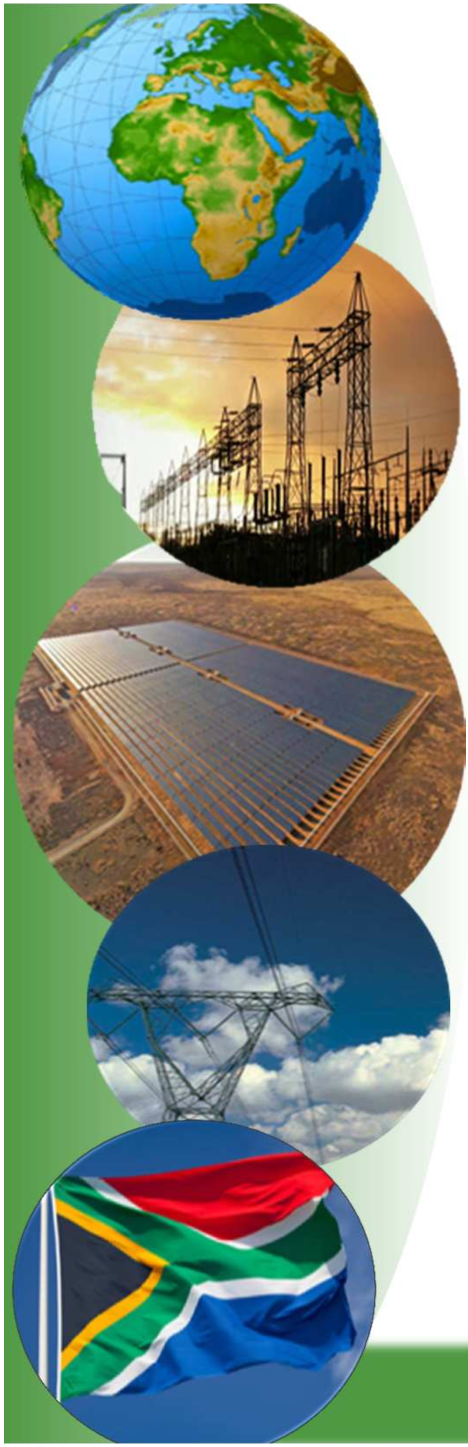

Consideration to include High Surge Impedance Loading (HSIL) lines as part of system planning in Eskom.

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Introduction

- Eskom is exploring methods to optimize both new and existing MTS assets
- Challenges that are faced with power lines are
  - High cost
  - Low return
  - Servitude acquisition difficulties
  - Strict statutory requirements
  - Challenging environmental considerations

Background

- Eskom is searching for design methods and technology that can make power lines more
  - Cost effective
    - Increase the amount of power that is transported per corridor (MW/m^2)
  - More reliable and efficient
    - Reduce the total investment cost (Rands/MW)

" The cost saving that is anticipated relates to the installation of series capacitors on long lines"

Surge Impedance Loading (SIL)

$$SIL = \frac{V_{LL}}{Z_C} \quad (MW) \qquad (1)$$

Where:

V_{LL} = Receiving-end rms line voltage (kV)

Z_C = Surge Impedance (Ω)

Where:

$$Z_C = \sqrt{\frac{L'}{C'}} \quad (\Omega) \qquad (2)$$

Where:

L' = Series inductance per unit length (H/m)

C' = Shunt capacitance per unit length (F/m)

High Surge Impedance Loading (HSIL)

- High Surge Impedance Loading (HSIL) methods can
  - Increase SIL of long lines by:
    - Decreases the series Inductive reactance
    - Increase in the shunt capacitive reactance
  - Depending on the network, the SIL can be increased substantially enough to eradicate the need to install series capacitors on long transmission lines

HSIL methods

- Increasing the number of sub-conductors in the bundle
  - Reduces the current in each subconductor which reduces the flux linkage of each sub-conductor
- Bundle expansion
  - Reduces the flux linkage of each sub-conductor
- Phase compaction
  - Increases the flux cancellation
  - Reduces the flux linkage of the phase conductors
- Different conductors

Advantages of series capacitors

- Series capacitors
  - Self-regulating devices
  - Reduce reactive power consumption
  - Control voltage
  - Improve the system stability
    - Reduce angular and voltage stability restrictions (limits)

- This is achieved by:
  - Reducing the line’s series inductive reactance
    - Electrical length

Disadvantages of series capacitors

- Series capacitors increase SIL of a line effectively and efficiently however it comes with the following trade-offs
  - Substantial increase in the investment costs
  - Extra maintenance
  - Reduction in network reliability (planned and unplanned outages)
  - Sub-synchronous resonance
  - Complex protection settings
  - Environmental impact.

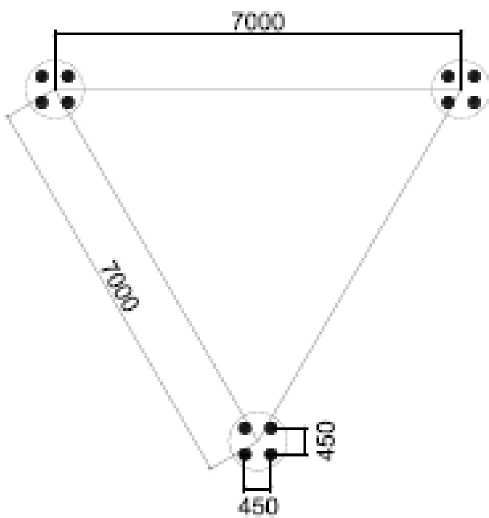
Tools

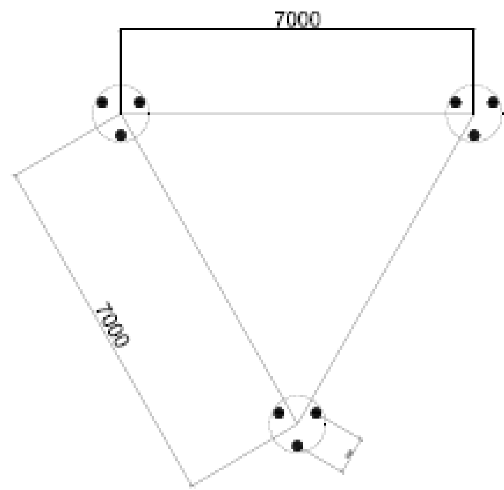
- Bonneville Power Administration (BPA)
  - Calculate the ionizing and non-ionizing field effects
- Alternative Transient Program (ATP)
  - Calculate the SIL and line parameters
- Power System Simulator for Engineering (PSS/E)
  - PV plots
- Voltage Security Assessment Tool (VSAT)
  - PQ plots

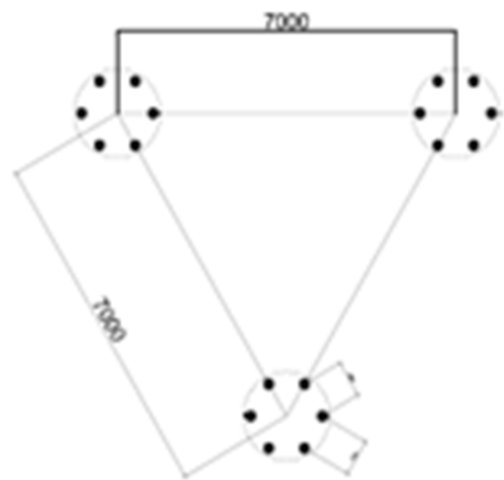
Methodology

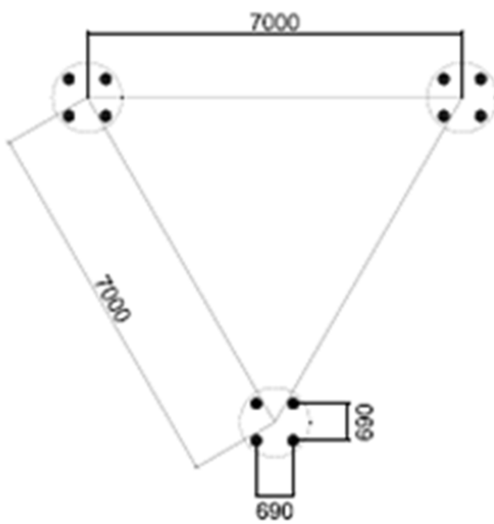
- Optimize the existing 528A tower using 4 x Tern ***(phase compaction)***
- Increased the sub-conductor spacing ***(bundle expansion method)***
- Conductor ionizing and non-ionizing field effects analysis ***(limiting criteria at an altitude of 1 800 m)***
- Select the biggest sub-conductor spacing that is workable on the 528A tower ***(proposed HSIL configuration)***
- Select different conductor types and bundle sizes ***(vary the sub-conductor bundle size and conductor types)***
- Calculate SIL and line parameters of each bundle ***(740 mm)***
- Select the superior bundle to do load flow studies **(RXB)**

Iterations of different HSIL configurations

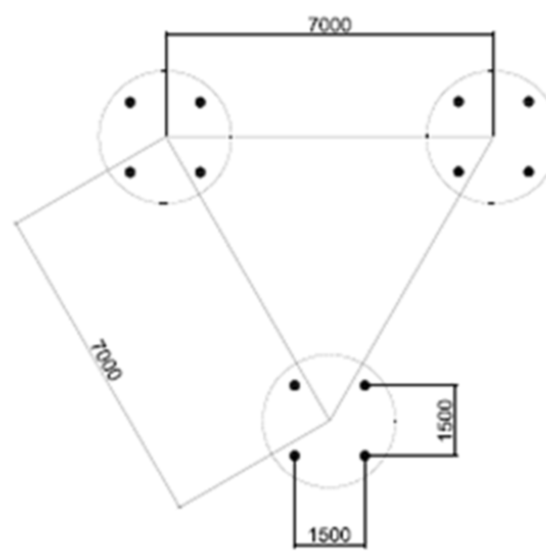






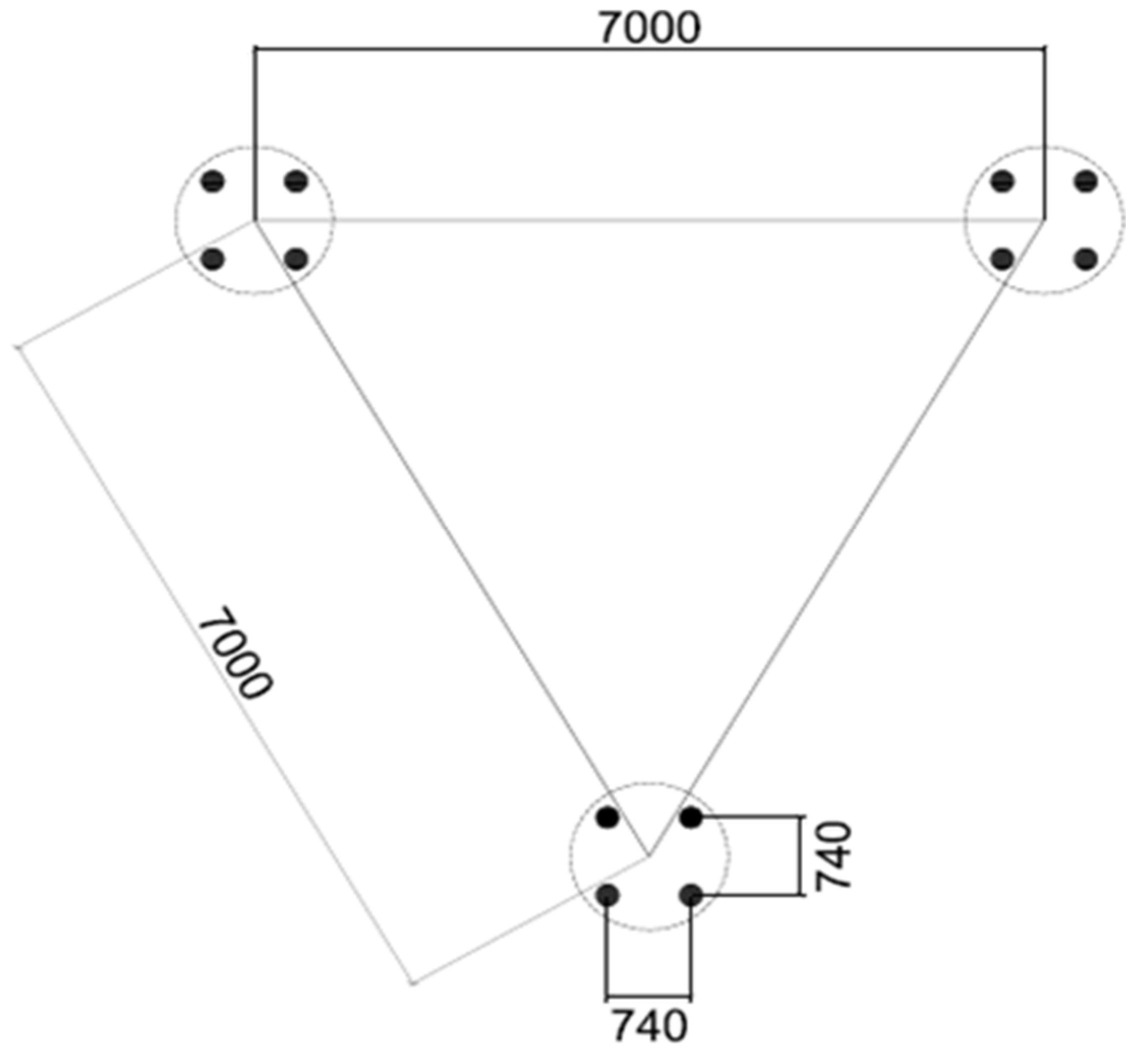


Only 9 of 13 bundles satisfy the ionizing and non-ionizing field effects limits with 740 mm sub-conductor spacing and base case is 4 x Tern



The recommended HSIL configuration

- **4 x IEC 450 (wins)**
- 9.6% improvement in corona inception
- R ↓ 10.1%
- X ↓ 0.43%
- B ↑ 0.44%

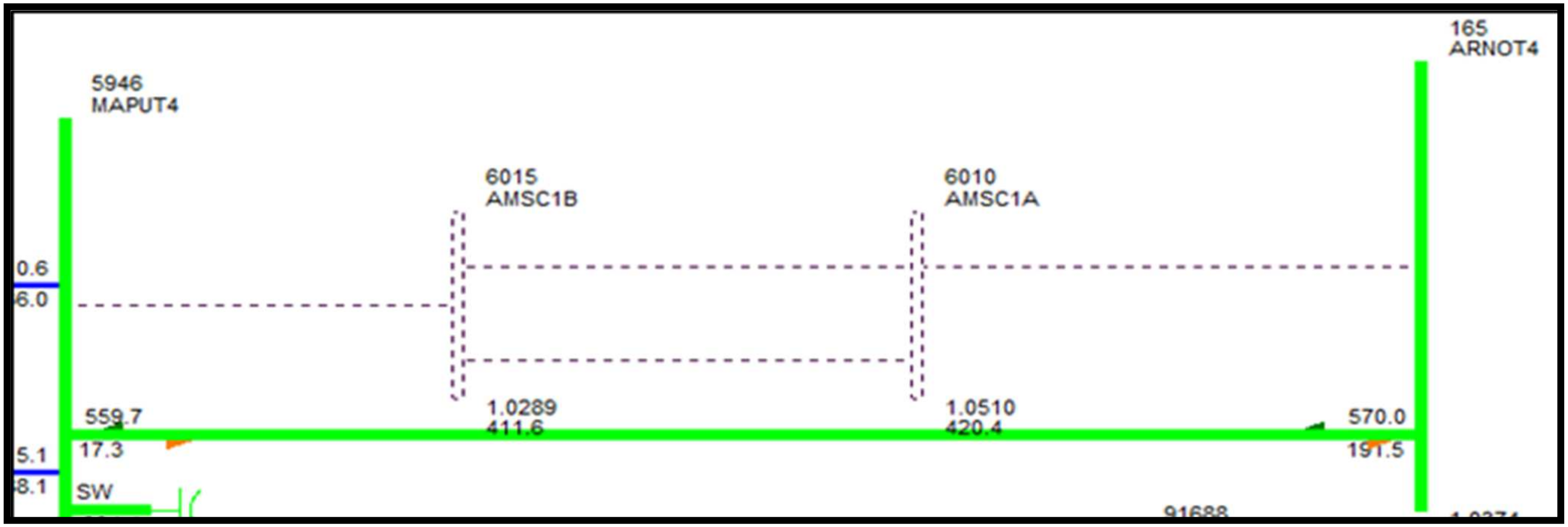


Criteria used to select a line

- 400 kV
- Length that's greater than 200 km
- Series capacitor is installed
- High load factor
- Constant load
- Operate at or above their SIL under system healthy conditions

Selected 400 kV line

- Arnot – Maputo 400 kV line
  - 284 km
  - Series Capacitor is 2.765×10^{-2}pu
  - Installed in the middle (2 sections of 142 km)



Simulated Cases

- Case i is the existing line from Arnot to the series capacitor
- Case ii is the existing line from the series capacitor to Maputo
- Case iii is the proposed HSIL line without a series capacitor
- Case iv is a summation of the as-built line parameters (R and B of the two sections are added and X_C is subtracted from X_L).

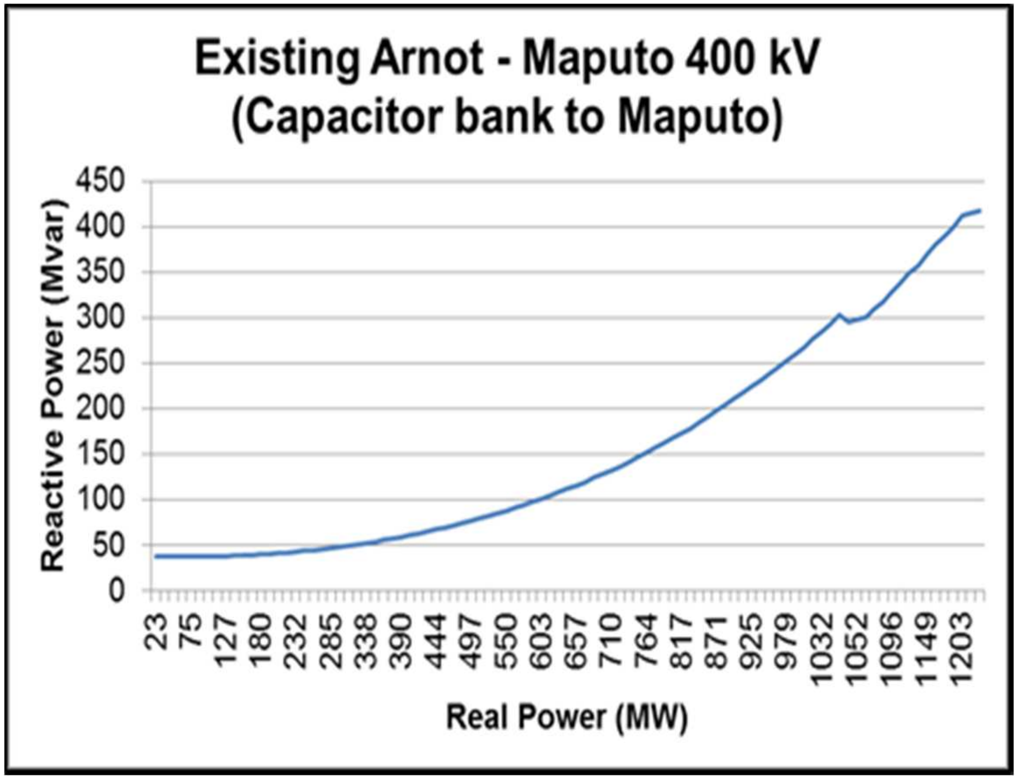
Line parameters for the 4 cases

Case No	Series Capacitor (pu x 10^{-2})	R (pu x10^{-3})	X (pu x10^{-2})	B (pu)
i	-	2.44	2.534	0.9117
ii	2.765	2.44	2.534	0.9117
iii	-	2.95674	3.56769	2.5615
iv	-	4.88	2.303	1.8234

Ranking the results in terms of SIL

- Case iv comes 1st with 906 MW **(summation)**
- Case iii is 2nd with 882 MW **(HSIL line)**
- Case i is 3rd with 627 MW **(convention line)**

'Case iv is a theoretical winner because the series capacitor supplies the reactive power (case ii) that increases the SIL"



Ranking in terms of reactive power

Case No	MW_{INI}	$MVAR_{INI}$	MW_{MAX}	$MVAR_{MAX}$
i	26	- 73	1250	323
ii	23	38	1211	418
iii	30	-256	1094	204.9
iv	39	-175	1297	232

- Case iii is 1ST where the natural capacity (Mvar) is increased by a factor of 3.5 when compared to case 1
- Which translate to reactive power requirement that is 33% less than the conventional line

Series capacitor sizing

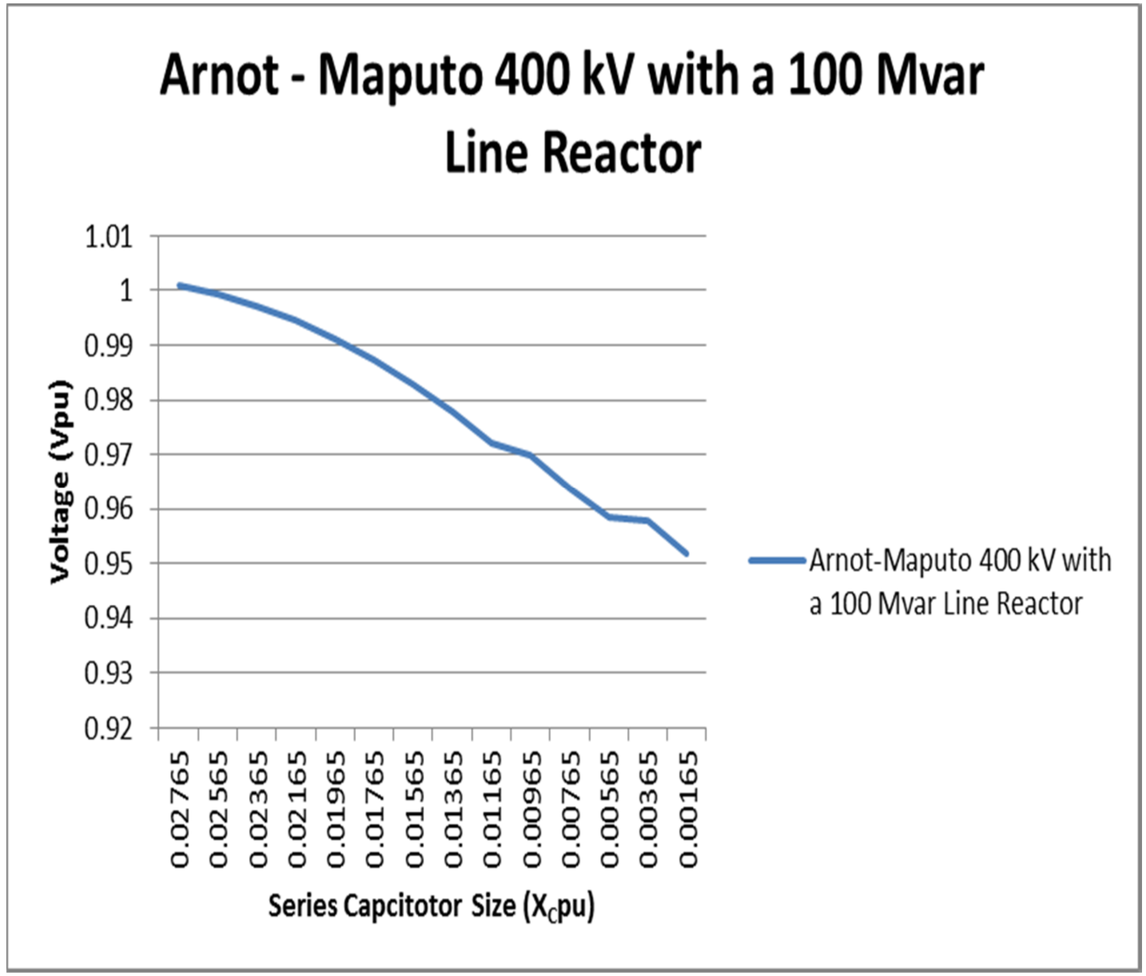
- Parameters for the HSIL line paired with the series capacitor bank and the 100 Mvar line reactor.

Series Capacitor (pu x 10^{-2})	R (pu x 10^{-3})	X (pu x 10^{-3})	B (pu)
2.765	2.95674	3.56769	2.5615

- The capacitor size was then reduced until voltage levels reached the statutory limit of 0.95 Vpu.
- Series capacitor can be reduced from 0.02765 pu to 0.00165 pu without infringing on the voltage limits of 0.95 Vpu which is equivalent to 3.25% compensation on the existing line.

Line reactor sizing

- Two sizes were simulated
- 50 Mvar
  - – voltage level is 1.07 Vpu during a no load condition
- 100 Mvar
  - – voltage level is 1.05 Vpu during a no load condition



Conclusion

- HSIL methods are a workable alternative to the installation of series capacitors
  - Series inductive reactance is reduced by 26%
  - SIL is increased by 36%
- For the selected case the series capacitor could have been eliminated
  - Estimated cost saving from GE is 1.5 million dollars ≈ R 19 385 100
  - The results also indicate that a 100 Mvar shunt line reactor is still required to prevent Ferranti effect voltages