UPRATING OF CABLE CURRENT CAPACITY FOR UTILITIES WHERE LOAD CYCLE PROFILES ARE KNOWN

Author & Presenter: P. Haripersad – Design Engineer of African Cables
Co-author: J. Ehrich – General Manager of Tshwane Electricity

1. Preface

This paper is based primarily on the paper written by the author for the Cigre 2005 Regional Conference [1].

2. Summary

Most Utilities today are faced with increased power demands from consumers and the costs associated with increased capacity can be very high. Cables are often over-rated because they are chosen based on 24 hour continuous operation at 100% load factor. In practice, this is usually not the case as the loading on a cable varies at different times of the day depending on the type of consumer and his demands. For such instances, the cables current capacity can be up-rated by a certain factor such that during this cycle, the conductor reaches, but does not exceed the standard maximum permissible operating temperature. This paper focuses on an international method (IEC 60853-1) [2] for determining such up-rating factors. Several different types of load profiles are analysed. The cyclic rating factors calculated show that the cable current capacities can be increased from 10% up to 40%. This allows Utilities to confidently meet higher power demands without upgrading their entire networks with larger cable sizes in the short term.

3. Introduction

As the population and economy of South Africa grows, more and more consumers are in need of electricity, placing higher power demands on the Utilities. These increased power demands extend from high and low cost residential areas, to schools and offices, as well as to the commercial and industrial areas.

The cost of electrical infrastructure to meet increased power demands can run into millions of rands with Utilities not only having to acquire more power cables and associated accessories, but also more switchgear, transformers, control and protection equipment as well as substations.

One way for Utilities to recognize cost savings and still meet the increased power demands, is to consider the up-rating of their existing assets, in particular, the up-rating of their existing power cables. Cables are often over-rated because they are chosen based on 24 hour continuous operation at 100% load factor. In practice, this is usually not the case as the loading on a cable varies at different times of the day depending on the type of consumer and his demands.

Cables laid in ground may take 24 hours or even longer for the temperature to build up to the steady state operating values on which sustained ratings are based. The temperature rise of the conductor is exponential [3] and hence during sustained loading the temperature change when nearing equilibrium is slow. If the loading is only a maximum for a few hours, or it is at a level below maximum for a longer period, then it is possible to calculate a cyclic rating or up-rating factor for the cable. This paper focuses on an international method (IEC 60853-1) [2] for determining such cyclic rating or up-rating factors.

4. Method for determining cyclic rating factors for power cables

The IEC 60853-1 standard [2] gives methods for calculating the cyclic rating factor for cables up to and including 18/30 (36) kV where the internal thermal capacitance can be neglected. The method has been simplified from a procedure published by Cigre Working Group 02 of Study Committee 21 [4].

The simplified methods in this standard require knowledge of the full shape of the load profile for not more than 6 hours immediately preceding the time of maximum temperature and an average value for times before that. Change in conductor resistance with temperature and the possible effects of moisture migration on the soil thermal resistivity are neglected. For cables in air the conductor temperature rapidly follows changes in load current, and therefore the usual daily cycles do not permit peak loads greater than the steady state value.

As defined by IEC 60853-1 and shown in Equation 1, the cyclic rating factor (M) represents the factor by which the 24 hour continuous current rating (I_o) [5] based on a 100% load factor can be multiplied to obtain the maximum current (I_{max}) during a daily cycle, such that during this cycle, the conductor reaches but does not exceed the standard maximum permissible operating temperature.

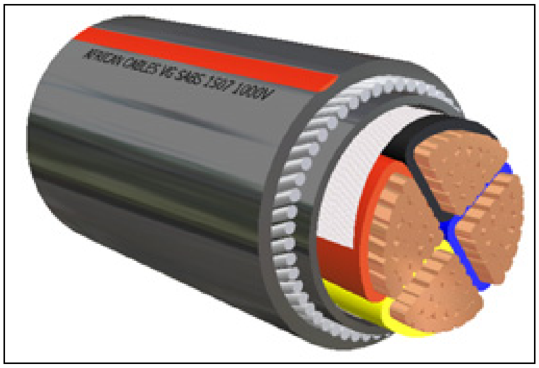
$$I_{max} = M \times I_o \qquad \{1\}$$

The daily load profile is first expressed as 24 hourly values by scaling the whole cycle so that its maximum value is equal to unity. The magnitude of each hourly value is squared to give 24 values representing the cycle of cable joule losses. Thereafter, this curve is expressed as a series of step function changes so as to give a stepped curve having approximately the same average value as the original one. After representing the load cycle profile in this way, the cyclic rating factor (M) can be calculated from the equations stipulated in IEC 60853-1.

5. Calculation of cyclic ratings for known load cycle profiles

Various load cycle profiles from Tshwane Electricity [6] were analysed and cyclic rating factors for a 240mm^2 x 4 Cu, PVC, SWA, PVC, 0.6/1.0kV cable (Picture 1) were calculated. An MS-Excel program [7] was developed to model each load cycle profile and to solve the appropriate equations listed in IEC 60853-1.

Figure 1 to Figure 6 show the load profiles for the areas that were modeled and analysed. Table 1 summarizes the results of the calculated cyclic ratings. The increase in current rating allowed should not cause the conductor to exceed its maximum operating temperature over the 24 hour period. All calculations have assumed that the load profile and soil thermal resistivity remain consistent.



Picture 1:
Typical 240mm² x 4 Cu, PVC, FR PVC, SWA, FR PVC, 600/1000V cable

	Areas, Load Profiles and Calculated Cyclic Rating Factors					
Area Analysed	Medium Industrial	Schools	Commercial	Offices	High Cost Residential	Low Cost Residential
Load Profile	Figure 1	Figure 2	Figure 3	Figure 4	Figure 5	Figure 6
$240mm^2$ x 4 Cu	1.12	1.19	1.19	1.21	1.27	1.40

Table 1:
Summary of calculated cyclic rating factors for load profiles shown in Figure 1 to Figure 6 on a 240mm² x 4 Cu, PVC, 0.6/1.0kV cable

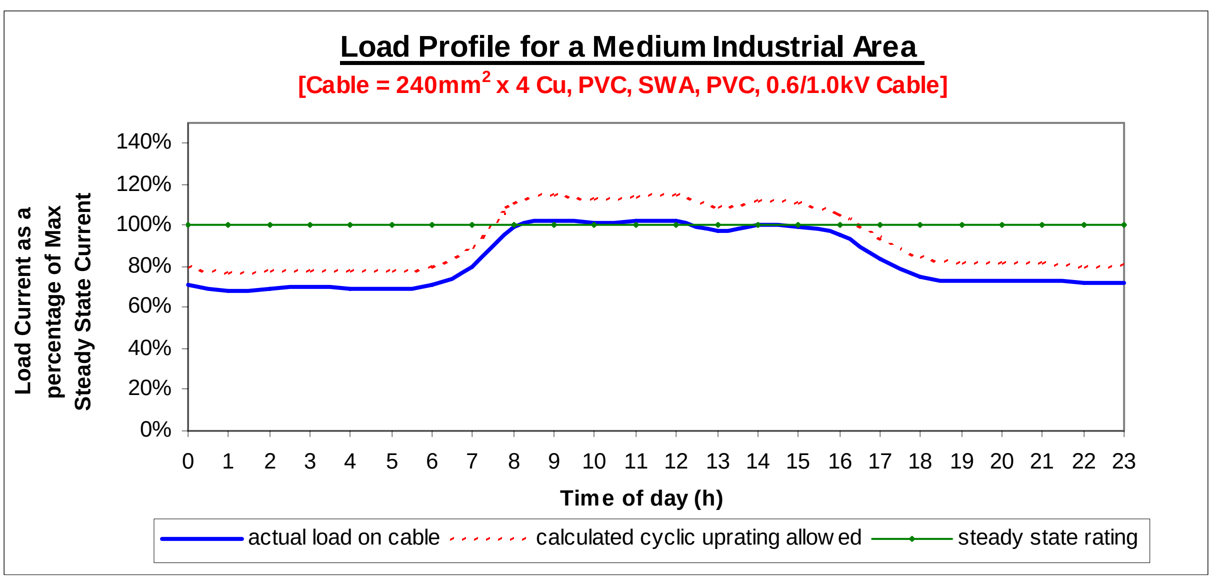


Figure 1: Load profile for a medium industrial area (dashed lines show calculated cyclic up-rating allowed on the cable)

In Figure 1, the load current on the cable for the first 8 hours of the day is about 70% of the steady state rating. As more employees report to work and more machinery are operational, the load current is increased to about 100% for a further 8 hours, before it reduces back to about 70% in the evening. Due to this type of load cycle profile, calculations show that the cable current rating may be increased by 12%.

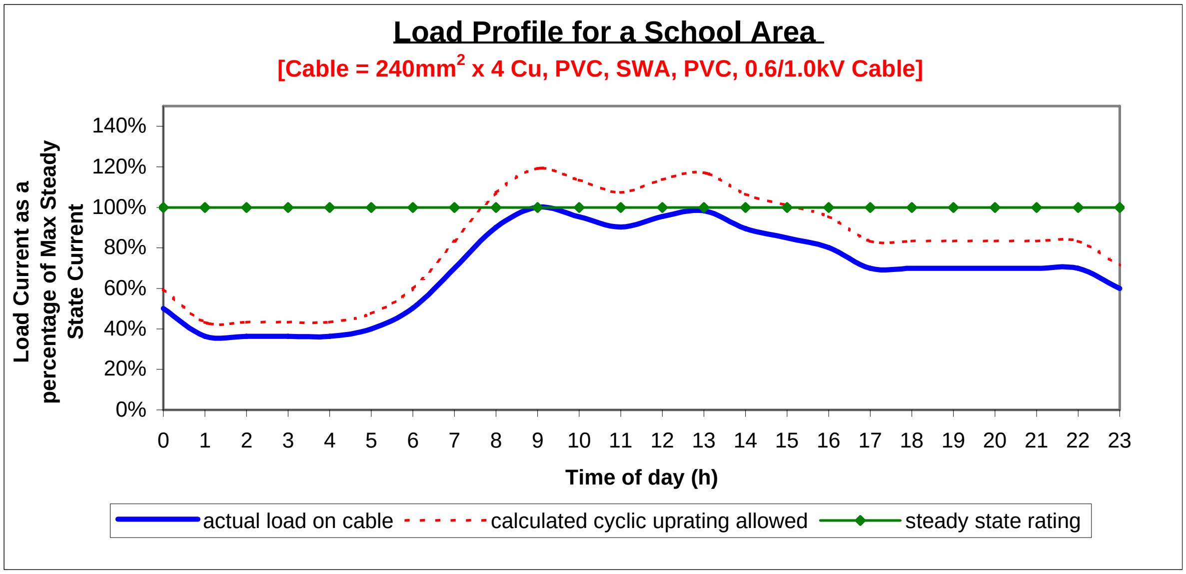


Figure 2: Load profile for a school area (dashed lines show calculated cyclic up-rating allowed on the cable)

In Figure 2, the load current on the cable for the first 6 hours of the day is about 40% and can be attributed to the school lighting only. As school begins in the morning, the load current increases to about 100% for a few hours, then reduces as it approaches lunch time, increases again and then reduces to about 70% in the evening when there are probably sporting activities. With this type of load cycle profile, calculations show that the cable current rating may be increased by 19%.

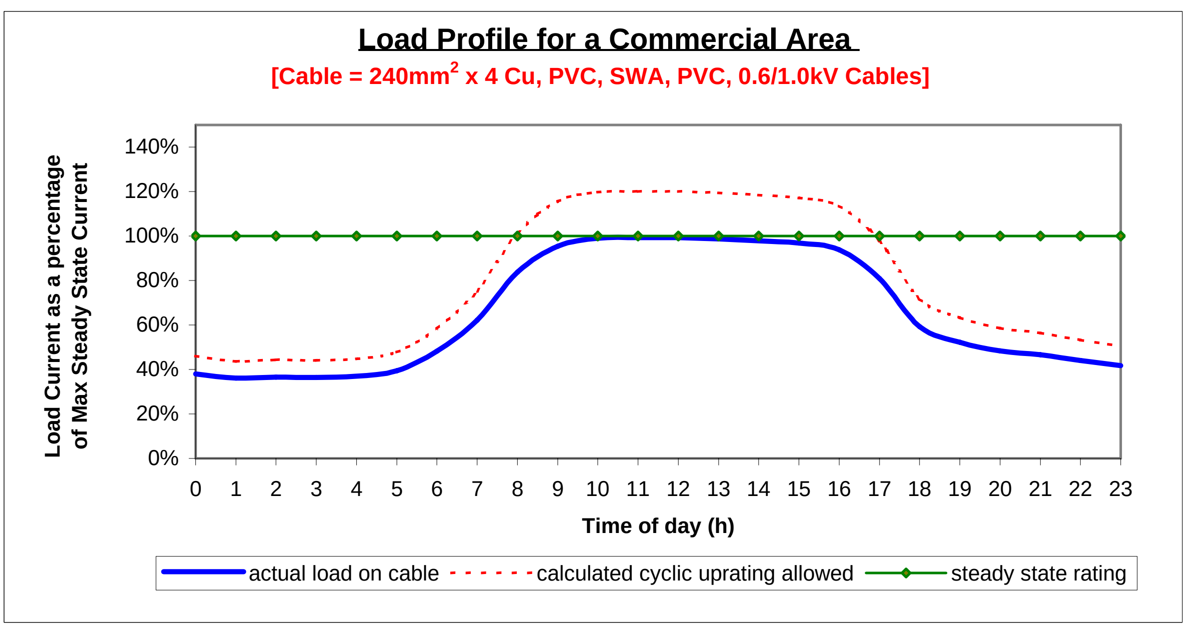


Figure 3: Load profile for a commercial area (dashed lines show calculated cyclic up-rating allowed on the cable)

In Figure 3, the load current on the cable is similar to that of Figure 2 and on average the heat generated within the cable over the 24 hour period is similar. Therefore, calculations reveal the same cyclic rating factor of 19%.

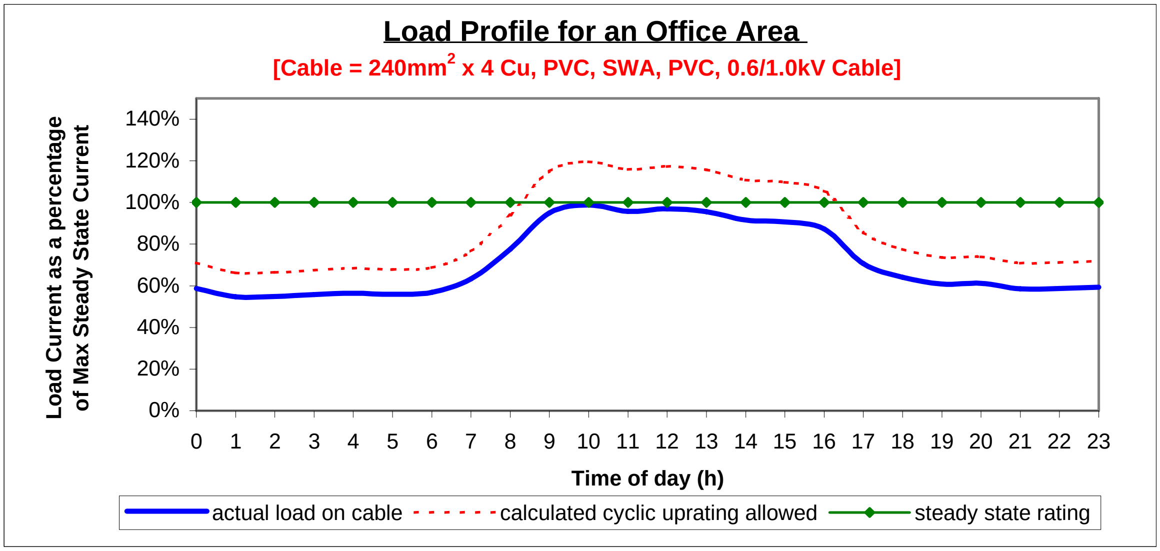


Figure 4: Load profile for an office area (dashed lines show calculated cyclic up-rating allowed on the cable)

For the cyclic load profile in Figure 4, the increase in current rating allowed on the cable is calculated as 21%. For the profile in Figure 5, it can be seen that the load on the cable is well below 80% of the steady state rating for most of the time, and as a result, the calculated cyclic rating factor is up at 27%.

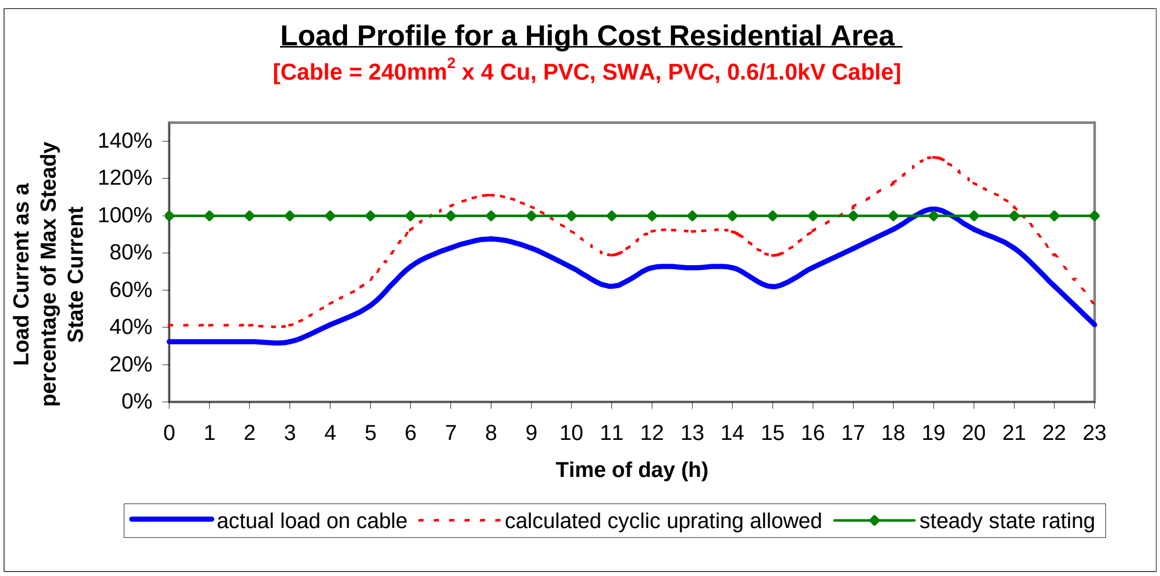


Figure 5: Load profile for high cost residential area (dashed lines show calculated cyclic up-rating allowed on the cable)

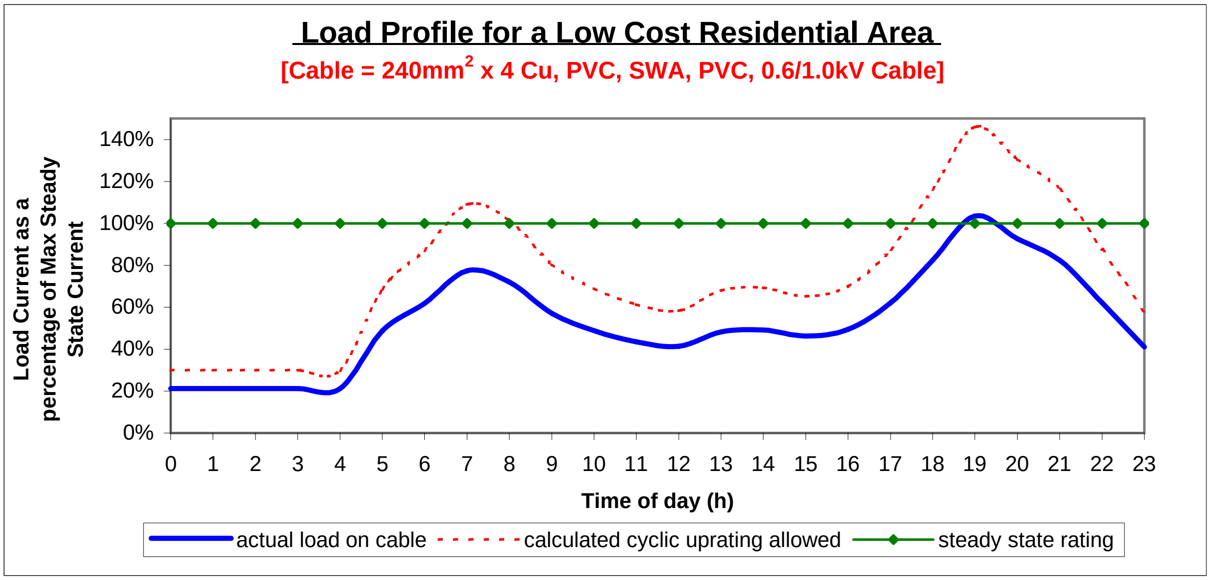


Figure 6: Load profile for low cost residential area (dashed lines show calculated cyclic up-rating allowed on the cable)

In Figure 6, the load on the cable is at 20% of the steady state rating for about 4 hours, typical of when people are asleep and the cable is supplying light loads like fridges and lights. The load increases to about 80% as people get ready for work in the morning, which later reduces to about 40% during the day. As it approaches evening, more people return from work and prepare super and take bathes. The load on the cables therefore increases to about 100% but as the night progresses, it reduces back to 20%. Calculations show that with such a load profile, the current rating of the cable may be increased by up to 40%.

6. Analysis of cyclic rating calculations

From the calculated rating factors in Table 1, it is conclusive that the current carrying capacity of the 240mm^2 cable can be increased by 12% when subjected to a load profile as in Figure 1, and up to 40% when subjected to a load profile as in Figure 6. Both the shape of the load profile and the size of the cable influence the cyclic rating factor.

Thus far all calculated results presented have been theoretical and no practical verification has been done on actual cables in operation. However, Cigre Working Group 02 of Study Committee 21 [4] have done intensive work on this subject and have quoted that the margin of error in these up-ratings is not expected to exceed 5% on the safe side. This is due mainly to the exponential heating of the conductor which will not exceed its maximum operating steady state temperature over the 24 hour period provided that the actual cyclic load profile and soil conditions remain consistent.

Practical verification of the calculated up-rating factors will entail some form of temperature measurement directly on the cable sheath since it will be difficult to access the conductor. Increased loading on the cables can be simulated by switching one feeder out in a double feeder system.

Such practical work and verification will be conducted with Tshwane Electricity in the near future.

7. Other methods of up-rating cable current capacity

Cable current ratings are usually based on a soil thermal resistivity of 1.2 Km/W, but below the subterranean water level, the actual soil thermal resistivity may be less than 1.0 Km/W. A reduced soil thermal resistivity from 1.2 Km/W to 0.8 Km/W for example, can allow for about 10% increase in the cable current carrying capacity. This method, however, requires an accurate measurement of the soil thermal resistivity for each location. Alternatively it can be obtained from the calculation of soil analysis [8] using the soils moisture content, percentage weight of clay and the density of the soil in the dry state.

Transmission capacity can also be increase by reviewing the IEC 60287 calculation method and its associated parameters, mainly using data accumulated in recent years. Such parameters may include revised skin effect factors, insulation thermal resistivities and soil temperatures. Such revisions of both calculation methods and parameters [8], may allow for an increase in transmission capacity by up to 15%.

Another method for increasing current carrying capacity of the cable is to measure and monitor on-line, the actual temperature rise of the cable along its length, and then to adjust the load currents accordingly such that the conductor does not exceed its maximum operating temperature. This is done using fibre optic technology, together with Distributed Temperature Sensing [9]. Since this method uses real-time measurements, the cables dynamic current carrying capacity may be more accurate than the calculation methods discussed in this paper. However, implementing such technology and maintaining it, may be quite costly.

9. Conclusion

This paper has illustrated that it is possible to calculate the cyclic up-rating factor of power cables where the load cycle profile is known. The modeling and analyzing of various load profile shapes can be implemented and solved in common software programs like MS-Excel.

The cyclic rating factors calculated show that the cable current capacities can be increased from 10% up to 40% depending on the shape of the load profile and the size of the cable. This allows Utilities to confidently meet higher power demands with the same cables to satisfy their consumers in the short term. In this manner, Utilities have up-rated their existing power cable assets meeting today's challenges with tomorrow in mind.

10. References

[1] – *Uprating of cable current capacity for Utilities where load cycle profiles are known* – P.Haripersad, Cigre 2005 Regional Conference paper, Capetown.

[2] - *Calculation of the cyclic and emergency current rating of cables – Part 1: Cyclic rating factor for cables up to and including 18/30 (36) kV*: IEC 853-1:1985, Ed 1.

[3] - BICC Electrical cables handbook, Third Edition, Pg 148.

[4] - *Current Ratings of Cables for Cyclic and Emergency Loads, Part 1*: Electra No. 24, October 1972, Pg 63-97.

[5] - *Electric Cables - Calculation of current rating*: IEC 60287-1995,Ed 1

[6] - 2002 Load Profiles courtesy of Tshwane Electricity, Pretoria, South Africa

[7] - *African Cables Cycling Rating Program - 2002*– MS-Excel software by P.Haripersad, African Cables, Vereeniging, South Africa

[8] - *Transmission capacity design of underground power cables*: Okada M, Karasaki T, Furuhata H, Imajo N, Mitani M, Sakuma S - JICABLE 1999, Paper A7.1.

[9] - *Determination of cable dynamic rating from distributed temperature sensing and hotspot temperature analysis*: SU Q, LI H.J., Tan KC, JICABLE 2003, Paper C8.1.3.