After the “Cape blackouts” in the summer period of 2005 to 2006, international consultants noted the vulnerability of the Palmiet pump storage because of it being connected to the rest of the Eskom grid only by means of the Bacchus Palmiet line.

The Palmiet Stikland line was challenging from an environmental perspective, as the route traverses partly through pristine properties and nature conservation zones. The goal of producing an environmentally friendly line within limited available land in some areas was achieved by the compaction and sharing of servitudes. This necessitated a number of new compact tower designs, including the first use of steel monopoles for a 400 kV line in South Africa.

The Palmiet – Stikland 400 kV line had been considered by Eskom since 1993, but the costs associated with constructing a 400 kV line through a largely urban area had always made the proposal marginally viable. The load growth of the area did not meet expected levels in the 1990s, and Eskom faced a situation of over capacity, until load growth started to take place in 2001.

A decision was made in 2005 to construct the line as part of a vital link to increase the strength of the national grid in the Western Cape. This line was required to provide a shorter additional route from the Palmiet pumped storage generation site into the grid through the new 400 kV substation at Stikland.

The conductor optimisation study indicated that a triple Kingbird conductor with a 380 mm sub-conductor spacing would be the preferred option. The relatively low cost of generation, and a low loading requirement of 450 MW dictated this choice to a large extent.

Environmental and servitude considerations

Environmental legislation requires the inclusion of project specific prerequisites which must be complied with during execution. The following section...
highlights the more notable pre-requisites (documented in a Record of decision, or RoD) for the Palmiet Stikland line.

Preliminary support options

One of the RoD conditions stated that a monopole design should be utilised in the densest urban areas. A secondary support option included the use of higher, multi circuit monopoles, which combined an upgraded 88/132 kV circuit with a 400 kV circuit on a single structure. This option was abandoned following extensive public participation, in which artists impressions for the 400 kV and 132/400 kV multi-circuit options were shown.

Servitude constraints

More than a third of the 50 km line route traverses areas where the procurement of a narrow 400 kV servitude (40 m) was not feasible due to existing land use. To solve this, Eskom negotiated with other para-statal entities to allow for a combination of servitude sharing and compacted spacing not yet undertaken in South Africa.

An important example of servitude sharing included the partial use and encroachment onto land zoned for the future N2 freeway extension through the industrial area of Somerset West. This co-operation between Eskom and the South African National Roads Authority (SANRAL) avoided routing the line through a business centre, but required careful planning to make allowance for future overpasses and associated freeway structures.

Other services impacted by partial servitude encroachment were bulk water supply mains and railway lines. In each case where standard separation distances were violated, negotiation with the potentially affected utility and supporting effect investigation was required.

A number of prominent wine farms such as Meerlust were affected by the proposed route, but the impact on these was limited by the construction of the 400 kV circuit over and parallel to an existing 88 kV line, at a highly reduced centre to centre line spacing of 8 m. Induction studies and impact mitigation on the 88 kV line was required to ensure the safety of maintenance workers.

Under normal operating conditions on the 400 kV line, it may become necessary to carry out maintenance on the 66 kV line. It will not be possible to de-energize the 400 kV line under these conditions and static (capacitive) induction will be present when the 66 kV conductors are disconnected and floating. Maintenance other than by live-line procedures, will have to take cognizance of the steady state induction of voltage from the 400 kV line, and steady state magnetic induction loops when earthing the ends of the 66 kV line conductors.

The earthing procedures will require that earthing is applied at the substation first, using substation earth switches, and also by installing portable earthing on either sides of the work site before any maintenance can be performed. This is in strict accordance with Eskom ORHVS.

During maintenance of the 66 kV line, there is a remote probability of transient conditions taking place on 400 kV line, such as when an internal over-voltage on the 400 kV system occurs. Therefore, verification that the 66 kV line insulation, even when polluted, would not flash over as a result of the 400 kV line induction had to be proved to ensure that it would be safe to do dead-line maintenance.
Environmentally sensitive areas

The line traversed nature conservation areas, requiring additional countermeasures. A guyed single mast lattice tower was developed for these and other rural areas. The guyed structure with lattice steel work was considered to have a low visual impact in natural settings. The guyed mast design was designed to fit within a narrower servitude width with a typical centre to centre spacing of 20 m to existing 132 kV structures (see Fig. 4). Five kilometres outside Palmiet Power Station, a "Red data" or endangered plant species was encountered, which was protected by fencing off of the area, and the use of maximum span lengths to avoid placement of towers within the affected zone.

The crossing of long spans, which often traverse deep valleys with natural vegetation are mostly earmarked for aerial construction techniques, involving the layout of pilot wire with helicopters. An 800 m span was earmarked on the line to assess the viability of using a model aircraft of rugged design to lay pilot cable. The model aircraft was successfully used to lay out a 100 kg strength pilot line, which was used to draw through successively higher capacity ropes.

Tower development

Since Eskom did not have 400 kV structures to support such a light conductor configuration in limited space, a range of new supports were developed specifically for the project. These consisted of lattice type supports for rural areas and monopole structures for urban areas.

Lattice towers

The 530 A compacted suspension single mast guyed lattice structure was developed to provide a structure to fit in the available narrow servitudes, which was used in combination with existing self supporting lattice designs. The structure has a delta configuration in order to compact the line and achieve longer spans. Phases are supported with string assemblies which utilise standard 120 kN assemblies in a 90°C opening. Provision is also made for maintenance under live conditions.

Use was made of a cross-over guy configuration and differential guy slopes to achieve the lowest possible tower footprint. A gull-wing cross-arm design was selected to achieve vertical compaction and improved aesthetics. The lower level conductor attachment heights vary between 17 – 35 m, and the structure weighs between 5 and 6,2 tons (excluding guys and fittings).

Steel monopole supports

The 531 series consists of five delta configuration steel self supporting poles developed to comply with the environmental requirements and very limited space available for the foundation. The 531 A (Suspension) and B (0 – 10 degrees angle deviation) were designed with a braced double post insulator assembly capable of supporting the tension and compression loads for which the towers were designed.

Bend angle ranges for the 531 C, D and E angle strain structures were selected based on the spread of line angles typically encountered in urban area line routes.

In keeping with recent changes to Eskom transmission design practice, all structures were equipped with cable-type fall arrest systems. Poles were designed for attachment heights varying from 17 m – 38 m on the lowest phase. The cost of the suspension poles including foundations (for typical soft founding conditions encountered on this project) varied between 2 – 2,5 times the cost of a self supporting lattice option, based on tendered prices received.

The poles were designed with restrictions of 4% deflection under normal conditions and 7% deflection for exceptional conditions. Section lengths were determined by equipment and galvanizing plant limitations. While deflections of the prototype test tower performed within this limit, experience in the field revealed that higher deflections were experienced in poles with wall thicknesses larger than 20 mm, due to variable manufacturing tolerances. (Following structural re-
evaluation which confirmed the integrity of deflected poles, Eskom elected not to replace such structures.

The specified heavy duty galvanizing on the poles was a challenge to the manufacturers, as different thickness of steel welded together in the same subcomponent experience different zinc take up during galvanising. The specified thickness had to be relaxed to avoid spalling on thicker steel components.

The implementation of this first series of 400 kV steel poles was an experience that presented a number of unexpected challenges. The designers and line constructors picked up valuable experience which will be applied to future projects.

The hardware design of the 531 A and B suspension single pole mast (see Fig. 7) dictated that fairly heavy transverse wind loading (for a long post insulator) in the order of 42 kN had to be accommodated.

Early in the design it was realised that composite post type insulators capable of handling such large compression loads were not readily available. (Large diameter hollow core insulators have successfully been used in such applications in a limited number of applications). To meet the performance specification, the supplier opted for a double solid core braced post design, based on internal manufacturing preference.

Details of typical base plates for the connection of the insulators were obtained from the insulator supplier. This was carefully studied and incorporated into the steel pole at the required locations. At the same time live line maintenance techniques were developed and suitable connection points for live line maintenance were incorporated (see Fig. 12).

The live end of the double post insulators consists of a plate which connects the

Fig. 11: Close-up view of double post insulator attachment to steel pole.

Fig. 12: Concept of live-line maintenance on 531 A and B steel pole.

Fig. 13: Close-up view of the live-end.

Fig. 14: Close-up view of brace insulator attachment.

Fig. 15: Close-up view of strain assembly attachment to tower.

Fig. 16: Virtual (PLS CADD) image of Invisible Tower concept.
insulators to one another as well as the connection plate where the hardware is attached. The attachment of the brace insulator was also accommodated on this plate. A compact type of corona/grading ring was developed in order to take care of the electric fields and corona noise on this fitting (see Fig. 13).

The brace insulator's top part was attached to the steel pole by means of a strap extension link which in turn connected to an attachment plate which was welded onto the steel pole. This attachment plate protruded through the diameter of the pole to form the attachment point of the adjacent phase on the other side of the pole. Service holes into this attachment plate formed part of the live-line maintenance techniques (see Fig. 14).

The strain assemblies for the 531 C, D and E towers were all similar and consisted of a twin insulator string that via yoke plates and other hardware attached to the vertical landing plate of the tubular cross arm.

Tower type 536 “invisible tower”:

One of the many challenges of the Palmiet-Stikland 400 kV line was to cross a mountain ridge known as Sir Lowry’s Pass. The line route crossed a neck in the range where it was possible to utilise the natural terrain as a conductor support, which would achieve low visual impact by placement of more visible support structures below the ridge horizon.

The site for the invisible tower was identified during the early 90s when the project was initially considered. To evaluate the visual impact of the concept, a mock up tower was constructed on the site with no attached conductors (see Fig. 20).

The RoD for the project also required that two other 132 kV circuits be routed through the invisible tower site, in addition to the 400 kV conductor and OPGW (see Fig. 16).

The height of the southern hill was insufficient to achieve the required attachment height, so an 11 m stayed mast was required at this end. The exact height of the mast and placement of support towers on either side of the ridge was refined in PLS Cadd, which made it possible to minimise the visual impact from various vantage points on the N2 freeway passing nearby.

The site is known for the high wind speeds. An anemometer installed at the site recorded wind speeds in excess of 150 km over a period of three years. A design wind pressure of 3500 Pa on the conductors was calculated based on the effect of wind acceleration at the site.

Increased reliability of the design was achieved by using two parallel steel ropes rated at a minimum of 400 kN each and designed in such a way that one steel rope...
and associated hardware could safely carry the required loading. The short lattice mast on the one side was also braced by counter tension in the steel cross ropes. For the hardware design, a running angle insulated cross rope for the 400 kV circuits, together with standard strain assemblies for 132 kV circuits was selected to achieve maximum compaction and attachment height (see Fig. 18).

Foundations for all structures in the vicinity of the sites were placed by pumping concrete (see Fig. 19).

Concluding remarks

For Eskom, the Palmiet-Stikland 400 kV line was a first in many respects. The complexity of the line design was increased by the line route which presented a host of challenges as described earlier. This led to the first introduction in Eskom’s history of the following solutions:

- Artist’s impressions used at public sessions to portray visual impacts.
- Development and use of 530 A guyed lattice mast.
- Development and use 531 series 400 kV steel monopoles.
- Development and use of braced post suspension insulator assembly (531 A and B).
- Development and use of Multi-circuit 400 kV/132 kV/132 kV invisible tower (insulated rope) to achieve minimum visual impact over Sir Lowry’s Pass.
- Use of fall-arrest system on monopole.

Acknowledgment

This article was presented at the Cigré 6th Southern African Regional Conference in Cape Town, and is reprinted with permission.

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