LOSS REDUCTION IN HIGH VOLTAGE URBAN DISTRIBUTION SYSTEMS

Thomas NIPPERT
Vattenfall Europe Distribution
Hamburg GmbH – Germany
thomas.nippert@vattenfall.de

Kathrin STEINKE
Vattenfall Europe Distribution
Hamburg GmbH – Germany
kathrin.steinke@vattenfall.de

Martin SCHRÖRS
University of Applied
Sciences Lübeck - Germany
schroerm@stud.fh-luebeck.de

ABSTRACT

The liberalisation of the European electricity markets has increased cost pressure on power companies and system operators. A search is in process for a potential lowering of network costs which can be put into practice with the minimum possible investment. The reduction of system losses by circuit state optimisation is an approach to this objective, analysed in the present study.

This paper describes how system losses can be saved by optimising the circuit states in typical exemplary 110 kV urban distribution systems under different load and generation situations as well as system configurations. Both a heuristic approach was introduced for systematic investigation of system diagrams and the prerequisites and boundary conditions were formulated for implementing the circuit state optimisation in power system management. In this way, low-loss system configurations could be developed which offer a verifiable reduction of line and transformation losses.

INTRODUCTION

The Energy Industry Act [1] defines the goals of economic efficiency and continuity of supply for planning and operation of power supply systems. In the past continuity of supply had been the absolute most important issue, now the liberalisation of the electricity markets focuses more and more the aspect of economic efficiency. Due to the customers' expectations the power companies and system operators come increasingly under cost pressure, therefore the efficient system operation while maintaining a sufficient continuity of supply is a major task.

This makes it all the more important to ascertain potential for savings which can be implemented with the least possible investment. In this context, methods are being considered for operational reduction of system losses in typical 110 kV urban distribution systems. It was expected that the greatest potential for savings would be found in optimising circuit states [2].The reactive-power voltage optimisation already implemented in transmission systems [3] can only make a limited contribution to loss reduction in distribution systems. A preliminary study has confirmed these expectations with the reduction of system losses in a model system similar to typical urban 110 kV distribution systems amounting up to 3% [4]. The focus of this study therefore concentrates on optimising the circuit states.

CIRCUIT STATE OPTIMISATION IN DISTRIBUTION SYSTEMS

Use in power system management

As with reactive-power voltage optimisation, circuit state optimisation can be used in both online open loop mode and in offline mode. In the online open loop mode, optimisation is implemented through the control system on the basis of an online load flow dataset. In the offline mode, optimisation is implemented by the control system or a remote computer on the basis of characteristic datasets. When using circuit state optimisation, care is always required to ensure that the resulting recommendations do not result in unsteady system operation with frequent changes in the circuit state. This is why the recommendations of the optimisation module are only implemented after being reviewed by the control centre staff.

The online mode requires a consistent load flow dataset based on static network data, current circuit states and measured values for current, voltage, active and reactive power. Necessary prerequisites for providing consistent load flow datasets are an adequate number of measuring points and a measuring topology which warrants the observability of the system and thus comprehensively images the current system state [5]. Online load flow datasets can also be used for online system analysis, online contingency calculations and for training the control centre staff. The offline mode uses scalable characteristic load flow datasets (e.g. for the seasons, days of the week) for carrying out load flow calculations.

Situation in typical distribution systems

In transmission systems, state estimation is used to generate consistent datasets [5]. The exemplary urban distribution system considered here has an incomplete measuring topology, like most 110 kV distribution systems. The few active power measured values are not sufficient for the observability of the system in terms of active power, so that state estimation does not provide any consistent datasets. It would be very expensive to upgrade the measuring and control system equipment. Therefore the imaging of the system state was examined to be improved by the use of artificial measured values [4]. The artificial measured values were generated from real current measurements and characteristic datasets. The procedure functions in urban distribution systems with high-power nodes (many branches and shunts, high power throughput), but only under slight angle deviations from the reference load flow, so that this is only conditionally suitable for the exemplary distribution system being considered here. In rural systems with far lower load density, comparable procedures are capable of producing quite feasible results [6]. Thus the application of circuit state optimisation in the online open loop mode has to be excluded, so that all following tests were carried out on the basis of characteristic datasets.

Procedure

Up to now, a systematic examination of optimising the circuit statuses of complex power systems in order to reduce grid losses has only been carried out at RWTH Aachen [2]. This paper describes two mathematical methods ("branch & bound" method, single step search method) which can be used for optimisation. The potential savings in a high and ultra-high voltage system of a German interconnection company with altogether 400 nodes thus amount to up to 6% of the system losses.

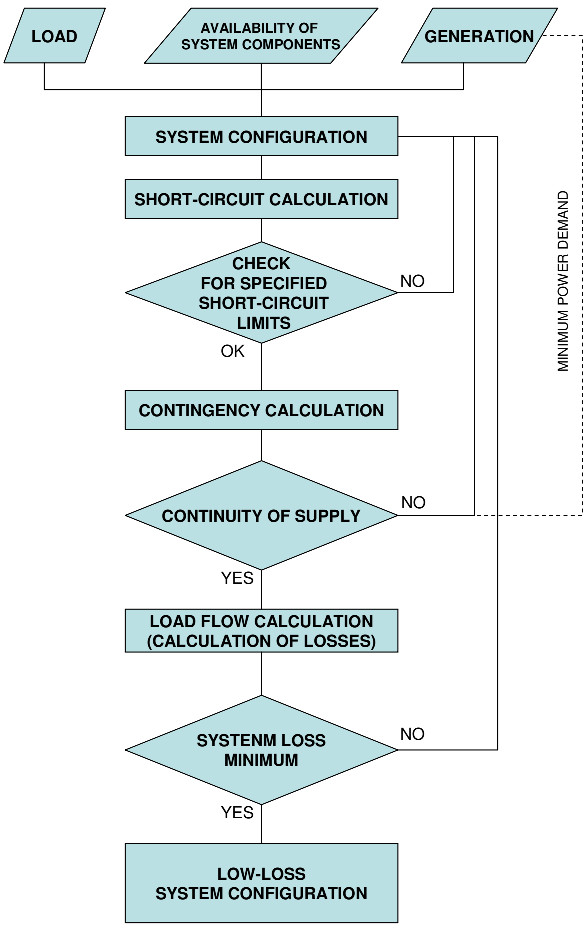

Fig. 1 Procedure for determination of optimum circuit states

On the basis of characteristic datasets, it is thus also possible to use a heuristic approach for optimising the circuit states, which is similar to the single step search procedure [4]. Fig. 1 shows the corresponding procedure. This results in a respectable reduction in system losses P_V in the exemplary 110 kV system (including transformation 380/110 kV and 110/10 kV) used for the following studies. A system configuration is developed on the basis of a certain load situation (winter or summer peak-load period), generation dispatch and the planned non-availability of system components. Compliance with the boundary conditions (short-circuit limit values, voltage range, equipment load, continuity of supply) is checked with short-circuit calculations and contingency analysis. The final load flow calculation is used to determine system losses or heat loss. However, up to now no criteria and rules have been formulated for the power system management to optimise the circuit states of the distribution system without online power flow calculation or computerised circuit state optimisation, The method used in this current study and the correspondingly determined low-loss system configurations are a suitable basis for developing such criteria and rules.

STUDIES

In circuit state optimisation, the availability of system components and generation dispatch play a major role as well as grid load and grid topology. This is why the planned non-availability of system components (maintenance, planned repair) is considered as well as different generation dispatch. Planned shutdowns primarily take place in the summer months taking into account that the maximum system load in summer is around 16% less compared with winter peak-load periods and some maintenance work can only be carried out depending on the weather. Concrete examples of system configurations with certain electrical equipment scheduled unavailable were examined to search for their system loss reduction potential. The calculations were performed using exemplary distribution systems illustrated in figures 2 to 5. These distribution systems are normally operated in 3 subsystems due to short-circuit current limitation.
The following studies were carried out:

- Summer peak-load with non-availability of system components
- Summer peak-load with all system components available
- Winter peak-load with all system components available
- Variation in generation dispatch

RESULTS

Figs. 2 and 3 show system configurations with planned shutdowns (system components not available). For the system diagram in Fig. 2, a difference of just around 6% between high-loss and low-loss configurations were realised by transferring load located at subsystem boundaries as well as optimising the system configuration for the power units feeding in the subsystem M. The system diagram as per Fig. 3 only offers little scope for circuit state optimisation because of the non-availability of electrical equipment, with a maximum loss reduction of less than 1 %.

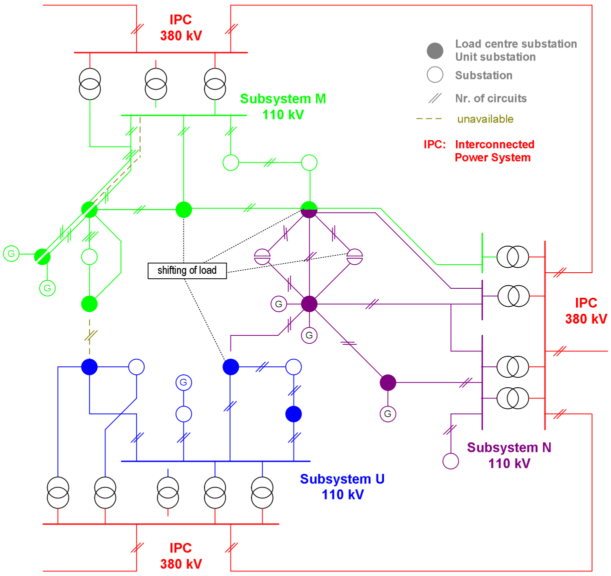

Fig. 2 Summer peak-load with planned non-availability of system components
Difference: 5.6 % ($\Delta P_V = 0.9$ MW)

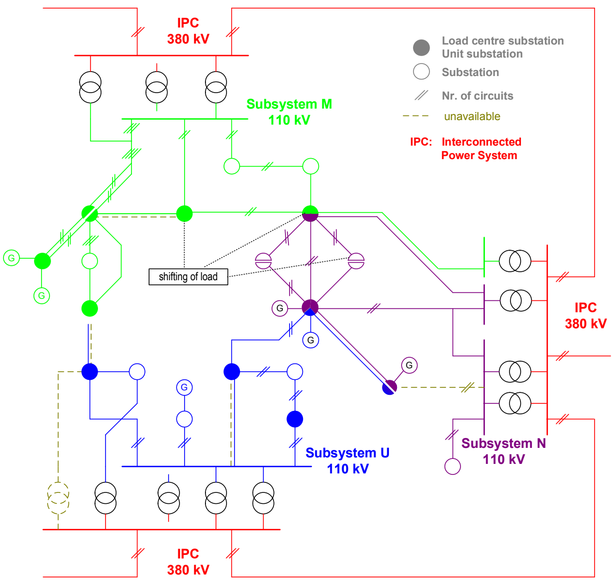

Fig. 3 Summer peak-load with planned non-availability of system components
Difference: 0.74 % ($\Delta P_V = 0.1$ MW)

It is clear that the potential for circuit state optimisation in terms of loss reduction depends greatly on the availability of the electrical equipment. The planned non-availability of system components is determined early on by an annual shutdown schedule. Continuity of supply and efficient execution of the planned services outrank the reduction of system losses.

A study of various system configurations under summer peak-load and availability of all system components resulted in a difference of approx. 11 % between high-loss and low-loss configurations.

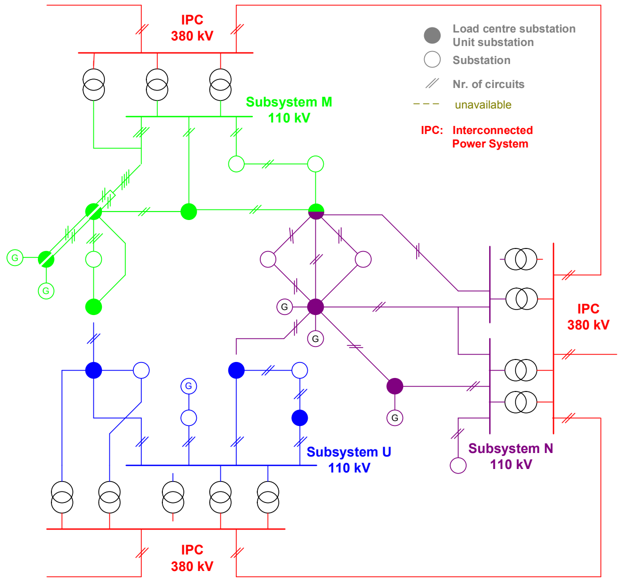

Fig. 4 System diagram 1: Winter peak-load with all system components available

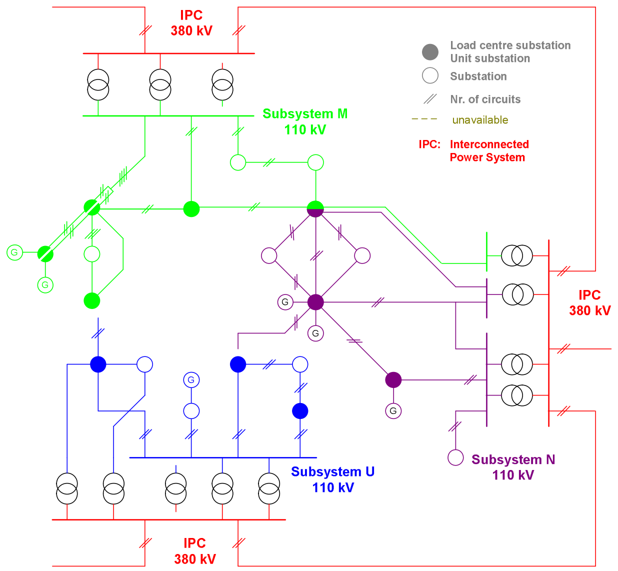

Fig. 5 System diagram 2: winter peak-load with all system components available,
Loss reduction compared to system diagram 1: 19.9 % ($\Delta P_V = 4.3$ MW)

Figs. 4 and 5 show system diagrams for winter peak-load and availability of all system components. By transferring network feeders and loads during the optimisation process, the system diagram 2 shown in Fig. 5 is capable of reducing losses by just about 20% compared to system diagram 1 (Fig. 4).

One essential general condition for optimising circuit states is a low rate of circuit state changes. This makes it important to evaluate also the chronological sequence of the system loss of a system configuration and with it the heat loss over a specific period. Fig. 6 shows the daily power loss curve for various system configurations on a winter peak-load day. It is clear that only system configuration C offers potential savings in both peak load and off-peak periods.

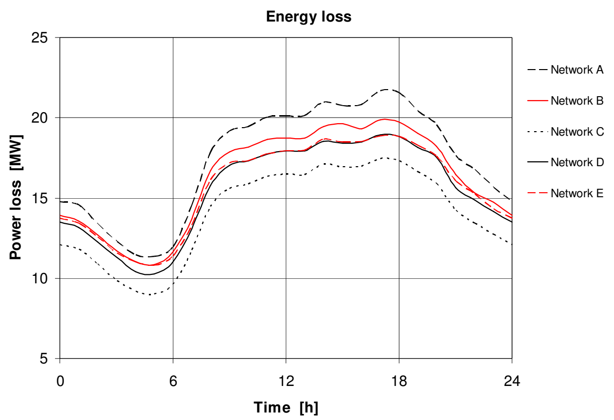

Fig. 6 chronological sequence of the system losses of different system configurations on a winter peak-load day

The reduction of system losses calculated for exemplary urban distribution systems depend on the particular network situation (load, generation, equipment availability, configuration). Therefore system loss reduction has to be determined for each single distribution system. A verification of these results in operational practice is necessary.
A projection of the potential reduction in yearly heat loss resulted in potential savings of 12.5 GWh. Here low-loss system configurations save approx. 30 MWh per day in the summer and approx. 70 MWh per day under winter peak-load. Potential savings for between the seasons was estimated at 45 MWh per day. This does not take account of the weekends.
Taking into account the volatile prices for hour contracts a loss reduction might influence the cost of losses in a corresponding range.

SUMMARY AND CONCLUSION

In high voltage urban distribution systems, network losses can be reduced by circuit state optimisation. Regardless of measuring and network topology, both mathematical optimisation methods and heuristic approaches can be applied. The online open loop mode is not always feasible for circuit state optimisation because of whose high demands on measuring topology. But the tests carried out show that already the offline mode offers respectably high levels of potential savings, with the characteristic load flow data being sufficient in this case to offer respectably high levels of system loss reduction. This system loss reduction in distribution networks depend to a high extent on the load and feeding situation and on the availability of electrical equipment, and therefore should be defined individually for every distribution system. In addition frequently adapting the system configuration by the power system management to minimise losses should be avoided in order to warrant steady system operation and prevent maloperation.
The heuristic approach used here to develop low-loss network configurations managed to achieve loss-differences of up to 20% between high-loss and low-loss configurations during peak-load periods. This resulted essentially from transferring the loads especially at the subsystem boundaries of the 110 kV network as well as from suitable adjustment of the feeding configuration. In this way costs can be reduced by implementing low-loss network configurations, thus the efficiency of system operation will be increased.
The results shown in this paper both have to be transferred from exemplary to real distribution systems and verified in the practical experience of power system management. Additionally it is assumed that well-trained control centre staff often implements low-loss system configurations by experience.
The voltage reactive power optimisation which has not been examined explicitly here provides additional system loss reduction potential of a further 3 % [4].

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