and ultimately reduce undistributed energy. The occurrence of any defect in the network, while not satisfying the subscribers, imposes a lot of losses on the consumers and the distribution network. Therefore, more attention should be paid to the distribution networks and efforts to eliminate the shortcomings of this part of the power system and reduce the undistributed energy, and ultimately increase its reliability and thus reducing the costs of regional electricity companies and gaining customer satisfaction should be on the agenda of those in charge. Investigating outages and solving them is one of the important duties of electricity companies. Although it is not possible to completely prevent blackouts, but since most of these blackouts are caused by the low quality of the execution work and the lack of insulation of the cable network or the unfavorable way of operation, it is possible to know the factors of the blackouts and by increasing the quality level and performing various tasks, including the use of aerial bundled cables, their number and amount and thus the undistributed energy is reduced [4].

3.1.1. Reduction of uncertainties due to ephemeral factors

Some of the effective factors that cause transient defects in the system are:

- Approaching and contact of conductors due to wind and storm
- Lightning striking the line and creating a spark on the insulator and insulating surfaces
- Birds passing between conductors and dealing with them
- The impact of trees in the sanctuary of conductors due to wind and storm
- Presence of foreign objects on the wires

Each of these factors can be investigated and analyzed separately, and methods to prevent them can be presented, using aerial bundled cables is the most effective and best method. In order to study and investigate the above factors, the statistics related to one of the wire to cable conversion projects have been used. In this study, the first year is the year that the network is wired, and the second year is the year that the network is equipped with a aerial bundled cables.

Table 2. Statistics of events in the aerial bundled cable network and wired network.

The type of events	First year	Second year	The rate of reduction in the percentage of events
Low pressure switch disconnection	3	1	66%
Broken wire and jumper	7	1	85%
Burnt fuse	12	3	75%
External factors (clash of trees and birds)	3	-	100%
Non-metal clamp connection	-	1	-100%
Sum of events	25	5	60%

By examining the number of incidents, it can be seen that the number of incidents has decreased significantly in the second year. By examining the type of incidents and the inappropriate and unprincipled condition of the low pressure air network in the desired situation, it is determined that the aerial network is prone to accidents and the replacement of aerial bundled cables is an effective way to reduce the occurrence of incidents. The average value of low-pressure shutdown in the entire target area in the first and second years based on the measurements is available in the table below. According to the number of events, the total distributed and undistributed energy is equal to:

Table 3. Amount of undistributed electrical energy in the first and second years.

Undistributed energy in the first year	Undistributed energy in the second year	Reduction rate
3200KWh	800KWh	75%

According to the above table, it is clear that after using the aerial bundled cable in the second year, the amount of undistributed energy has been reduced to 2400 KWh [5].

Table 4. Household electricity tariff in the first and second year.

Average monthly energy consumption (KWh per month)	The base price of the first year per KWh (Rials)	The base price of the second year per KWh (Rials)
0 to 100	372	409
100 to 200	434	477
200 to 300	930	1023
300 to 400	1674	1841
400 to 500	1922	2114
500 to 600	2418	2660
More that 600	2666	2933

According to the average price of electricity in the second year given in Table 4, the amount of profit from the reduction of undistributed electricity energy in the second year can be calculated.

2400 kilowatt hours x 24 hours x 30 days x 1637.6 rials = 289772800 rials

3.2. Cutting Off Unauthorized Branches by using Aerial Bundled Cables

Unauthorized use of electricity network is always one of the main problems of distribution companies. According to existing estimates, unauthorized electricity losses in the country constitute 1.5% of the total delivered energy [3], which of course is the average amount of the total unauthorized electricity in the country and the amount of this type of losses is different in different parts of the country. In the area under study, due to the presence of unauthorized agricultural wells and religious bodies that make unauthorized use of the electricity network, this number increases to 2%. The use aerial bundled cables can reduce unauthorized power losses to zero. The average amount of power in the system under study is equal to 300 KW. Based on this, the total amount of unauthorized electricity losses in the study area in one year can be calculated [5]:

0.02 × 24 hours × 365 days × 300 KW = 52560 h
1637.6 rials x 52560 Kwh = 86072256 rials

3.3. Reducing Costs Related to Pruning

The costs related to pruning and the costs of pruning by the hot line method, as well as the tension with the municipalities and the trees owners, have always been one of the problems of the distribution companies. By using aerial bundled cables, the expenses related to branch cutting and administrative tensions are minimized and in some places, they reach zero. In the studied area, due to its rural and mountainous location, the cost of pruning is high, and its amount is calculated as follows. The cost of branching the airlines in the second year's price list amounts to 5784.5 riyals per meter. If it is assumed that pruning is done once a year and the price of pruning remains constant in the coming years, the cost of pruning in the area under study is 59925000 Rials.

3.4. Preventing the Theft of Copper Wires

Nowadays, the high price of copper in the black market and the easy buying and selling of this metal have intensified the theft of copper wires. The thieves risked their lives to cut the copper wires and cables, which caused many problems for the electricity distribution networks. It seems that the use of aluminum wire or aerial bundled cables is a more appropriate and optimal option in areas where there is less possibility of network theft or unauthorized electricity or privacy problems, and also in single-shot projects where the network is implemented intermittently based on the request of the applicants, it is better than copper wire because, in addition to the advantages of copper wire, some of the advantages of aerial bundled cables, such as the low initial investment cost and the incentive to steal the network, are greatly reduced.

3.5. Income from the Removal of Copper Wires

One of the advantages of wire-to-cable projects for distribution companies is to provide a large part of resources by selling discarded copper wires. Of course, to provide the required financial resources, several solutions have been planned. In order to reduce losses and in the conditions of lack of liquidity, the contracts to convert the copper network to aerial bundled cables are one of the most suitable methods to solve the mentioned problems as a comprehensive strategy. The features and advantages of this type of contract show its superiority over other types. This proposal is of considerable importance, if the current trend (upward trend of copper network theft) continues, the network will be destroyed and the liquidity of electricity distribution companies is in a very unfavorable condition. In this article, for the purpose of economic study and capital return time, conventional clearing contracts are not used and the rial value of copper returned from this project is considered based on the project's systemic agenda. In Table 5, the return cost from the sale of copper wires in the system under study is presented [6].

Table 5. Return on capital from recycling copper wires.

Copper wire type	Amount (Kg)	Return on Capital
Grade 10 copper wire	17	20889881
Grade 16 copper wire	1259	214021187
Grade 25 copper wire	1697	288478121
Total sum	2973	505389189

3.6. Reducing the Voltage drop and improving the voltage profile at the end of the lines

Today, with the expansion of the distribution network and the increase in the level of consumers' expectations for increasing the reliability of electricity consumption, the issue of improving the power quality indicators of the network has been raised. The distribution system is very important because it is the closest link to the consumer and should have a satisfactory performance, it is also expected to receive more attention in order to improve the performance in the coming years. In the design of power networks and regulation of energy distribution projects, determining the appropriate cross section of the cable using the permissible current and voltage drop is very important. Every cable with a specific cross-section is capable of transmitting a certain current, if the current exceeds that limit, it will cause loss of electrical energy, shorten the life of the cable, or burn it. For the economic design of the network and optimization, statistical data and real values such as cable price, installation and maintenance cost, price per kilowatt-hour consumption, duration of cable use, etc. are needed. By increasing the cross-sectional area, the resistance decreases, so the voltage drop is reduced and as a result, the power loss is reduced. Therefore, the price of the power lost in the cable is also reduced, on the other hand, the cable with a larger cross section has a higher price. Therefore, optimizing these two items is important. In wire-to-cable projects, since aluminum cable with a larger cross-sectional area is used than networks with copper conductors, the voltage drop is much less than before [6].

This case study network has 10 feeders. Table 6 shows the lowest recorded voltage levels for two modes.

Table 6. Voltage profile before and after replacing the aerial bundled cables.

Feeder name	Voltage level with aerial bundled cable			Voltage level with wire cable		
	A	B	C	A	B	C
TR1-1	95.62	96.92	96.59	91.41	93.77	93.01
TR1-2	97.83	97.83	97.83	91.64	94.1	93.29
TR2-1	97.64	97.64	97.64	89.79	98.6	96.62
TR2-2	96.59	96.89	96.56	89.66	91.76	88.56
TR3-1	100	100	100	93.37	95.02	90.93
TR3-2	99.38	99.38	99.38	97.2	99.91	99.22
TR4-1	97.91	97.91	97.91	94.34	97.39	96.4
TR4-2	95.85	95.85	95.85	92.98	95.15	90.19
TR5-1	95.59	95.59	95.59	86.29	91.99	89.21
TR5-2	96.92	96.92	96.92	93.98	95.13	94.76

As can be seen from the data in the table, the amount of voltage drop calculated using CYMDIST software is very inappropriate in the case of wired network, which reaches 15% in some feeders in the worst case. After the implementation of the aerial bundled cables, it can be seen that this amount of voltage drop has decreased to 4.3% in the worst case, which is the same as the amount of voltage drop allowed in the instructions (5%).

Usually, during peak consumption (summer), the voltage drop beyond the permissible limit causes damage to the electrical equipment of the subscribers, and at this time, the distribution companies face a large volume of complaints from the people to compensate for the damage caused by the burning of the electrical equipment.

4. COSTS OF IMPLEMENTING AERIAL BUNDLED CABLES

The implementation of aerial bundled cables in wire networks requires special goods and fittings related to cable networks. Usually, aerial bundled cables are implemented on the existing beams, and if they are used, the budget is provided in the network improvement agenda. In Table 7, the necessary items and the cost of its implementation are considered.

Table 7. Types of items and their cost in the implementation of the network with aerial bundled cables.

Types of items	Amount	Unit	Cost of implementation and materials (Rials)
Aerial Bundled Cable 4*50+25+25	5355	Meter	641437965
1 to 4 conversion connector	353	Number	25774295
Hanging clamp	109	Number	9842264
Branching clamp line by line	536	Number	43858200
Cable end clamp	156	Number	20257536
End-Cap	145	Number	582030
Total sum	-	-	741752290

At this stage, in order to calculate the amount of return on capital time, the incomes resulting from the implementation of aerial bundled cables are presented in a summary form in Table 8.

Table 8. incomes from the implementation of aerial bundled cables.

Source of income	Amount (riyals)
Reduction of undistributed energy	289772800
Cutting the unauthorized branches	86072256
Reducing costs related to pruning	59925000
Income from removal of copper wires	50538918
Total sum	941159245

Now, by comparing the values of Table 8 and Table 7, it can be seen that the cost of implementation related to the implementation of aerial bundled cables in the system under study is equal to 741752290 Rials, which is equal to 941159245 Rials, including the total income from the implementation of aerial bundled cables. The amount of capital return in this type of projects will be less than one year. It should be mentioned that the rest of the features related to the implementation of this project, such as improving the voltage profile or reducing the theft of copper networks, etc., could not be converted into Rial values, or accurate statistics were not available to present in this article.

5. CONCLUSION

In this article, after examining the advantages and features of using aerial bundled cables in electricity distribution networks, including reducing outages and undistributed energy, improving the voltage profile, preventing the theft of copper wires, and... the Riyal value related to the performance characteristics of aerial bundled cables has been calculated. After performing these calculations, it was determined that the amount of capital return in the system under study is less than one year, which indicates the efficiency and cost-effectiveness of implementing these types of projects for distribution companies. Also, according to the mentioned advantages, it is recommended to use this type of cable from the very beginning during the construction of the network.

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