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Impact of Superconductor Technologies on Network Design and Energy Cost- a Case Study in Libya

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Abstract— **Several studies and investigations have attempted to introduce a new design for the conventional distribution networks. This proposed design aims to offer a reduction in substation installation cost and in power losses by eliminating some voltage levels in networks. Sine, this is difficult to achieve with conventional distribution networks, when the conventional cables and transformers are used, where the impedance of conventional equipment is high. Due to High-Temperature Superconductor (HTS) materials provide extremely low impedance to AC when cooled to the boiling point of liquid nitrogen (77K), the interest in using HTS materials to produce power cables and transformers is increased. The present paper investigates the practical impacts of installing HTS cables and transformers and seeks to introduce a future network design which leads to the best implementation for superconducting networks, thus, a drop in the substation installation cost and energy losses cost by eliminating some voltage levels in the traditional networks.**

Index Terms: **Superconductor, capital cost, Energy Losses, HTS, Networking design.**

I. INTRODUCTION

Delivering a large amount of power at different voltage levels in distribution networks affects the value of current that flows through network equipment, for example cables, overhead lines, and transformers [1]. This leads to an increase in the network power losses and a rise in the cost of substations and power transforms [1,2]. The key challenge to decrease the capital cost and power losses of distribution networks is to eliminate some voltage levels in the network, which is because of the impedance of the conventional equipment [3]. Since HTS cables and transformers offer a very low impedance to AC at the boiling point of liquid nitrogen (77K), the potential in implementing HTS equipment is significantly improved [4]. HTS transformers and cables promise to increase the delivered power 10 times more than the conventional cables at a lower voltage level with zero resistance. The power losses produced by HTS equipment results because of the hysteretic losses and eddy current losses, these AC losses are up to 86% less than those coming from the conventional power conductors [5].

Many studies have recommended employing HTS transformers and HTS cables in urban areas and capital cities. HTS techniques could overcome many obstacles that face conventional technologies in urban areas such as voltage drop, power losses, CO_2 emissions and increased power density to meet future power demand [6-9]. HTS cables can deliver a higher power capacity with lower voltage (<50kV) and lower losses, hence, they can reduce the cost of high voltage substations in urban areas [7]. Moreover, researchers have carefully examined the losses in the HTS cables. The AC losses and thermal considerations for HTS cables have been investigated in [10]. Operational limits for long length HTS depend on the refrigeration configuration, HTS cable losses, and the thermal losses. An analysis of liquid nitrogen refrigeration systems and electrical insulation contraction for HTS cables was presented in [11]. This paper aims to find out the practical impacts of installing HTS cables and transformers in a real part of the Libyan power network -Hoon City- to identify the future Libyan network design which results in the best implementation for superconducting network to reduce the substation installation cost and power losses by reducing some voltage levels in the network.

II. CASE STUDY

The existing Libyan power network consists of three voltage levels. The first voltage level is a 220kV busbar which is connected with three step-down transformers 220kV/66kV with 63MVA each. Thus, the next voltage level is 66kV that is transmitted to 11kV substation with two 20MVA transformers as shown in Figure 1.

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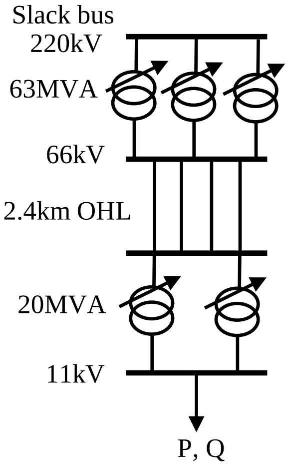

Figure 1: Network configuration of the case study

Figure 1 illustrates the present conventional network design. Based on the annual load factor of 8%, the study assumes that the loads will reach 46.61MW by 2040 [12]. In order to meet the future demand, one 20MVA, 66kV/11kV transformer was added to the substation. As shown in Figure 2. The data of the transforms and the cable are in the appendix.

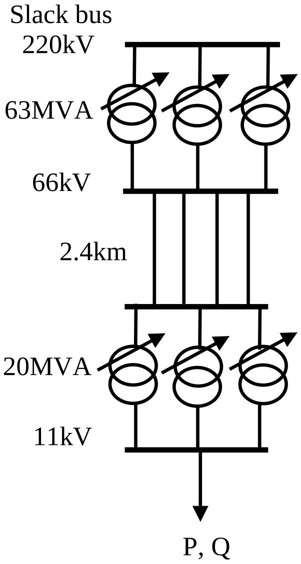

Figure 2: Configuration of the future network

III. NEW PROPOSED DESIGNS OF SUPERCONDUCTOR NETWORK

HTS equipment is a promising technology to increase the power capacity many times at lower voltage levels with minimal power losses, which cannot be provided by using the traditional cables and transforms [13]. This would need to provide a new design of the Libyan existing distribution network 220/66/11kV - Hoon City- using superconducting equipment such as cables-transformers, and that is to reduce the cost and power losses and to meet future demand by eliminating some voltage levels in the network. HTS 11kV Cold Dielectric Cable produced by Nexans is now available in the market and can supply loads of up to 10 times the capacity of conventional cables [13].

A new design for the Hoon city network can be achieved with using HTS 11 kV cables and transformers by transferring the same amount of power from 220 kV directly to 11 kV substations. This means that the 66kV network and the 66kV/11kV transformers will be removed from the system and this will reduce the capital cost of systems. The new design of the 11kV superconductor distribution network aims to eliminate the 66kV medium voltage lines and transformers by transferring power from the 220kV network to the 11kV network as shown in Figure 3.

This design cannot be implemented using conventional cables and transformers, because of the high current values delivered and the impedance of conventional equipment at 11kV [4]. The future demand has considered in this study which will reach to 46.61MW by 2040. Figure 3 depicts the 11kV superconducting distribution network. The present traditional distribution network has been simulated using NEPLAN 5.5.5 software as well as the new 11kV superconductor distribution network for various loads from 2023 up to 2040 (46.61MW).

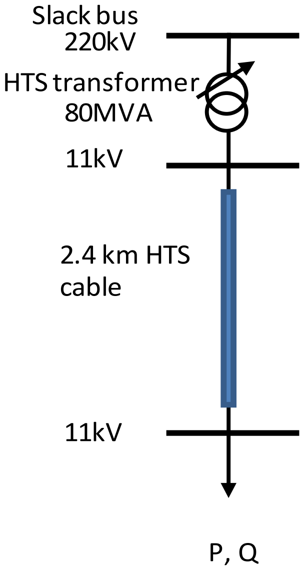

Figure 3: 11kV superconductor distribution network

IV. TOTAL ENERGY LOSSES COST COMPARISION

Based on the results shown in Figure 4, the total power losses in 11 kV superconductor distribution network including refrigeration systems is 0.05 MW, while the total power losses in the existing distribution network at the peak demand (46.61MW) is 0.619MW in 2040 . This result has been calculated using equation 1 and 2.

$$P_{loss} = \sum_{i=1}^{N_{br}} |I_i|^2 R_i \qquad (1)$$

$$Q_{loss} = \sum_{i=1}^{N_{br}} |I_i|^2 X_i \qquad (2)$$

Where, N_{br} is the number of branches in the distribution network; I_i is the magnitude of current flowing in the branch, R_i and X_i are the resistance and the reactance of the branch i respectively.

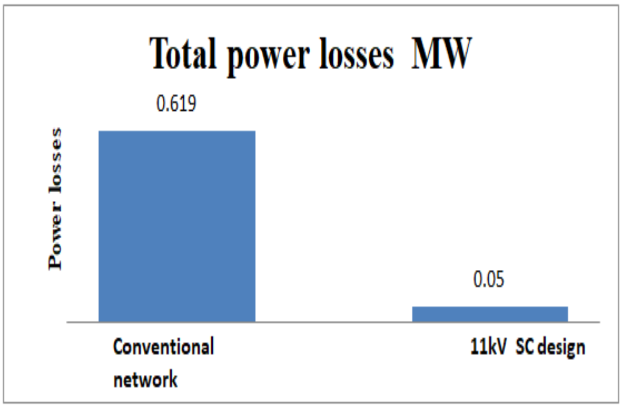

Figure 4: Total power losses comparison

This led to a reduction in the power losses by 92% when HTS technologies were considered. Therefore, the cost of power losses can be also reduced by 92 % using HTS technologies from conventional one. As a result, the 11kV superconductor network design can save 314 k$ per year as shown in Figure 5 .The results of the energy cost per year for superconductor and conventional networks have been calculated using equation 3.

$$\text{Energy losses cost} = \text{MW} \times 24\text{h} \times 365\text{D} \times 63(\$/\text{MWh}) \quad (3)$$

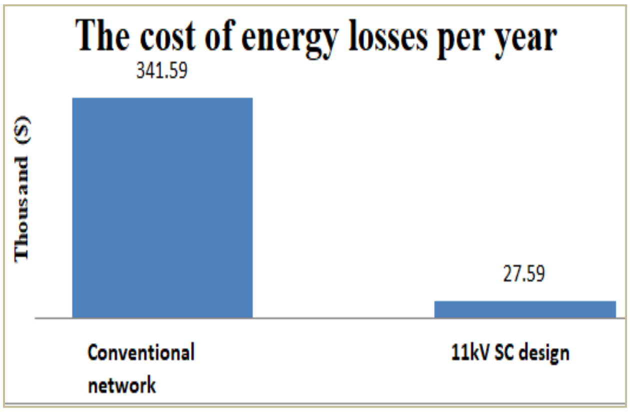

Figure 5: The cost of energy losses comparisons

It is clear that 11kV superconducting distribution network design provided lower total power losses than the current network. Therefore the capital cost of these two network designs must be calculated to find out the best design which offers lower energy losses and lower capital cost. Before exploring the capital cost comparisons between 11kV superconducting distribution network and the current conventional distribution network, it is necessary to refer to the cost of HTS cables, transformers and their continuous decline along the years, as the prices of superconducting materials decease which led to a reduction in the capital cost of the distribution networks using superconducting technologies.

V. HTS CABLES AND TRANSFORMER PRICE

The main challenge of HTS cables and transformers is to continue to drive down the prices of superconducting tapes and refrigeration systems, which are used in superconducting technologies. B_{i2223} or YBCO tapes are superconducting materials used to produce HTS cables and transformers. The cost of B_{i2223} tapes was about 107.6 -143.5 $/kAm in 2009. However, in 2020 the prices of B_{i2223} tapes has decreased to 14.3 $/kAm [15]. Another study estimated that the price of B_{i2223} tapes could drop to 7.2 $/kAm by 2030 [16], and 3.6 $/kAm by 2040 [11].

The prices of refrigeration systems was about 694 $/kAm in 2009, and has decreased to about 69.4 $/m in 2020. This may leads to a decrease in the prices of refrigeration systems down to 17.4 $/kAm by 2040 [17]. Many studies suggest that the gap price between HTS technologies and conventional one would be very closed in near future [18]. Table 1 shows the prices of HTS cables and B_{I2223} tapes with refrigeration systems in 2009, 2020, and the expected in 2040[18].

Table 1: cost and future cost for HTS cables and refrigeration systems

The price of B_{i2223}tape and HTS cable			
Item	**Bi-2223tape, $/kA m,77K**	**Refrigeration system $/m,77K**	**HTS Cable $/m**
2009	107.6-143.5	694	21.5k
2020-2040	14.35-3.6	69.4-17.4	2.15-0.53 k

Asea Brown Boveri (ABB) Ltd concluded that the HTS transformer has more efficiency at higher power levels because it offers several advantages over the conventional transformers, such as lower operating losses, lower resistance, better voltage regulation and less weight [19]. Moreover, ABB conducted Studies which indicate a decrease in the capital cost to 20%, and a reduction in the weight to 50%, and a decline in the power losses to 70% for 100MVA transformers that use HTS materials compared to conventional transformers [20]. Another study in [21] found that the price gap between a 60MVA HTS transformer and a conventional 60MVA transformer decreased to 36.5 k$ when the price of B_{i2223} or YBCO tapes was 21.5 $/kAm. Earlier in 2009, the prices of HTS transformer cooling systems were estimated at 69.4 $/W at 77K, but now the prices have dropped to 17.90 $/W. As a result, 10 years ago, the total price of HTS transformers including the refrigeration systems was higher by 30% of the total price of conventional one, but at the present time, the current price of HTS transformers with the refrigeration systems has decreased to 10% from conventional one [22]. Furthermore, the operation cost of the superconducting cables has become less than that of the traditional cables [23].Table 2: summarizes the prices of the HTS transformers based on the prices of B_{i2223} tapes with refrigeration systems in 2009 and 2020, and the expected prices in 2040.

Table 2: The prices of the HTS transformers with refrigeration systems in 2009, 2020 and expected in 2040.

The price of B_{i2223}tape and HTS cable			
Item	**Bi-2223 tape, $/kAm, 77K**	**Refrigeration system $/W,77K**	**HTS Transformer (with Refrigeration system) $**
2009	107.6-143.5	69.4	30% more
2020-2040	14.35-3.6	17.9-4.47	10%more

In the future, HTS cables and transformers are expected to be more common in distribution networks, and it is expected that the price of HTS cable including refrigeration system will decrease to 0.53 k$/m by 2040. Also, the cost of HTS transformers with the refrigeration system will be about 10% less in the same year. Many researchers believe that HTS technologies are one of the major technologies in this century and that HTS cables and equipment will seize a large scale from the global market [22].

VI. TOTAL CAPITAL COST COMPRESSION

The 11kV superconductor distribution network provides a potential to carry high amounts of power at lower voltage with lower losses. Therefore 66 kV networks and 66kV/11kV substations can be removed from the current system. Based on tables 1 and 2, the capital cost of the 11kV superconductor network design has been evaluated in three periods of time which are in 2009, 2020 and 2040. In Figure 6, 7 and 8 the capital cost compression between the conventional and the superconductor network designs was drawn in these different years. The investigating provides the capital cost of 11kV superconductor distribution network design, which was 53.53 M$ in 2009 and that is higher by 51.33 M$ From the conventional network design. However, due to the continuous decline in the prices of HTS equipment, the price gap has reduced to 3.35 M$ in 2020. In 2040, the cost of the 11kV superconductor distribution network design is expected to be 710 k$ less than the traditional one, saving about 28% of the cost. Figures 6, 7 and 8 show the capital cost of 11kV superconductor network design in 2009, 2020 and the expected cost in 2040 compared to the conventional network.

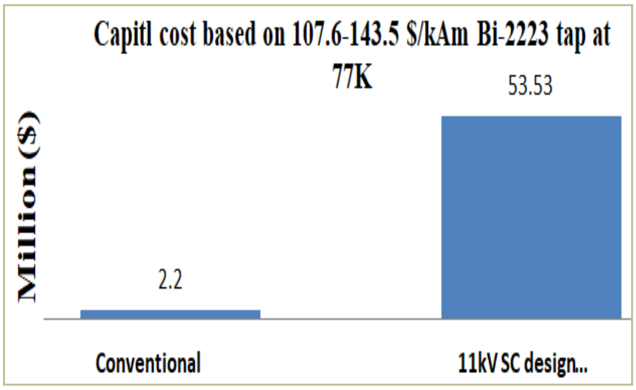

Figure 6: The capital cost comparisons between 11kV superconductor network and future conventional network when B_{i2223} wire and cooling system is 143.5$/kAm and 694$/m, in 2009

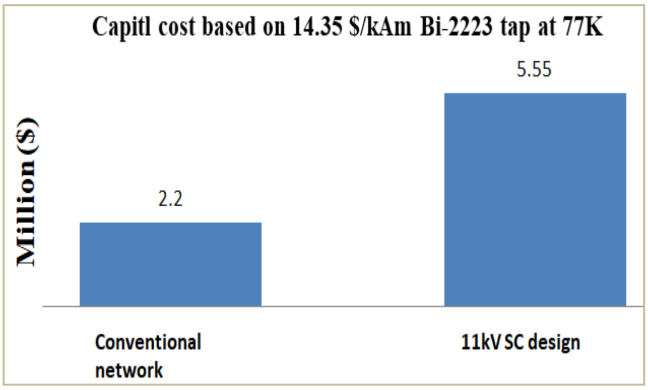

Figure 7: The capital cost comparisons between 11kV superconductor network and future conventional network when B_{i2223} wire and cooling system is 14.35$/kAm and 69.4$/m, in 2020.

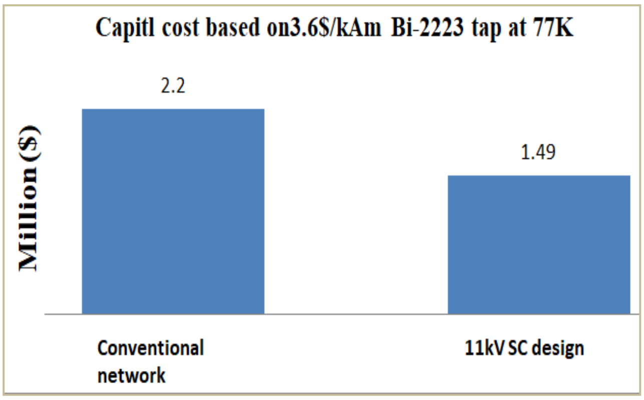

Figure 8: The capital cost comparisons between 11kV superconductor network and future conventional network when B_{i2223} wire and cooling system is 3.6$/kAm and 17.4$/m, in 2040.

VII. CONCLUSION

This study provides possible future designs for the superconductor distribution network that has led to lower energy power losses and also lower capital cost design, when compared the current conventional design. Implementing the proposed 11kV superconductor network design in near future 2040 could save 710$k from the capital cost of the existing Libyan conventional network, in addition to about 314M$ could be saved from the cost of energy losses coming from the existing network in 2040.

This means that the energy losses cost in superconductor network design can be reduced by 92% from the cost of energy losses of the existing conventional network in the near 2040. While up to 28% could be saved from the capital cost of the existing Libyan conventional networks in the near future. This indicates that using superconductor technologies with larger distribution networks is more beneficial in terms of reducing capital cost and energy losses in the whole distribution system design. However, the risk level of 11kV superconductor network design is very high compared with the existing conventional network due to the redundancy systems that have not been applied to the 11kV superconductor network design. Consequently, further work will be focused on introducing a new 11kV superconductor network design for lower power losses, capital cost and risk level than the conventional distribution networks.

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APPENDIX

A. Conventional Transformers:
20MVA, 66/11kV, Vector Group Dyn11, Impedance Voltage Z=10% , Tap Step 1.25%.

B. HTS Transformer:
80MVA, 220/11kV, Vector Group Dyn11, Impedance Voltage Z=5%.

C. 500mm 2 copper cable type (NA2XS(FL)2Y 1×500 R/V 36/66 kV) , R=0.068 Ω/km , X=0.102 Ω/km,
C=0.0004 nf/km, I max =606A.

BIOGRAPHIES

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