International Journal of Electrical Engineering.
ISSN 0974-2158 Volume 7, Number 2 (2014), pp. 315-326

http://www.irphouse.com

# Reduction of the Risk Level in Future Superconductor Distribution Network

**Mustafa.A. Elsherif**

*University of Misurata*
*E-mail: m.a.m.elsherif@gmail.com*

## Abstract

Many studies introduce new designs for future superconductor distribution networks to reduce the capital cost and power losses at the same time. Most of these designs propose a high amount of power delivered at low voltage which is impossible to achieve with existing conventional distribution network designs. However, a serious issue is arise when future superconductor network designs are implemented is that they are resulted in approximately 3 times higher risk level than conventional network designs. Consequently, this paper provides a novel future superconductor distribution design that results in lower power losses , capital cost and risk level than those occurs in existing conventional network designs.

**Keywords**: Superconductor networks, Conventional networks, Risk level, Power losses, Failure rating and Capital cost.

## 1. Introduction

High-Temperature Superconductor (HTS) cables are superior to conventional equipment because of their potential to carry larger amounts of power at low voltage (LV) with lower power losses [1-3]. Many studies have proposed new designs for superconductor distribution networks that target a reduction in the capital cost and in power losses which exist in conventional distribution network designs. They imply that using HTS technologies within larger distribution networks offers future benefits in terms of reducing capital cost and power losses associated with current distribution network designs [4-7]. Paper [8] introduces a new design for a 33kV superconductor network which demonstrates lower power losses and capital cost than existing conventional distribution network designs. However, the risk associated with operating the future 33 kV superconductor distribution network design is much higher than the risk associated with the existing conventional network design because the 33kV superconductor distribution network does not include any redundancy systems such as (n-1) to maintain customer supplies in the event of a short circuit, where n is the number of branches. Including a redundancy system such as (n-1) for future superconductor distribution network designs increases capital cost because of the high cost of HTS technologies for power systems. Therefore, any new planned superconductor distribution network should result in lower power losses, carry lower levels of risk and have a lower capital cost than the present conventional distribution network design.

This paper evaluates comparable risk studies between existing conventional distribution networks and the new 33kV superconductor distribution network obtained, which has used in [8], and proposes a new design for a 33kV superconductor distribution network, that has the desirable attributes listed above using the case study in [8].

## 2. Conventional Case Study Network

Fig. 1 shows the conventional case study network used in this study, it has been simplified to fit with the case study that has used in [8]. The network introduces the relevant 132 kV, 33 kV, and 11 kV circuits such as circuit breakers (CBs) for cables and its associated ancillary assets for the transformers. The present configuration of the conventional distribution network has been classified into nine zones to introduce the network configurations with all voltage levels in conventional network in more detail as shown in table 1.

**Table 1:** All Relevant 132kv, 33KV and 11KV Circuits and Transformers with Associated Ancillary Assets.

| Zone | Assets |
|---|---|
| A | One transformer 275/132kV with its associated ancillary assets and 132kV CB |
| B | One transformer 275/132kV with 132kV CB |
| C | 0.153km of 132kV overhead lines with 33kV CB |
| D | 11.75km of 132kV overhead lines with 33kV CB |
| E | 3.364km of 132kV overhead lines, 132kV CB and transformer 132kV/33kV with associated ancillary assets, 33kV CB and 132kVCB |
| F | 7.337km of 132kV overhead lines, 132kV CB. transformer 132kV/33kV with associated ancillary assets, 33kV CB and 132kV CB |
| G | 0.5km UG cables, transformer 33kV/11kV with associated ancillary assets and three 33kV CBs |
| H | 0.5km UG cables, transformer 33kV/11kV with associated ancillary assets, two 33kV CBs and 11kV CB |

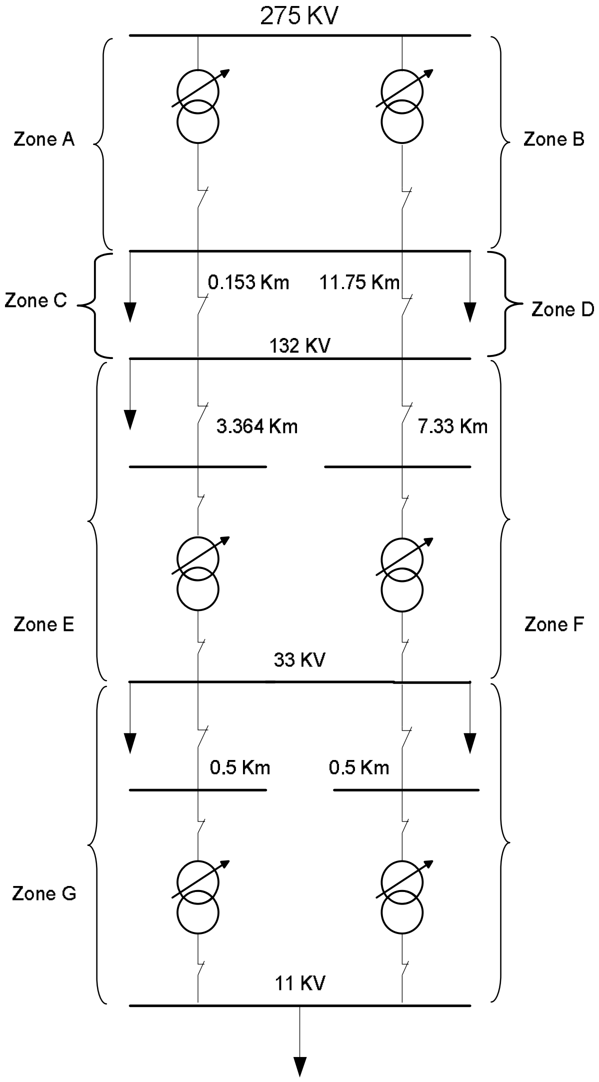

**Fig. 1**: Existing Configuration of Case Study Conventional Network

## 3. Conventional Distribution Network-risk Assessments

### 3.1 Failure rates assumptions

The risk calculation for the conventional distribution network shown in *Fig.* 1 has introduced failure rates for all assets in the network circuits. Using data from [9], the failure rates for all assets in each zone, are listed below in table 2 .

The average failure rating for conventional cables and transformers, which is shown in table 2, is taken from [9]. These numbers have been assumed based on the historic events of failure ratings for cables and transformers from real networks. More information is presented in [9].

**Table 2**: Failure Rates for Conventional Network Elements.

| Asset Category | Failure Rate |
|---|---|
| 132/33kV OHL (per meter) | 0.0320 |
| 132/33kV UG (per meter) | 0.0376 |
| 132/33 kV CB | 0.0303 |
| 11 kV CB | 0.0259 |
| 132/33/11 kV Transformer | 0.0276 |
| All ancillary assets, per Transformer | 0.0448 |

### 3.2 Calculation methodology of the conventional distribution network

The calculation methodology is adopted from [9]. The risk level of the conventional network case study has been achieved in 7 steps. These steps are provided as follows.

- **Update the failure rates to each zone**

With reference to the assets listed in tables 1 and using the failure rates in table 2, an overall failure rate for zone A can be calculated.

The calculation of the average failure rate in zone A depends on the calculation of the total average failure rates for all equipment in that zone. Thus, the total average failure rate in zone A consists of an average failure rate for one transformer 275/132kV with all associated ancillary assets added to the average failure rate for 132kV CB as shown in table 2. In the same way the overall failure rate for all zones has been calculated. The new failure rates are given in table 3

**Table 3:** New Failure Rates for Case Study Zones

| Zone | A | B | C | D | E | F | G | H |
|---|---|---|---|---|---|---|---|---|
| Failure /year | 0.103 | 0.103 | 0.005 | 0.376 | 0.24 | 0.37 | 0.147 | 0.147 |

- **Estimated proportion of failures**

The percentage of proportional failures made in the present study is as follows, based on the degree of geographical and electrical proximity between circuits under normal operation [9].A fault in zone A has a 15% chance of being followed by a fault in zone B before A is restored and a negligible chance of being followed by fault in zones C and D. In the same way, the assumptions relating to the percentage of proportion of failures for all zones have been achieved and they are provided as follows.

A→B, B→A, C→D, D→C, E→F and F→E=15%

- **Calculating the probability of power failure for customers**

The calculation of the probabilities of customers losing power supply has been undertaken based on the previous step. Should (n-1) failure occur in any zone in the network, power will still be delivered to all customers, here n is numbers of elements. For example, (n-1) failure in zone A will not result in loss of supply power for any customers in the network because zone B will maintain customer supplies. However, an (n-2) failure in any part of the network will result in a loss of supply power for customers. The results of this step have been calculated as shown in table4.

**Table 4**: Probabilities of Customers Losing Power Supply

| Event | Failure rate |
|---|---|
| Loss of A only | 0.087 |
| Loss of B only | 0.087 |
| Loss of both zones A & B | 0.0309 |
| Loss of C only | 0.0042 |
| Loss of D only | 0.32 |
| Loss of both zones C & D | 0.057 |
| Loss of E only | 0.204 |
| Loss of F only | 0.32 |
| Loss of both zones E & F | 0.092 |
| Loss of G only | 0.126 |
| Loss of H only | 0.126 |
| Loss of both zones G & H | 0.044 |
| Losing supply power to all customers | 1.5 / a year |

- **Calculation of the repair cost (RC)**

Assuming an average unit cost of £20k per repair (RC), the expected cost of repairs with the present configuration of conventional network is given by:

$$RC = £20{,}000 \times 1.5 = £30{,}000 \text{ per year}$$

The number of average unit cost is assumed based on three assumptions: life time for equipment, direct cost of equipment and average value of repairing cost in the network. Life time for equipment is the cost life of equipment. For example, if an overload happens for the transformer, then the life time of it will be the cost money. Therefore, £12k is assumed to cover the cost life part for equipment in the whole network per repair. Direct cost of equipment consists of the cost of facilities which are used to repair the faults in the network such as people and the price of replacing new equipment, for example, circuit breakers. Thus, £6k is assumed to address the direct cost of equipment in the network per repair. A total of £2k is assumed to be the average repair cost. As a result, the average unit cost per repair in the network is the total of life time for equipment, direct cost of equipment and the average value of a repair cost in the network which is £20k per repair. More information is represented in detail in [9].

- **Calculation of the customer interruptions (CI) costs**

Assuming a unit CI cost of £5, and based on customer numbers in network:

CI=0.22 × £5 × 8,000 (customers)=£8,800/ year

- **Calculation of restoration time (RT) and the customer minutes lost (CML) costs**

Based on the restoration time (RT) assumptions in [9], the average restoration time in minutes for customers at low voltage following an EHV fault can be calculated as follows.

CML=0. 22 × £10 × 8,000 × 0.8(hour per events)=£14.1k / year

- **Calculation of total network risk (TNR)**

Total network risk is obtained as follows.

TNR=RC + CI + CML

TNR=£8,800 + £14,100 + 30,000=£52.9k / year

## 4. Superconductor Case study Network

Fig. 2 shows the superconductor case study network which has been used in [8]. However, the superconductor network has been simplified to fit with the case study as shown in Fig. 2. The network introduces the relevant 33 kV circuits such as circuit breakers (CBs) for cables and all associated ancillary assets for transformers. The configuration of a 33kV superconductor distribution network has been classified into four zones to introduce the network configurations with all relevant 33kV circuits and all transformers with all associated ancillary in more detail. Table 5 indicates details of the 33kV superconductor distribution network configurations with all relevant 33kV circuits and all transformers with their associated ancillary.

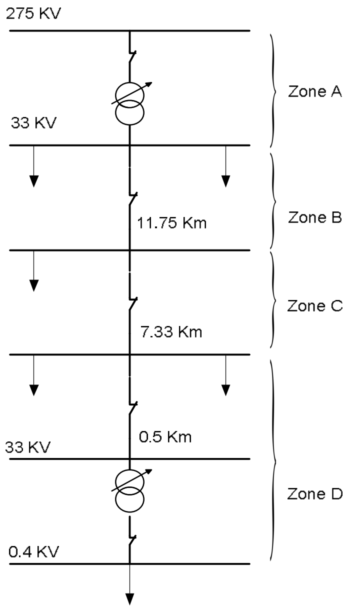

**Fig. 2**: 33KV Superconductor Network Circuits.

**Table 5:** All Relevant 33KV Circuits and Associated Ancillaries of Transformers in a 33KV Superconductor Distribution Network

| Zone | Assets |
|---|---|
| A | One transformer 275/33kV with all associated ancillary assets and 33kV CB and one 33kV CB |
| B | 11.75km of 33kV UG and one 33kV CB. |
| C | 7.337km of 33kV UG and one33kV CB |
| D | 0.5km UG cables, one transformer 33kV/0.4kV with all associated ancillary assets, one 33kV CBs and two 0.4kV CBs |

## 5. Superconductor Distribution Network-risk Assessments

### 5.1 Failure rates assumptions

The superconductor network risk calculation has been introduced based on the failure rates for all assets for network circuits. Failure rates for all assets in each zone are listed below in table 6; this includes failure rates for refrigeration systems for HTS equipment [10].

**Table 6**: Failure rates for superconductor network elements.

| Asset Category | Failure Rate |
|---|---|
| 132/33kV OHL, per meter | 0.0320 |
| 132/33kV UG, per meter | 0.0376 |
| 132/33 kV CB | 0.0303 |
| 11/0.4 kV CB | 0.0259 |
| 132/33/0.4 kV transformer | 0.0276 |
| All ancillary assets, per TX | 0.0448 |
| Refrigeration systems | 0.3700 |

### 5.2 Calculation methodology of the 33 kV superconductor distribution network

The same methodology has been used to calculate the risk level in the superconductor case study network using failure rates which are given in table 4. However, there is an additional failure rating which must be added to each HTS cable and transformer, which is the refrigeration system failure rate as shown in table 4[10].A fault in zone A has a 100% chance of being followed by a zone B fault. In the same way, the assumption of event probabilities of losing customers for all zones is provided below

B→ 100% , C→100% and D→100%

Calculating the event probability of power loss for customers has been undertaken on the same basis as for the conventional network. Should (n-1) failure occur in any zone in the network will result in a loss of supplying power to all customers. This step has been calculated and the results are given in table 7.

**Table 7**: Probabilities of Customers Losing Power Supply.

| Event | Failure Rate |
|---|---|
| Loss of A only | 0.103 |
| Loss of B only | 0.442 |
| Loss of C only | 0.276 |
| Loss of D only | 0.15 |
| Loss of E only, for refrigeration systems | 0.37 |
| Total/year | 1.34 |

This study provides the evaluation of risk studies for the future 33kV superconductor distribution network. Consequently, the projected prices for HTS technologies have been used in this step to predict the future cost of repairing the 33kV superconductor distribution network. The reason for assuming an average unit cost of £20k per repair of the superconductor case study network, which is the same average unit cost per repair of the conventional case study network, is because the price of 33kV cables is likely to be the same or slightly lower than conventional cables in the future [8,11]. However, the average unit cost in the present for repairing the 33 kV superconductor distribution network design is likely to be very high, compared to the average unit cost for repairing the existing conventional distribution network design, because the present price of superconductor technologies is up to 8 times greater than the present price of conventional equipment [1,2,8,11]. Consequently, assuming an average unit cost of £20k per repair, the expected cost of repairs with the superconductor case study network is given as follows.

$$\text{CR} = £20{,}000 \times 1.34 = £26.8\text{k / year}$$
$$\text{So CI} = 1.34 \times £5 \times 8000 = £53.6\text{k / year}$$
$$\text{And CML} = 1.34 \times £10 \times 8000 \times 0.8 = £85.7\text{k/year}$$
$$\text{Therefore, TNR} = \text{CR} + \text{CI} + \text{CML} = £166.2\text{k/year}$$

These results showed that a 33 kV superconductor network design proposed in figure2 results in much higher levels of risk than the present conventional distribution network design, which is approximately 3 times more than conventional distribution network design which is shown in Fig. 1. Thus, a novel approach to designing a 33 kV superconductor distribution network is required to facilitate lower risk levels.

## 6. New 33kV Design for a Superconductor Distribution Network

The need for a new design of 33 kV superconductor distribution network has been identified in [8]. The proposed new design of a 33 kV superconductor distribution network incorporates a conventional distribution network to reduce the risk level in the 33 kV superconductor distribution networks as shown in Fig. 3. Normal Open Points (NOP) forms a key component of this network. During normal operation, NOPs are open and all network demand will be supplied solely by the 33 kV superconductor distribution network. Should a fault occur in any zone in the 33 kV superconductor distribution network, one of NOPs will close and activate the conventional distribution network to maintain power supplies for all customers in the network. Based on Fig. 3, the fault zones are categorized into four zones: A, B, C and D. When there is no fault at any part of 33 kV superconductor distribution network, all demands in the network will be supplied by only the superconductor distribution network by keeping all NOPs open. However, when one of the categories faults in any part of superconductor network, then the conventional distribution network needs to be operated using NOPs to keep supplying all loads in the superconductor distribution network. Operating NOPs (on or off) relies on faults occurring in 33 kV superconductor distribution network.

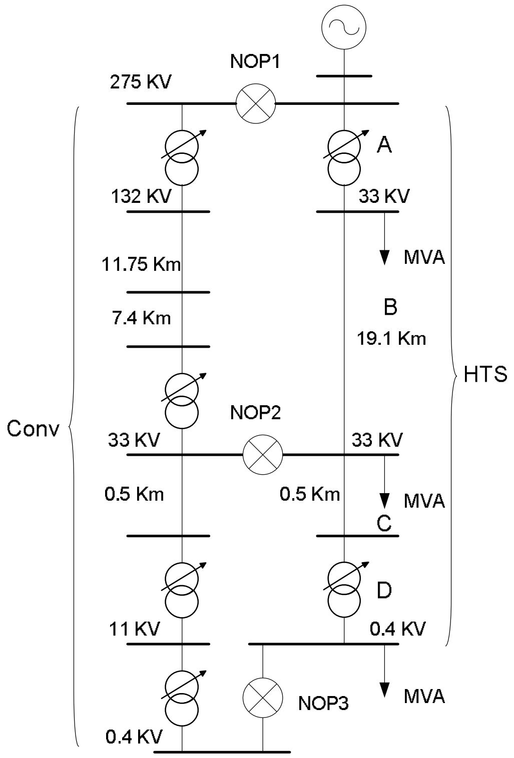

**Fig. 3**: The Superconductor Case Network Study

## 7. New 33 kV Design of Superconductor Network-risk Assessments

The same assumptions for failure rates for HTS technologies have been used with this network as shown in tables 3 and 4. However, the risk assessment of conventional distribution networks needs to be included because a fault occurs in the superconductor network should to maintain power delivery to all customers.

### 7.1 Calculation of event probability of customers losing power

The same calculation for a 33 kV superconductor distribution network is used which was obtained from Fig. 2; therefore the same result for this step is used which is 1.34 per year.

### 7.2 Calculate RC cost

The same result is obtained from this step because RC has been done on the superconductor distribution network only, so:

RC=£20,000 × 1.34=£26.8k per year

### 7.3 Calculation of CI cost

Assuming a unit CI cost of £5, and based on customer numbers of 8,000 over the whole network the same percentage for event probabilities of losing customers in conventional distribution network has been used, which is 0.15 %, in this calculation. Thus, the CI cost calculation is given by:

CI=1.34 × 0.15 × £5 × 8,000=£8.2k / year

And CML=1.34 × 0.15 × £10 × 8,000 × 0.8=£12.9k per year. So CML=£47.7k / year.

## 8. The Power Losses Comparisons

Table 7 compares power losses between the existing conventional distribution network and the new 33 kV superconductor distribution network design during different fault operations at peak demand.

**Table 7**: The Power Losses Comparisons

| **New 33 kV design of Superconductor network** | | | | **Existing design of Conventional network** | |
|---|---|---|---|---|---|
| **Fault A or B** | | **Fault C or D** | | | |
| P (MW) | Q (MVArs) | P (MW) | Q (MVArs) | P (MW) | Q (MVArs) |
| 1.9 | 4.4 | 0.3 | 0.4 | 2.2 | 4.9 |

Based on results, the total power losses in the new 33 kV superconductor distribution network design (Fig. 3) were less by 30% than the conventional distribution network (Fig. 1) even during fault operations. The reason for the increased real power losses during faults in zones A or B is because the majority of the conventional distribution network was operated to share.

The future design of the 33 kV superconductor distribution networks, which is shown in Fig. 3, has proved that the risk level and power losses could be lower than the risk level and power losses in the existing conventional distribution network as shown in Fig. 1. However, the capital cost of these designs needs to be introduced to find out whether the capital cost of the new design will be less than the existing conventional distribution network in the future.

## 9. Capital cost comparisons

Based on cost prices for HTS technologies in [8, 11], the capital cost for the proposed new design of a 33 kV superconductor distribution network (Fig. 3) in the future shows as follows.

- Capital cost=the capital cost of conventional network + the capital cost of 33 kV superconductor distribution network when superconductor material ( BSCCO / Bi-2 223) is 6.4 £/kAm=23.3 + 20.1=£43.4M.
- While the cost of the existing conventional distribution network (Fig. 1) is equal £46.6 M.
- If the whole network adopts this new design that was presented in [3], the capital cost of a 33 kV superconductor distribution network will be as follows:
- Capital cost=61.7 + 78.1=£139.8M when superconductor material ( BSCCO / Bi-2 223) is 6.4 £/kAm
- While the capital cost for whole current design of the conventional network is £156.6M.

## 10. Conclusion

This paper has introduced a novel future design of 33kV superconductor distribution networks which can result in lower power losses, lower risk levels and lower capital cost than the existing conventional distribution network designs. The future 33kV superconductor network (without applying a hybrid design), proposed in Fig. 2, gives a risk levels approximately 3 times higher than the present conventional distribution network design of Fig. 1. The risk level in the new design of Fig. 3; a 33kV superconductor distribution network, with applying a hybrid design, can be reduced by £5.8k events per a year from the risk level occurring in the present conventional distribution network design. Implementing a new 33kV superconductor distribution network design could save £16M from the capital cost of the current conventional network design. This paper has shown that HTS assets have the opportunity to reduce power losses, risk levels and capital costs in distribution networks in 2030.

## References

[1] A. P. Malozemoff, "The new generation of superconductor equipment for the electric power grid," Applied Superconductivity, IEEE Transactions on, vol. 16, pp. 54-58, 2006.

[2] Z. Han and X. Hu, "Power application of superconductivity technology in China," Superconductor Science and Technology, vol. 19, p. S109, 2006.

[3] M. Elsherif, P. Taylor, and D. Hampshire, "Investigating the Impact of High temperature Superconductor Cables on Electrical Distribution Networks ,"In International Conference on Energy Systems and Technologies (ICEST 2011), pp. 11-14, 2011.

[4] C. Matheus, H. J. Haubrich, and D. Willen, "Superconducting cables as a new option in network planning," in Power Tech, 2005 IEEE Russia, pp. 1-7,2005.

[5] C. Matheus, H. J. Haubrich, D. Willen, W. Heuken, and R. Fischer, "Industrial distribution networks with superconducting cables," in Future Power Systems, 2005 International Conference on, pp. 6 pp.-6,2005.

[6] D. Willen, C. Matheus, D. Lindsay, and M. Gouge, "The application of triaxial high-temperature superconducting power cables in distribution networks," in Electricity Distribution, 2005. CIRED 2005. 18th International Conference and Exhibition on, pp. 1-4,2005.

[7] L. Ren, Y. Tang, J. Shi, L. Li, J. Li, and S. C. Cheng, "Techno-Economic Feasibility Study on HTS Power Cables," Applied Superconductivity, IEEE Transactions on, vol. 19, pp. 1774-1777, 2009.

[8] M. Elsherif, P. Taylor, and S. Blake, "Investigating the potential impact of superconducting distribution networks," in Electricity Distribution (CIRED 2013), 22nd International Conference and Exhibition on, 2013, pp. 1-4.

[9] S.Blake, "Methodologies for the evaluation and mitigation of distribution network risk," PhD, School of Engineering and Computing Sciences, Durham University, 2011.

[10] Y.Zhang ; F.Li ; W.Yuan," Economic analysis of interconnected distribution substations vis superconductor cables," Power and Energy Society General Meeting, 2012 IEEE, p 1-5, 22-26 July, San Diego, CA, 2012.

[11] M.Elsherif, "The application of superconducting technologies in future electrical power systems," PhD, School of Engineering and Computing Sciences, Durham University, 2013.

## Biographies

**Mustafa Elsherif** was born in Misurata /Libya, on September 5, 1981. He received Bsc degree in Electrical and Electronics from University of Sirt, in 2003. He got Msc degree in Cybernetics and Communications from Nottingham Trent University /UK in 2007. Moreover, he got PhD degree in Electrical Power Systems from the Durham University/UK in 2013, where he is currently lecturer in Department of Electrical and Electronics Engineering (EEE) at University of Misurata/Libya. His research field is applied superconducting technologies into power distribution and transmission systems.