Eskom's proposed strategic research into HVDC transmission

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Eskom has recently started a large research and development programme for the study of long-distance HVDC transmission in Sub-Saharan African conditions. This paper explains why the research is being done, what its strategic context and technical scope are, how it is being managed, and the progress made so far.

In particular, it is explained why the primary focus of the research is, firstly, on the provision of basic scientific data (concerned with high altitude and corona effects), and secondly, the verification of key electrical design parameters of transmission lines intended to operate in the 800 to 1000 kV range. (The emphasis is not on the convertor plant at this stage.) The human and laboratory resources needed for the programme are also reviewed.

This paper explains the background and technical scope of the HVDC research programme recently started by Eskom. The programme is generic in that it addresses the technical issues associated with the design of long-distance HVDC transmission lines for Sub-Saharan African conditions. The requirements of the proposed Westcor Project are not explicitly considered. However, the programme will attempt to pre-empt the technical needs of Westcor and other possible regional HVDC schemes by providing the scientific information on which these, and other projects, can draw. It is expected that with this approach, Eskom and South Africa will be well positioned to contribute effectively to the design and construction of long HVDC lines (probably at ±800 kV) in Southern Africa. The research will also, it is hoped, contribute new insights and scientific knowledge to the design and operation of long-distance, high altitude HVDC lines. The topics of convertor plant technology, power quality and system dynamics are not dealt with here. Nonetheless, the research team will liaise closely with specialists and equipment vendors in these fields. This is to ensure that the Programme remains technically well aligned and at all times relevant.

Strategic background

The urgent need for Eskom to expand its internal generation capacity, and also to acquire reliable externally generated power, form the strategic backdrop to this research. The re-commissioning of Eskom's mothballed coal-fired power stations will yield an additional 3600 MW of generation by 2011. As this will not meet the predicted electricity demand of the South African grid in the next 10 years (at the present growth rate of 3 to 4%), Eskom is investigating, amongst other local and regional options, the importation of hydro-electric power from Inga and additional power from Cahora Bassa [1,2,3].

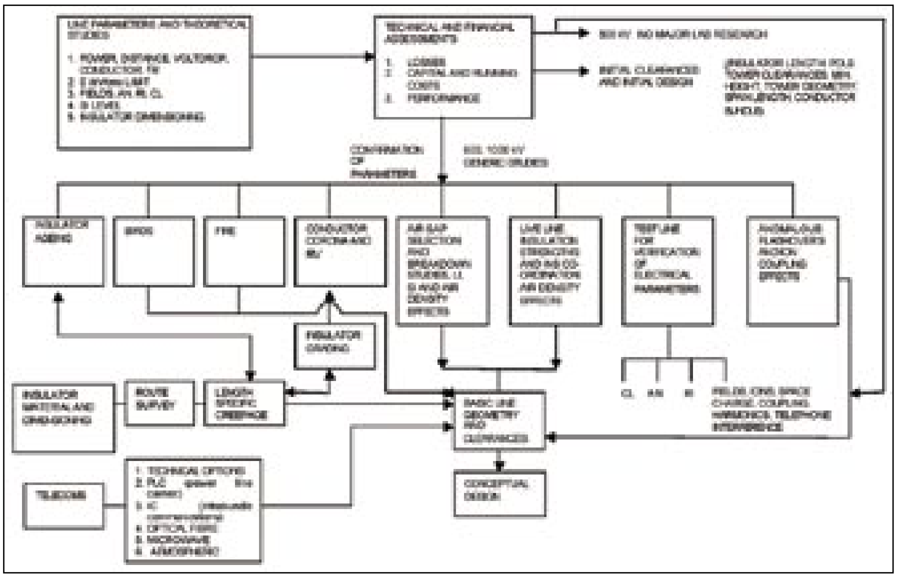

Fig. 1: HVDC Line research and design processes

Initial feasibility studies show that, as regards Inga, an ultimate level of 6000 MW will have to be transported over 3000 to 4000 km to meet local and regional needs by 2012. This can only be done economically by point-to-point or multi-terminal HVDC transmission at ±800 kV at least [4, 5]. A possible alternative is the 50 Hz half-wavelength HVAC line concept, but the feasibility, or otherwise, of this option has not yet been evaluated in a Southern African context [6,7]. The first stages of the Westcor project will make use of ±500 kV (an established voltage and technology), and thereafter ±800 kV or higher. Because of particular local conditions, both voltages will require research - of a verification nature - to be undertaken. The scope of this work is explained in the following sections.

The need for the research and related policies

Why is a major local research programme being undertaken at this time? It could be countered that the extensive worldwide experience with HVDC schemes and the large amount of research done by EPRI, Cigré and Hydro-Québec obviate the need for Eskom to do its own research [4,5,8,9,10,11,12,13,14]. As the highest operating voltage anywhere is presently ±600 kV, the proposed voltage of ±800 kV could not be adopted without rigorous theoretical and laboratory study. This is particularly so, because of the influence of the following design and operational factors:

- The required voltage of ±800 kV, not so far used operationally.
- Optimisation or minimisation of the conductor power losses on lines of 3000 to 4000 km long.
- The influence of altitude in the range of 1200 - 1600 m above sea-level on the insulation strengths of basic air gaps.
- The influence of altitude on conductor and insulator corona.

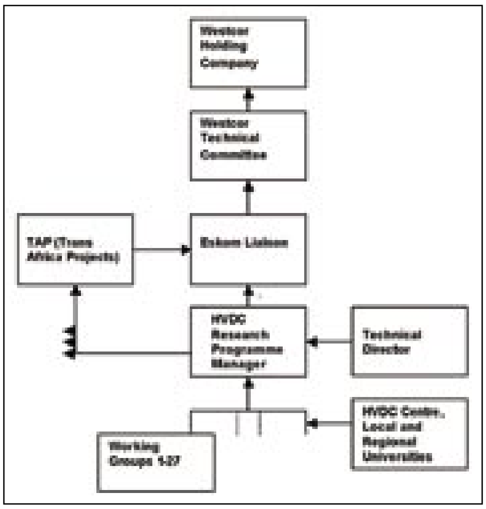

Fig. 2: Basic management structure for the HVDC research project

- Insulation in tropical and sub-tropical environments (particularly insulator pollution, fires and bird streamers).
- Lack of experimental confidence in the scaling up of insulator stresses to ±800 kV; this applies to both ceramic and non-ceramic types.
- The possible deleterious influences of enhanced space charge and ion clouds on insulation strengths at ±800 kV; this also applies to live working.
- Development of compacted and flexible supporting structures for monopolar and bipolar options.
- Safety of bare-hand live working at ±800 kV, this also combined with the effects of reduced air density.
- The degree to which DC pre-stress (at least up to ±800 kV) will increase the switching impulse strength of air gaps with clearances = 5 m.
- Assessment and choice of technically and economically feasible telecommunications technologies.
- The performance and reliability of power line carrier on long lines subject to high levels of corona and atmospherically induced noise.

On most of the above topics, only limited research has been done, anywhere in the world. What is significant for the practicability (and credibility) of the Eskom research programme is the finding by Cigré in 2002 that modern convertor plant up to voltages of ±800 kV is technically feasible and implementable [11]. This was also confirmed at the Eskom HVDC Workshop held in Johannesburg in 2004 and the recent EPRI HVDC Workshop held in India [15,16]. Extensive studies of published information on the design of HVDC lines (at voltages above ±400 kV) are already being done, amongst others, in [5,8,9,10]. Laboratory research will only be done in cases where:

Classification	Working group
Basic parameters	1. Voltage selection
	2. Tower configuration line/ pole(s) configuration and associated supporting structures
	3. Electrical characteristics of long HVDC lines
	4. Optimisation of the conductor cross-sectional area
Corona and interference	5. Conductor corona
	6. Corona losses
	7. Radio interference and RIV
	8. Audible noise
	9. Field effects (electric and magnetic fields, ions, etc)
	10. Telephone interference
	11. Power line carrier noise
	12. Conductor surface gradient on shield wire
Insulation	13. Lightning and switching surge performance
	14. Insulation co-ordination
	15. Insulators and insulator pollution
	16. Live-line working and insulation co-ordination
	17. Voltage and current uprating
	18. Anomalous flashovers in clear conditions
	19. The effects of fire on line insulation
	20. The effects of bird streamers on line insulation
	21. Performance of HBDC lines
Telecommunications	22. Telecommunications technologies
	23. Power line carrier system design
	24. Antenna characteristics of long HVDC lines
Other	25. Characteristics of long DC arcs
	26. Selection and design of local HVDC test facilities
	27. Conversion of AC lines to HVDS operations
	28. Training/selection of tchnical personnel needed

Table 1: Technical working groups

- essential technical information is not available
- verification of final or possible line designs is necessary

It is stressed that laboratory research will not be done because it is "nice to do," but will be carried out only in cases where it is technically essential. However, a cornerstone of Eskom's research and design policy here is that local, full-scale verification tests will be done to confirm likely design parameters. Hence, there is a need for affordable local laboratory facilities to be created; this will be done by upgrading existing laboratories. Local research will also help to develop and maintain critical technical skills. The use of foreign facilities and consultancy services will, where appropriate, also be considered.

Technical scope of the research and design studies

Fig. 1 shows the overall technical scope of the research programme, together with the relationships between the various topics. The flow chart in essence classifies the parameters to be evaluated and steps to be taken in arriving at conceptual designs for long distance ±500 and ±800 kV (or higher) HVDC lines. This process is a combination of inter-related research and design studies.

The initial review of the electrical parameters of selected HVDC lines (see Appendix) serves as an introduction to the design process. In particular, the complex inter-relationships between voltage, conductor selection, current density, dielectric and corona parameters are seen.

Management of the research

The Programme is managed from within the Resources and Strategy Division of Eskom, and is structured as shown in Fig. 2.

The Technical Working Groups (presently 28), which make up the core of the Programme, are listed in Table 1 below. Each is managed by a Project Leader. The HVDC Research Programme Manager is responsible for the overall co-ordination of the activities of the Technical Working Groups, the HVDC Centre and in time, the South African Universities. It is planned that the Programme will complete the bulk of its work within 4 years, namely, by early 2009.

The cost of the Programme is R40-million and will be borne by Eskom.

It should be noted that Working Group 27 does not deal directly with regional long distance HVDC transmission, but it does have a lot in common with the various insulation topics, in particular. (This topic covers the possible conversion of certain of Eskom's 400 kV AC lines into HVDC or hybrid AC/DC lines.) Consolidation of the Working Groups into a more manageable number will take place.

Local laboratory resources

One aspect critical to the envisaged HVDC Research Programme will be adequate, local laboratory resources. South Africa presently has a number of high voltage laboratories, mainly catering for HVAC and some HVDC studies. These laboratories or facilities are located at the following sites:

- HVDC Centre (University of KwaZulu-Natal, who already have an HVDC research programme and test facility).
- University of Stellenbosch (limited HVDC capabilities).
- University of the Witwatersrand (limited HVDC capabilities).
- National High Voltage Test Facility (NETFA) (presently no HVDC capabilities).
- Corona Cage at Megawatt Park (presently no HVDC capability).

Because the programme is in the national interest, the thrust will be to exploit all the above facilities, in the following ways:

- The Universities' role will be to carry out fundamental, small-scale studies. In order to facilitate this, the HVDC Centre at UKZN may acquire an additional HVDC source to augment their existing ±500 kV (10 mA) HVDC generator. The facilities at both Witwatersrand and Stellenbosch Universities will probably remain unchanged. Postgraduate students, as well as Eskom personnel, will do this work.
- NETFA will be used for full scale testing, including the verification of studies undertaken at the Universities. Although NETFA at present has no HVDC capabilities, a test source with a rating greater than ±800 kV may be acquired for the proposed activities. This test source will be used in conjunction with NETFA's existing test equipment (impulse generator) and infrastructure for the proposed activities. It is also proposed to build a 1 km bipolar test line at NETFA. Eskom personnel will do the required research and testing together with NETFA staff.
- The Corona Cage will be used for measuring and confirming the HVDC corona parameters of conductor bundles and line hardware. This work will be done mainly by Eskom staff and postgraduate students.

Some studies, in particular, the insulator pollution work, require a ±1 MV test source of at least 2 A and dedicated clean and salt fog chambers. Due to the high cost involved, these studies will be done at a suitable test facility overseas. In doing so, transfer of skills to Eskom personnel will form part of any contract. The above approach will ensure that duplication of effort and facilities will be avoided, and that the research activities complement each other. Various regional universities are being invited to join the Programme, particularly those in the countries participating in the Wescor project. This will help to ensure that specific local factors are considered in the research.

Concluding remarks

The following observations are made:

- The paper reveals and elucidates details of a major strategic research Programme, one of national and regional importance.
- The research will provide a mix of design-oriented data and generic scientific information.
- As the transmission voltages of interest are above the present operational limit of ±600 kV, the research will be pioneering, especially given the combined influences of long distances, high power levels, high altitudes and environmental factors.
- Close technical liaison with the vendors of convertor plant will be essential in ensuring the overall relevance and success of the Programme.
- The various local high voltage laboratories will require some degree of upgrading, so as to enable research in the ±1000 kV range to be done.
- Eskom, the HVDC Centre, the Universities and South Africa as a whole possess the technical skills and experience to undertake the research. This will contribute strongly to the maintenance of a local pool of sustainable expertise in HVDC design and technology.
- There is every expectation that the programme will contribute meaningfully to the development of viable long-distance HVDC Transmission Schemes in the Southern African Power Pool (SAPP) and elsewhere.

HVDC SCHEME	Pole Voltage kV	Rated Power MW	Nominal Current A	Line length km	Conductors/pole	Bipolar/monopolar (B,M)	Total resistance Ω pole	Volt drop % of rated	Current density A/mm²	Resistive loss % (max)	Corona loss % (max)	*Gradient kV/cm	Pole/pole stress kV/m	Insulator stress kV/m	Insulator specific creepage mm/kV
Apollo-Cahora Bassa (RSA/Moz)	±533	2000	1876	1440	4	2x M	32,6	5,6	0,7	5,6	0,4	20,6	N/A	106	30 N** 27G**
Inga-Shaba (DRC)	±500	1120	1120	1691	3	2x M	92,3	7,0	0,7	7,0	0,6	23,6	N/A	89	34 G
Des Cantons-(Can/USA)	±450	690	767	78	4	B	1,4	0,2	0,5	0,2	0,4	20,6	76	98	33G
Sylmar-Oregon (USA)	±500	3100	3100	830	2	B	17,3	5,4	1,0	5,4	1,0	25,5	82	108-111	22-28G
Henday-Dorsey (Canada)	±500	2000	2000	916	2	B	21,8	4,3	1,5	4,3	1,1	27,4	67	140	21G
Adelanto-Mountain (USA)	±500	1600	1600	782	3	B	5,4	0,9	0,4	0,9	1,0	20,0	78	108-74	28-30P**
Itaipu (Brazil)	±600	6300	5250	800	4	B	14,5	6,4	1,7	6,4	0,3	24,9	75	110	28G
Fictitious Long-Distance Design	±800	3000	1875	3000	4	B	93,4	9,8	0,9	9,8	4,4	32,9	100	100	30N
	±800	3000	1875	3000	6	B	55,6	6,5	0,6	6,5	5,6	26,5	100	100	30N
	±1000	3000	1500	3000	6	B	55,6	4,2	0,5	4,2	8,3	31,8	100	100	30N
	±1000	3000	1500	3000	8	B	41,7	3,1	0,4	3,1	7,3	25,6	100	100	30N

Table 2: Parameters of selected HVDC lines

** Refers to maximum conductor surface gradient in kV/cm*

*P**, G**, N**: porcelain, glass, non-ceramic insulators respectively*

- The brief technical review of HVDC line parameters given in the Appendix serves to introduce the subtlety and complexity of the HVDC line design process.

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Appendix: initial review of the electrical parameters of existing HVDC lines

Table 2 lists some of the basic parameters of a selection of modern HVDC lines [9,14,17]. This gives the reader some feel for the associated resistive and corona losses. For comparison, the corresponding parameters of two fictitious, longdistance (3000 MW, 3000 km), ±800 and ±1000 kV bipolar lines are included. Initial comparisons show that the volt-drop and losses on the fictitious ±800 and ±1000 kV lines, with 6 and 8 sub-conductors per bundle respectively, are higher than those on typical examples of short, existing lines. It is here that voltage level, conductor size, number of sub-conductors, corona effects and costs will have to be researched and optimized. This will be based on the complex interaction between overall losses (including corona losses), insulation clearances , corona/field effects and comprehensive Life Cycle Cost analysis.

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