Superconductor based Power Distribution

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1 Motivation

One of the major concern of power companies in the present time is the loss on electrical power in the supply process. Present day's electrical connections in cities use aluminium wires. These wires cause a high power loss of around 740 kW/km due to higher electrical resistance[1]. Also the aluminium wires have to be carefully cleaned to remove the aluminium oxide. Even better conductors like copper cause a significant power loss. The environmental impact in term of CO2 emission in the manufacturing process of aluminium wires is 778 ton C/Km/year. It is highly desirable to remove the existing aluminium cables with some superconductor wires such that power loss due to high resistance could be reduced. As global warming is one of the major concern of the world, the alternative for electrical power transmission should also reduce CO2 emission. In early days, the major difficulty with super conductor wires was their critical superconducting temperature. With the discovery of high temperature superconductors in 1986 which could operate at a temperature higher than 67K (temperature of liquid nitrogen), it is possible to use superconductor cables for power transmission. The transmission loss is very less for DC current as compared to AC and it also required less number of cables. With these high temperature superconductors, we propose to transmit DC current in the main lines and which can be further converted to AC depending on the individual requirement. In this proposal we present the potential of replacing the existing aluminium power lines with high temperature superconductor YBCO cables[2] in the city of Chandigarh. Since the superconductor cables are much costlier than the traditional copper and aluminium wires and required to be maintained below a certain temperature, checking the economic viability of the same should be checked and it is important know the time period over which the establishment cost is compensated by the reduced loss of power.

2 Blue Print

2.1 High Temperature Superconductor Wire

Superconductivity is a phenomenon where the resistance of some material is made zero by cooling it. High Temperature Superconductor (HTS) was discovered in 1986. Superconducting cables have been developed where coated conductors of YBCO wires are used. This results in low loss and low cost for a power cable. YBCO wire, often called a coated conductor, can be used for carrying AC current in a superconducting cable. In these circumstances, hysteresis becomes important in determining the resulting AC loss. This consequently causes unnecessary load on the cooling system.

2.1.1 Structure of a single YBCO tape

On the base substrate, there's an intermediate layer of some insulating material. This is followed by a superconducting layer of YBCO, which has minimal thickness. In case of current flow exceeding the critical current, the YBCO wire will burn out due to heating. To prevent such short high current pulses from causing accidents, an additional layer of silver and copper is laminated. To prevent AC losses, multiple such wires are closely wound around a cylinder, as AC loss results from large magnetic field perpendicular to the edge.

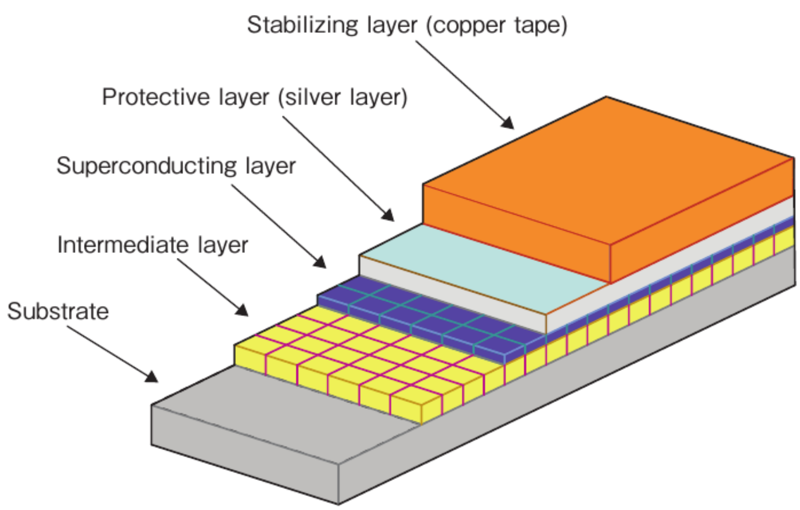


Figure 1 Structure of YBCO tape.

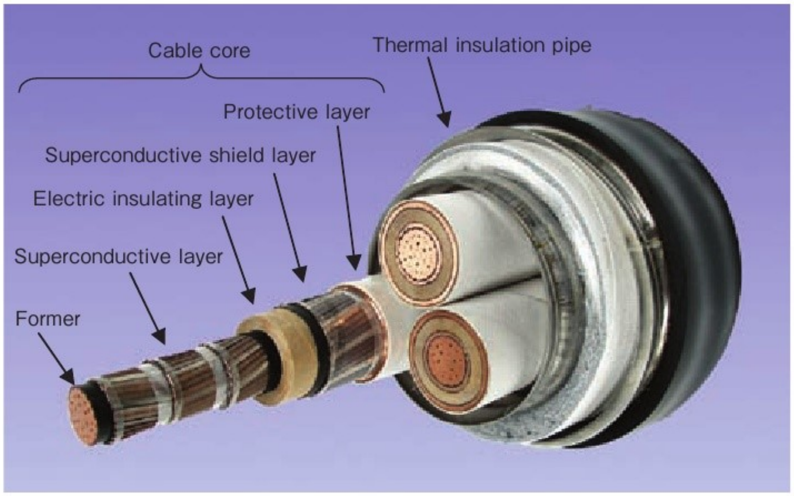
2.1.2 Cutting of the YBCO Tape

For cutting the YBCO tape, laser methods are available. They have been reportedly efficient enough to cause a minimal degradation in the critical current

(2-5%).

2.1.3 Structure of a usable 3 phase wire

A current insulating layer is added to a single YBCO wire. Three these are assembled to create a 3 phase wire. They are enclosed in a larger cable through which liquid nitrogen flows, to maintain low temperature. The diameter of the duct cable is 150 mm. The maximum transportable length of wire is 500 m. Tests have been performed on a 20 m long wire, with a joint at 10 m.



2.2 Small scale experiment

We plan to set up a small scale test of our experiment on some existing power line. Basically, we located a 11KV power line and then plan to implement our model there (near Aiyappa Temple, Dilshad Garden, Delhi), for which we require permission from BSES Delhi. We chose Delhi because we had our model town as Delhi from where we got all the data for the length of 11kv lines as well as other specifications. We can perform our tests there on the 200 m range where we would place 2 pumps and can easily see whether we can get the desired results of our transmission and also we can measure all the costs and see the pros and cons of our experiment.

3 Cost Estimate

3.1 Estimated Loss in the current distribution

The cost involved in laying the power transmission lines is estimated for the city of Delhi.

1. Rate of laying a kV lines $(= b)\, 6.59 \times 10^5$ Rs/Km
2. Length of a kV lines $(= d)\, 6520 \times 10^6$ Km
3. Now the laying cost is simply $= db = Rs.\, 2.572077 \times 10^9 \sim Rs.\, 200$ crore rupees

Running Cost was estimated by finding the current flowing through the wires and calculating the resulting power loss due to joule heating. The current flowing through the wires was found indirectly by using the capacity of the distribution power stations $(= c)$ connected by these wires. The running cost was calculated as below

1. Power line voltage $= a = 11 \times 10^3$ V
2. Distribution Transformers' total capacity $= c = 6520 \times 10^6$ VA
3. Maximum current flowing through all the three wires combined $= i = c/a = 592.73 \times 10^3$ A
4. Running Cost$=$ $i^2\rho\left(\frac{d}{A}\right)t = 4.44 \times 10^{15}t$ Joules (=Ws) which for 3.90 Rs./kWh becomes $= 4.81 \times 10^9 t \sim 481t$ crore Rupees, with t in hours (where $A = 100mm^2$ and ρ has been evaluated from the specification of the a V lines, viz. '11kV overhead line with 'DOG' (100 mm^2 ACSR on PCC)'.)

3.2 Estimated Installation Cost of Superconducting distribution

We are still awaiting quotations for pipes and the cooling system. However, we have a quote for the superconducting wire, \$250 to \$400/A-m which we've been told will drop as we get closer to finalizing the requirements. If we evaluate the price using just the numbers for the superconducting cable we'll have (with 1\$˜Rs. 60, cost of wire as \$300/A-m), Rs.$6.96 \times 10^{19}$for the model discussed in the previous section. The corresponding time to recover the cost would then be $1.6509 \times 10^6 \sim 1.6$ million years. This although is a little overwhelming, can be reduced significantly if as is expected, the wire cost is reduced in the near future. Thus, it is anyway suitable to start perfecting the techniques.

4 Implementation Phases

1. We first of all plan to set up the small scale experiment which was described earlier.
2. The next phase of our project is to see if the small scale experiment is properly implemented or not and if implemented we can go directly to the next phase. If there are some cons then we would try to rectify them and proceed again to repeating the first step until the defects are corrected.

3. With the help of BSES Delhi, if we can convince them of the benefits of such a project, we can implement our plan for replacing the overhead 11kv lines with our high temperature superconductor lines and as a result we can practically realize our project.

5 Reference

- www.forumofregulators.gov.in/data/study/capital-cost-branchmark.rk
- www.bsesdelhi.com/HTML/wb-bsesatagiance.html
- YBCO_wire (paper) Author: The Furukawa Electric Co.; Ltd.
- [1] M. HIROSE, T. MASUDA, K. SATO, R. HATA, High-Temperature Superconducting (HTS) DC Cable. **SEI TECHNICAL REVIEW 2006, 61, 29**.
- [2] S. Mukoyama, M. Yagi, H. Hirata, M. Suzuki, S. Nagaya, N. Kashima, Y. Shiohara, Development of YBCO High-Tc Superconducting Power Cables. **Furukawa Review 2009, 35**.