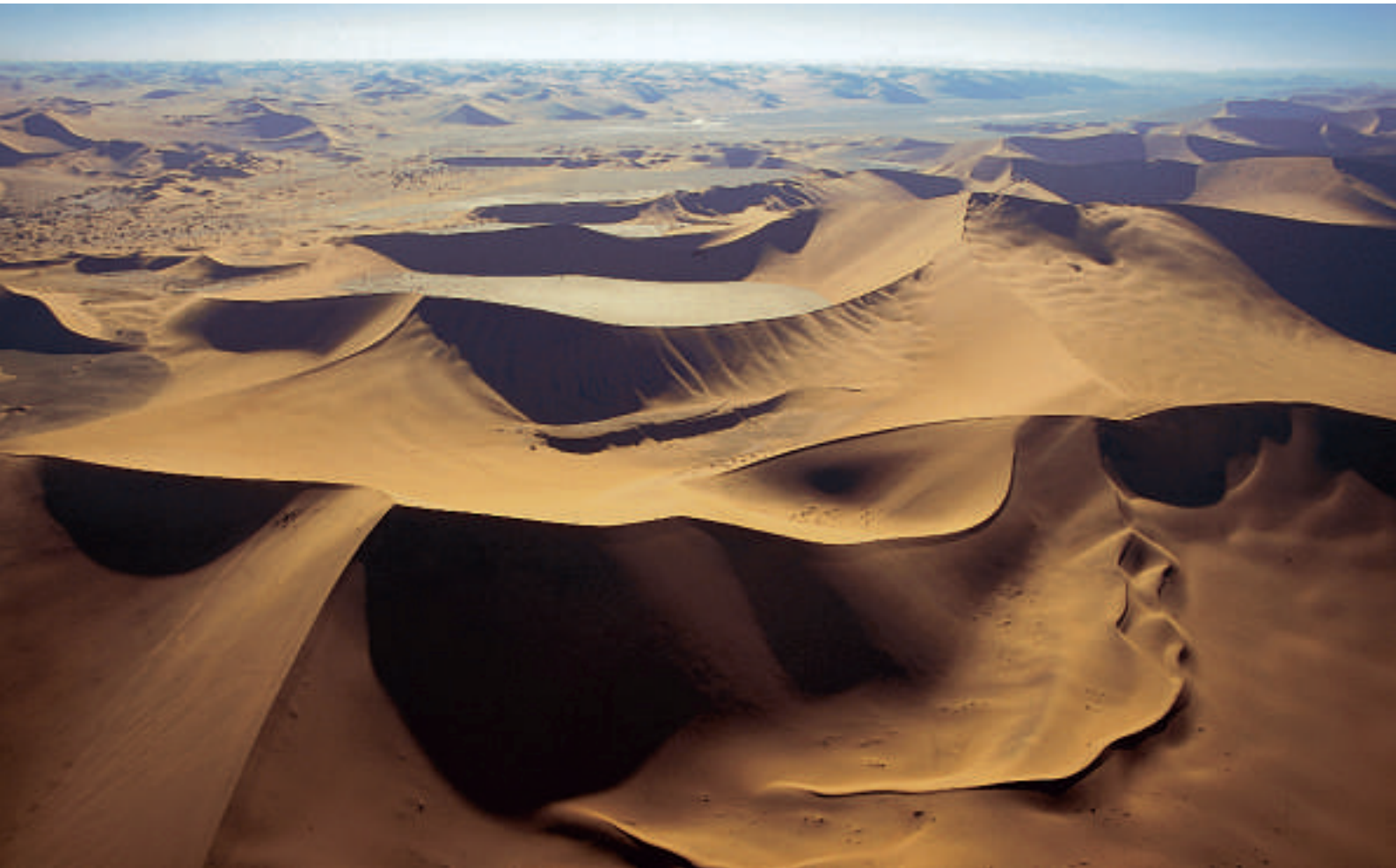


Power

ABB static var compensator stabilizes Namibian grid voltage |

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factor!



The spectacular dune landscapes of Namibia are a key factor in the country's booming tourist industry and a valuable source of revenue for the nation. Another, even more important pillar of the Namibian economy is the power-hungry mining industry. To cope with growing energy demand in these two sectors and to ensure a reliable power supply for the country as a whole, NamPower, Namibia's national electricity utility, has installed a new 400-kV AC transmission system linking its grid system with the Eskom grid in South Africa. Voltage stability problems, which the new line would have aggravated, have been resolved by installing a static var compensator from ABB.

While construction of the new line has brought reliable power to Namibia, it was not without problems of its own. The line's length of 890 km, for instance, aggravated certain problems – mainly voltage instability and near 50-Hz resonance – that already existed in the NamPower system.

An ABB static var compensator (SVC) rated from 250 MVar inductive to 80 MVar capacitive has been installed to solve these problems. The turnkey project was concluded with the successful commissioning of the SVC in NamPower's Auas 400-kV substation **1**, just 18 months after the contract was signed.

The case for a new 400-kV grid

Power consumption in Namibia is concentrated in Windhoek and in the northern region, where most of the mining and mineral industry is located. Until recently, the NamPower grid consisted of a radial network, with bulk power supplied by the Ruacana hydro-station in the north via a 520-km 330-kV transmission circuit, linked by an 890-km 400-kV interconnection to Eskom's system in the south.

This network was often loaded to its stability limits during low-load periods

1 Auas static var compensator



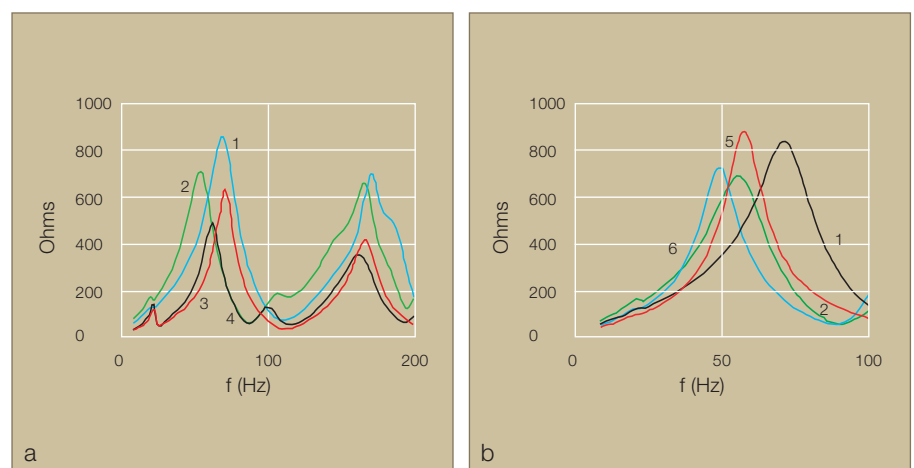
when Ruacana was not providing power. The system is also unique for its long 220-kV and 330-kV lines and the fact that the loads are small in comparison with the generation sources – two features that further aggravated the stability problems in low-load conditions.

To solve these problems, the utility decided to build a 400-kV grid. The final phase of construction – a 400-kV interconnection between Auas and Kokerboom **2** – was completed in 2000. This single-circuit 400-kV AC transmission line strengthens the NamPower system by connecting it to Eskom's system in

2 NamPower network



3 System impedance/frequency characteristics (a) and system near 50-Hz resonance (b)



- 1, 2 Existing system, with four and no generators
- 3, 4 New system, with four and no generators
- 5, 6 During 400-kV energization, with four and no generators

the south. However, with a length of 890 km it is also very long, in fact one of the longest lines of its kind in the world. This and the network's tree-like configuration, coupled with remote generation and the very long radial lines operated at high voltage, results in the charging capacitance being high. The effect of this is to shift the existing parallel resonance closer to 50 Hz, making the network more voltage-sensitive during system transients, for example when the 400-kV line is energized or during recovery after a line fault clearance. Each of these phenomena manifests itself as an extremely high and sustained overvoltage.

Resonance and overvoltages

The NamPower network has a first natural parallel resonance frequency well below 100 Hz, namely in the 55–70 Hz range (curves 1 and 2 in 3).

The effect of adding the new 400-kV line section (Aries-Kokerboom-Auas) and its four 100-MVAR shunt terminal reactors has been to shift the system's first resonance into the 60–75 Hz frequency range (curves 3 and 4). (The reduction in system impedance at 50 Hz is due to the new 400-kV line, and an

indication of how the system has been strengthened.)

Curves 5 and 6 in 3 show the network impedance as seen at the Auas 400-kV bus the instant the 400-kV line is energized from the northern section (from the Auas side) and before the circuit-breaker on the Kokerboom side is closed.

The impact of the resonance problem in the NamPower system is best illustrated by simulating the condition at Auas substation, represented by curve 6. The voltage situation is shown in 4, in which the line circuit-breaker at Auas is closed at time $t = 1.0$ s and it is assumed that the breaker at Kokerboom is synchronized at $t = 1.2$ s. Due to the large charging capacitance of the line the voltage first dips, then overshoots.

The extremely high overvoltages appearing at Auas, with a peak value in excess of 1.7 pu and a sustained transient overvoltage (TOV) of more than 1.5 pu, attest to the severity of the problem. It is clear that as soon as 50-Hz resonance is triggered very high dynamic overvoltages appear with large time constants under certain system load and generation conditions.

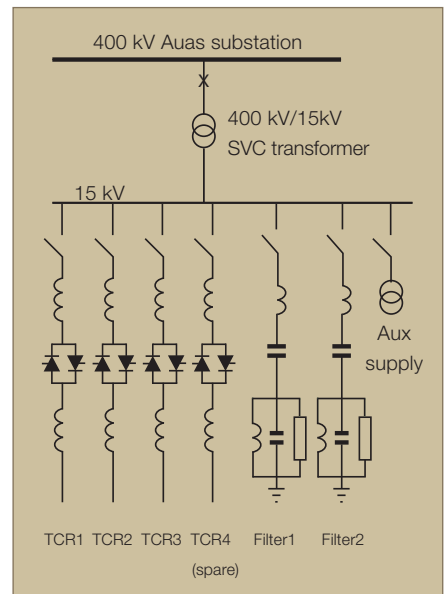
Preliminary studies indicated that overvoltages would appear that would make the NamPower system inoperable unless very fast, effective and reliable countermeasures are taken. Several solutions were considered as an answer to the resonance

problem, including fixed and switched reactors, before deciding to install a FACTS device in the Auas substation. Preference was given to conventional, proven SVC technology [1].

SVC design features

The Auas SVC has a dynamic range of 330 MVAR (250 MVAR inductive to 80 MVAR capacitive) and is installed primarily to control the system voltage,

5 Single-line diagram of the Auas SVC



in particular the extreme (up to 1.7 pu) overvoltages expected as a result of the near 50-Hz resonance. An uncommon feature of the project is that the SVC is installed in a system with very long lines, little local generation and fault levels lower than 300 MVA.

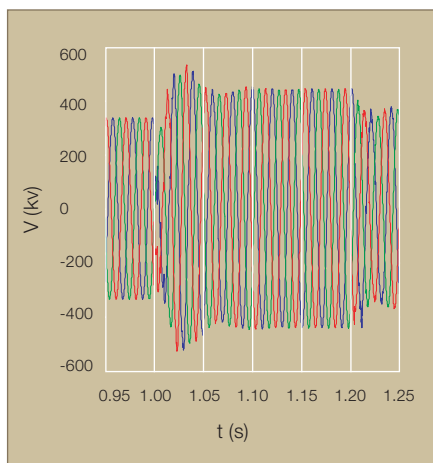
The SVC that is installed is of a new type, developed by ABB for power applications. Its unique control principle has since been patented. The inductive

power of 250 MVAR is provided by three thyristor-controlled reactors (TCRs), a

fourth, continuously energized TCR being always on standby 5. Two identical double-tuned filters, each rated at 40 MVAR, take care of harmonics and supply capacitive reactive power during steady-state operation.

High availability is essential for the Auas SVC. If, for any reason, it should have to be taken out of service, the 400-kV transmission system could not be oper-

4 Energization of the Auas-Kokerboom 400-kV line from the northern section, without the SVC

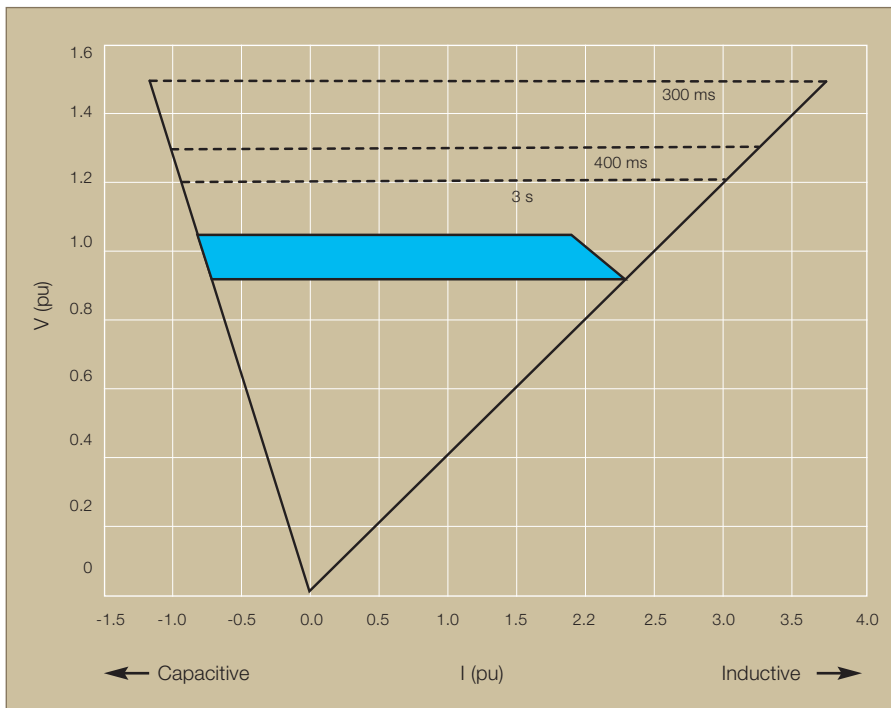


The blue, green and red curves represent the different phases (instantaneous values).

Studies showed that overvoltages could make the NamPower system inoperable unless very fast, effective and reliable countermeasures are taken.

6

V/I characteristic, showing the possible steady-state and transient operating points of the SVC



The colored area represents continuous SVC operation. Above this area, the SVC can be operated up to 1.2 pu voltage for 3 s, up to 1.3 pu voltage for 400 ms, and up to 1.5 pu voltage for 300 ms.

ated without risking dangerous overvoltages. As a result, an availability figure of 99.7 % was specified, and this strongly influenced the design, quality, functionality and layout of its components and subsystems as well as of the SVC scheme as a whole.

Operating range

The Auas SVC provides resonance control over its entire operating range **6**, which extends well beyond its continuous range. Controlled operation is possible all the way up to 1.5 pu primary voltage – a necessary feature for controlling the resonance condition. Besides providing resonance control, the SVC also controls the positive-sequence voltage (symmetrical voltage control) at the point of connection.

Single-phase transformers

Four single-phase transformers, including one spare, are installed. Due to the high overvoltage demands made on

them during resonance these transformers have been designed with a lower flux density than standard units; they should be the last transformers in the NamPower system to go into saturation.

TCR reactor and valve

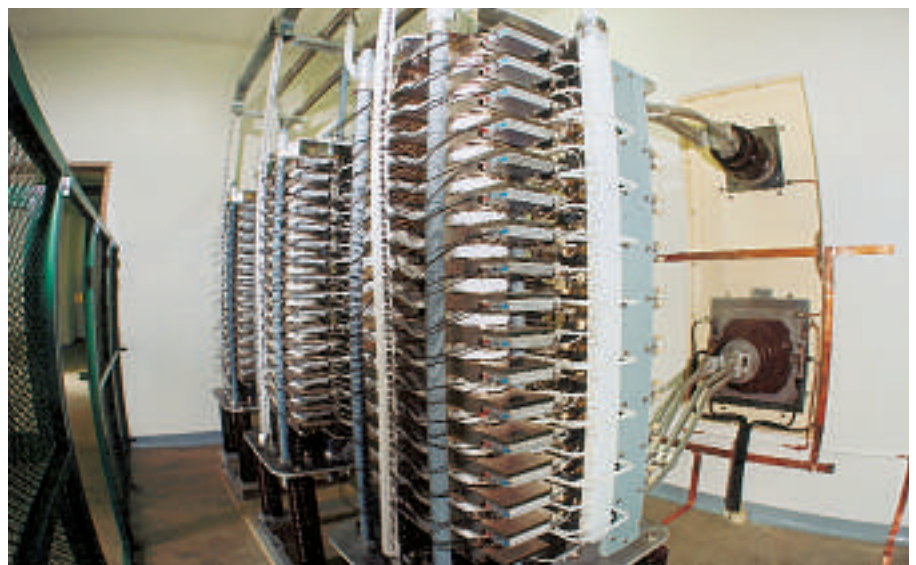
Each TCR branch consists of two air-core reactors connected on each side of a thyristor valve. The reactors have special exterior surfaces to protect them from the effect of sand storms and sun in the harsh desert environment.

A secondary voltage of 15 kV was chosen as an optimum value for both the thyristor valve and busbar design. The thyristor valves consist of single-phase stacks of antiparallel-connected thyristors (16 thyristors, two of which are redundant, in each valve). Snubber circuits (series-connected resistors and capacitors) limit overvoltages at turnoff. The thyristors are fired electrically using energy taken directly from the snubber circuit.

An overvoltage protection device limits the voltage that can appear across the valve, being triggered by control units that sense the instantaneous voltage across each thyristor level.

Redundant TCR branch

Three TCR units rated at 110 MVar have been installed to cope with the NamPower network's sensitivity to reactive power and harmonic current injections. A fourth, identical TCR is kept on hot standby. The SVC control system automatically rotates the current standby TCR unit every 30 hours to ensure equal operating time for all units.



Redundant cooling system

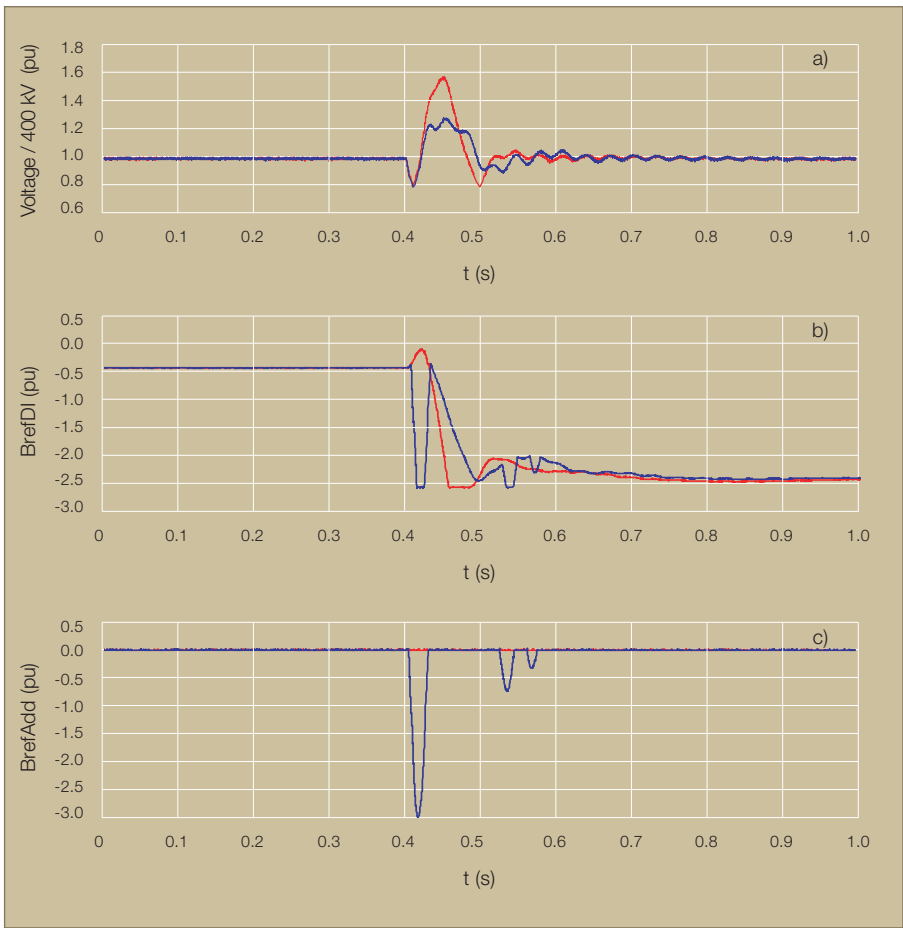
An unusual feature of the Avas SVC is that each TCR valve has its own cooling system, making four in all. Thus, outage time is minimized and availability is increased. A water/glycol cooling media is used to avoid freezing in case of auxiliary power outages during the cold desert nights.

Filter branches

The required capacitive MVar are provided by two 40-MVar filter banks. Each filter is double-tuned to the 3rd/5th harmonics and connected in an ungrounded configuration. The double-tuned design was chosen to ensure sufficient filtering even in the case of one filter becoming defective.



7 Real-time digital simulation. 400-kV line energized from the north, with and without the new resonance controller



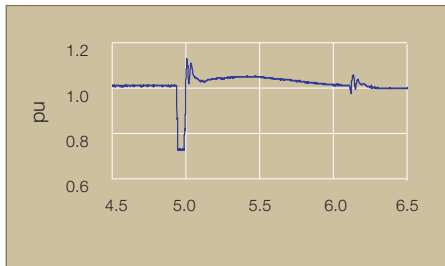
a	Voltage response, 400 kV	Red	Conventional PI controller
b	SVC controller output	Blue	Resonance controller
c	Impact of resonance controller		

Black-start performance

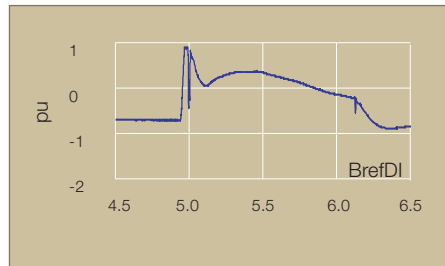
Since the SVC is vital for operation of the NamPower system, everything has to be done to avoid the SVC breaker tripping, even during a network black-out. In such a case the network could be energized from the Eskom side and the SVC would have to be immediately ready to control a possible resonance condition. To handle this task, the SVC has three separate auxiliary supplies, one of which is fed directly from the SVC secondary bus. The SVC is capable of standby operation with its MACH 2 controller active for several hours without auxiliary power, and automatically goes into resonance control mode as soon as the primary voltage returns.

Worst-case situation: energization from north to south

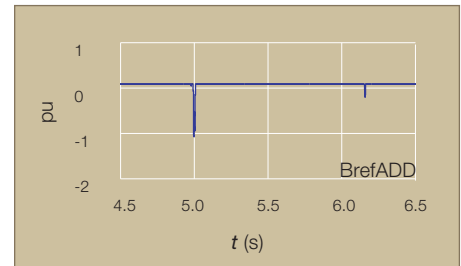
The worst-case scenario for the SVC and the Nampower system is energization of the 400-kV line from the northern section (Avas substation). This system condition, which initiates the critical 50-Hz resonance, was therefore simulated in a real-time digital simulator with and without the new resonance controller. As shown in 7 the overvoltage that appears at Avas is 1.62 pu with a conventional PI controller. (The two resonance frequencies – 56 Hz and 81 Hz – that can be seen in the result correspond to the system’s first and second pole, respectively.) The new resonance controller has a considerable impact on the system’s behav-



a Voltage response, 400 kV



b SVC controller output



c Impact of resonance controller

ior and the voltage controller's additional contribution forces the SVC to become inductive. As a result, the peak voltage appearing at Auas is reduced to a value of 1.32 pu.

This extreme test was also performed in the field. Comparison of the simulation results and the system performance test shows very good agreement and underlines the improvement capability of the new resonance controller under resonance conditions.

As a result of installing the ABB SVC, the resonance problems that had previously plagued the Namibian grid are a thing of the past.

Staged fault test

After the Auas substation had been commissioned, a phase-to-ground fault was used to test various SVC control functions and the interconnection protection scheme. The performance of the SVC is shown in 8. As the results show, the SVC controls the voltage and the resonance controller forces the SVC to become fully inductive in resonance conditions. The fault is initiated at $t = 4.9$ s and is cleared by opening the faulty phase in the

Auas-Kokerboom line. A single-phase auto-reclosure is initiated after 1.2 s, starting with the breaker on the Kokerboom side. The overvoltage at Auas is reduced to 1.14 pu.

Easier cross-border power sharing

As a result of installing the ABB SVC, the resonance problems that had previously plagued the Namibian grid are a thing of the past. Southern Africa's state energy sectors can now be more easily integrated and power more easily shared. And the growing demand for power – the motor driving the region's economic ambitions – can be more easily met.



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[1] R. Grünbaum, M. Noroozian, B. Thorvaldsson: FACTS – powerful systems for flexible power transmission. ABB Review, 5/1999.