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POWER TRANSFER CAPABILITY ASSESSMENT OF TRANSMISSION INTERFACES WITH SVC AND LOAD SHEDDING SYSTEMS

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ABSTRACT
The article deals with the problem of the transfer capability assessment and monitoring for interfaces with SVC and load shedding schemes. It is shown that transfer capability calculation off-line includes models' inaccuracy and uncertainty. The special measure to monitor transfer capability on-line is proposed. This measure is a distance to voltage instability point. The distance may be observed by measurement of SVC output.
The problem of optimal SVC size selection is considered. The new approach is proposed. The approach is based on P-V curves analysis. From the transfer capability point of view optimal SVC size may be obtained from P-V curves for various system conditions caused by outage of different elements. The new approach allows to rate SVC optimally for increasing transfers capability of transmission corridors.

KEY WORDS
Voltage stability, SVC, Load Shedding, and Transfer Capability

1. Introduction

Deregulation in power industry leads to the changes in the technological operation of the power systems. Energy trade and markets push transmission system operators to operate their systems closer to the edge of the power transfer capability. In many power systems the transfer limits are determined by voltage stability issues for majority cases. Voltage instability followed by inadequate reactive power support of generators was a key factor in the most of major outages worldwide [1,2]. A lot of research has been carried in the area of on-line human supporting anti-emergency systems. Various artificial intelligence techniques have been use to assist operators in dealing with complex emergency situations in power systems [3-5].
However, the most effective way to control power systems is to avoid complex emergencies by reliable planning and secure operation of power systems. In this aspect, precise calculation of the power transfer capability of transmission interfaces is an important task on the planning and operation stages [6]. Also, FACTS introduction in power systems [7] contributes to the stability and increases power transfer capability.
This article deals with power transfer capability limited by voltage stability issues [8] in power systems with FACTS and load shedding schemes. The tasks of this article are to find a new measure for on-line monitoring of power transfer capability (by monitoring the distance to voltage instability point) and to create a simple rule for SVC size selection for interfaces with load shedding schemes.

2. Problem Formulation

Power transfer capability is determined according to the local policy [9] as maximal allowable active power transfer P_{MAP}:

$$P_{MAP} = \frac{P_T - P_O}{1 + K_R} \tag{1}$$

where P_T is a threshold active power; P_O is an amplitude of low frequency active power oscillation; K_R is a transmission reliability margin coefficient.
P_T is limited by angle or voltage stability, or by thermal overload of equipments. It is usually determined P_T by series of load flows with increasing power transfers. Load flows are being solved while monitoring convergence, angles, voltages at critical buses and equipment loading. The point where the power flow last solved (or voltage or loading constraint violations are found) corresponds to the critical point and determines P_T for those conditions.
P_O might be found from eigenvalues analysis, time-domain simulation, measurements or empirical formulae.
For normal system conditions (all N-elements of the interface remain in operation) K_R is standardized as 0,2 [9]. For abnormal system conditions caused by single

outage of generation unit or transmission element (N-1 elements remain in operation) K_R is standardized as 0,08. Therefore for normal system conditions the formulae (1) gives:

$$P_{MAP}^{N} = \frac{P_T^N}{1{,}2}.$$

Note, that P_O may be neglected for interfaces connecting power system area with installed generation much greater than load demand with area of insufficient installed generation (installed generating capacity is much less then the demand load). Fig. 1.

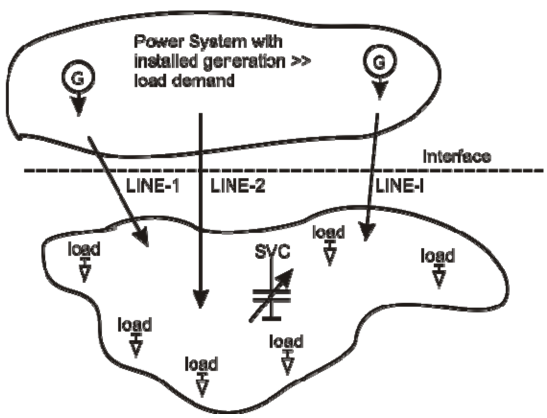

Fig. 1

For N-1 system conditions power transfer capability is:

$$P_{MAP}^{N-1} = \frac{P_T^{N-1}}{1{,}08}.$$

where P_T^N and P_T^{N-1} corresponds to P_T in normal and N-1 system conditions, respectively. From operational security point of view we are interested in the minimum values of P_T^{N-1} which correspond to the system condition caused by failure of the most significant element. It should be noted that in power systems with insufficient installed generation P_T^{N-1} is limited by voltage stability. Therefore, the maximal allowable active power transfer (with No Load Shedding - NLS) is defined as

$$P_{MAP,NLS} = \min(P_{MAP}^{N}, P_{MAP}^{N-1})$$

and may be illustrated by the P-V curves (Fig. 2).

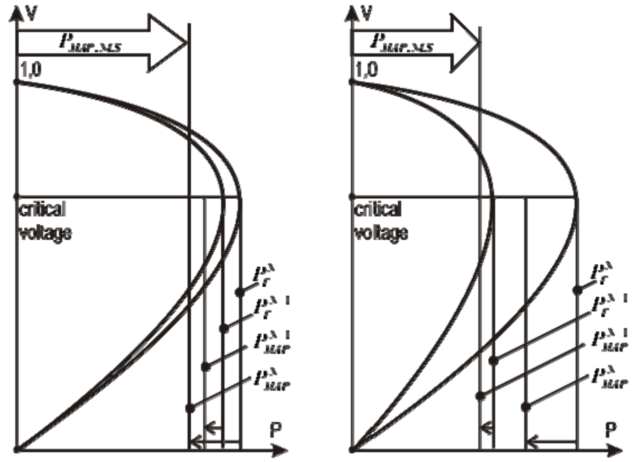

Fig. 2

If the interface consists of number transmission lines, N-1 emergency will not lead to significant limitation of transfer capability (Fig. 2, left). On the other hand, if the interface consists of a few transmission lines only, N-1 emergency will lead to significant limitation of transfer capability (Fig. 2, right). For such interfaces the special load shedding (LS) scheme is effective measure to increase the transfer capability (Fig. 3, left).

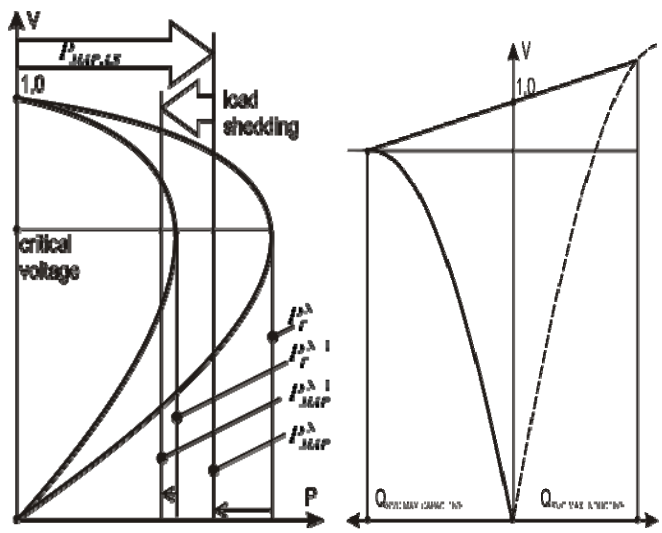

Fig. 3

For interfaces with LS maximal allowable active power transfer is defined as

$$P_{MAP,LS} = \min(P_{MAP}^{N}, P_{MAP}^{N-1} + P_{LS})$$

where P_{LS} is value of load to be shed automatically in case of lost of any elements in the interface. In reality the load shedding scheme selects the value of active power to be shed depending on which element of the interface is lost and what was the pre-fault power transfer. It is necessary to curry out a lot of calculations of threshold active power for different interface's configurations in off-line mode to adjust the load shedding scheme optimally. Threshold active power depends on load characteristics, elements' models, voltages at neighbouring substations etc. It brings random uncertainty in the off-line calculations. Therefore the monitoring of voltage stability is based on values (usually active power and voltages at selected busses) calculated off-line with many conservative assumptions made. Uncertainty in the calculation is the main reason to increase transmission reliability margin. The margin limits the transfer capability. Therefore the important task here is to find a new measure which allows monitoring voltage stability directly and to avoid calculations' uncertainty.

The load shedding schemes are widely used in the power systems of Ukraine and Russia. However, deregulation of power industry makes this approach an ineffective measure to increase transfer capability of existing interfaces.

On the contrary, the FACTS technology proposed an affective tool to increase transfer capability of existing interfaces. In particular, SVC (V-Q characteristic is depicted on Fig. 3, right) is capable to provide reactive power to support voltage and to improve the voltage stability. It is very important task to select right place and size of the SVC. Many researches have been devoted to the problem of FACTS selection and allocate on [10-11]. However, it is still uncovered the issue of SVC size selection for interfaces controlled by LS automatics.

3. The approach proposed

It is well known that SVC contributes voltage stability. In normal operation (all lines of the interface and SVC are in service) P_T^N is increased due to the reactive power support from the SVC (Fig. 4). Note, that critical voltage will be increased also.

For the interfaces with no load shedding the size of SVC has to be selected taking into account N-1 criteria. The impact of the SVC loss on transfer capability of the interface should not be bigger than the impact of loss of any lines and vice versa. Consider two cases. First one is an abnormal system condition caused by outage of SVC (N-1, SVC) and second one - caused by outage of line (N-1, Line).

Case: N-1, SVC. If the minimum value of P_T^{N-1} corresponds to the system condition caused by failure of the SVC (as most significant element), then conclude that SVC size is too big (Fig.4, left). Transfer capability is limited by loss of SVC. Therefore the size of SVC has to be reduced (Fig.4, right).

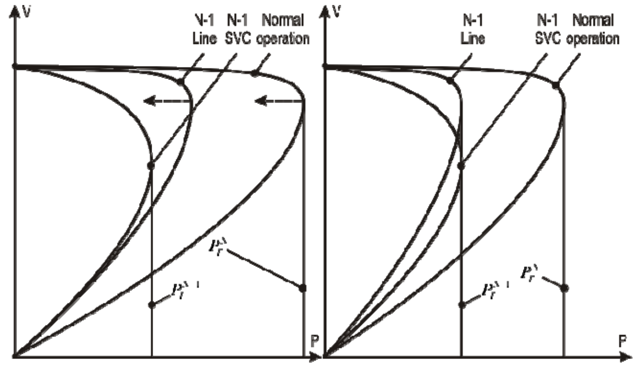

Fig. 4

Case: N-1, Line. On the other hand if the minimum value of P_T^{N-1} corresponds to the system condition caused by failure of certain line (as most significant element), then conclude that SVC size is too small (Fig.5, left). Transfer capability is limited by loss of this line. Therefore size of SVC has to be increased (Fig.5, right).

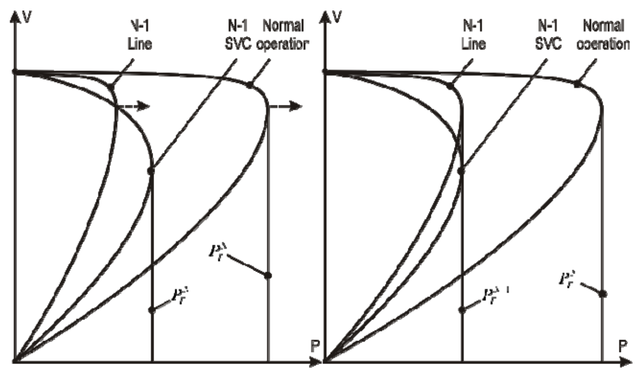

Fig. 5

The criteria of optimal SVC size is

$$P_T^{N-1,\,SVC} - \min(P_T^{N-1,\,LINE-i}) = \varepsilon,\ for\ i = 1, N \quad (2)$$

Where $P_T^{N-1,\,SVC}$ is P_T^{N-1} cased by loss of SVC; $P_T^{N-1,\,LINE-i}$ is P_T^{N-1} cased by loss of Line i; ε is a small value (threshold).

From the transfer capability point of view utilisation of SVC may be considered as a measure to replace load shedding schemes in deficient power system (Fig. 6, left) and as a measure to increase transfer capability using load shedding (Fig. 6, right). It should be noted that criteria (2) is not valid for interfaces with load shedding. If the SVC size is quite big and impact of the SVC loss on transfer capability of the interface bigger than the impact of loss of any lines, then additional load have to be added to shedding scheme.

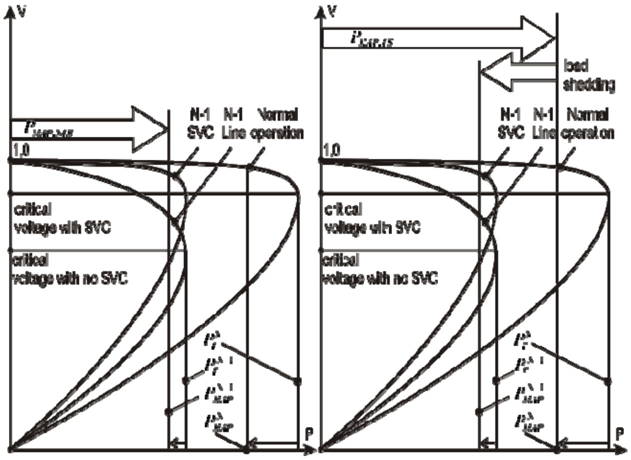

Fig. 6

On the other hand, quite big SVC may be considered as a flexible controlled souse of reactive power. It is known that the reason for voltage collapse is the reactive power balance violation. Therefore voltage instability point may be monitored on-line by measurement of SVC output. If the SVC Mvar reserve is ended, then the reactive power balance violation and voltage instability will be observed immediately. The idea is illustrated on Fig. 7. The figure has been created by combination of P-V curves with V-Q characteristic of SVC.

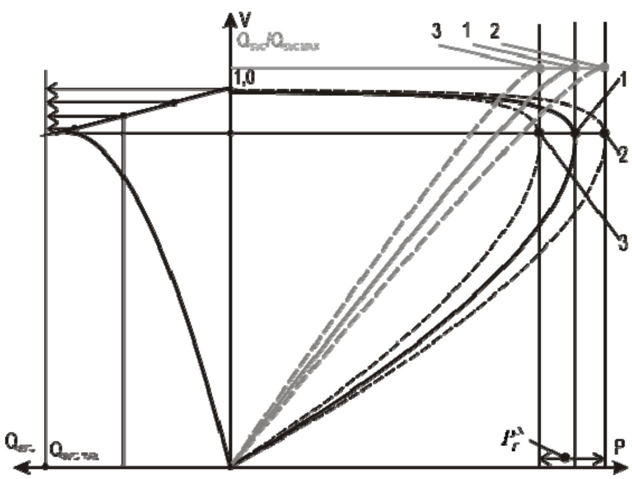

Fig. 7

Note, that P_T^N may vary significantly with voltage at neighbouring substations and load characteristics changes. On Fig.7 P-V curve 1 corresponds to default calculation parameters, P-V curve 2 obtained by changing voltage dependency of all loads, and P-V curve 3 obtained by small reducing of voltages at neighbouring substations. Grey coloured curves are dependences SVC generated reactive power (in p.u.) from active power transfer. When the relation (3) approaches to 1, it means that the SVC reserve is almost ended and voltage instability will occur.

$$\frac{Q_{SVC}}{Q_{SVC\ MAX}} \qquad (3)$$

where Q_{SVC} is a reactive power generated by SVC in actual state of power system, $Q_{SVC\ MAX}$ is a maximal (rated) reactive power of the SVC installed.
Therefore,

$$1-\frac{Q_{SVC}}{Q_{SVC\ MAX}}$$

may be considered as operational distance to voltage collapse (left arrows on the Fig.7) and the measure to monitor voltage stability.

4. Case Study

The proposed approach is demonstrated on the IPS Ukraine-Crimea interface (Fig. 8). The interface consists of four lines (three 330kV and one 220kV). The SVC (350 Mvar) is simulated at substation Dzhankoy-330.

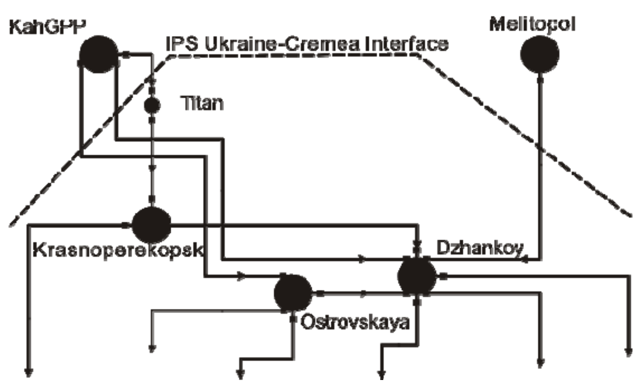

Fig. 8

The Crimea power system model includes 236 busses and 325 lines with nominal voltages from 110 to 330kV. The simulations have been performed using DIgSILENT Power Factory software [12]. The simulation results in the form of P-V curves are depicted on the Fig. 9.

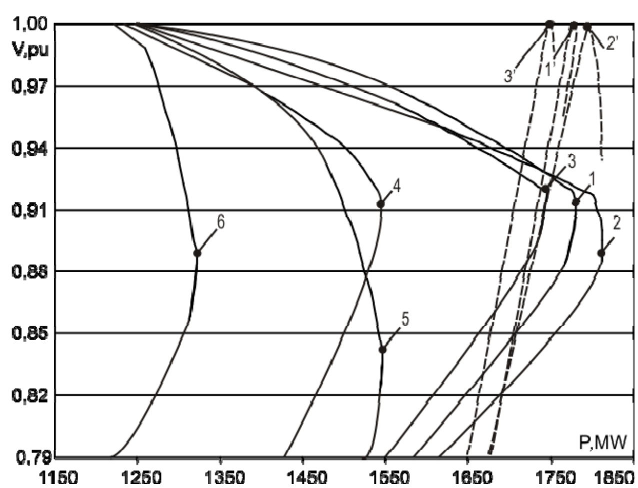

Fig. 9

The P-V curve 1 on Fig.9 corresponds to calculation of transfer capability with default parameters. The threshold active power is 1780 MW. If the voltage at upstream substations is reduced on 5%, the threshold active power of Ukraine-Crimea interface is about 1745 MW (P-V curve 3). If the model of loads (voltage dependency is increased) is changed, the threshold active power is about 1812 MW (P-V curve 2). In spite of the fact that threshold active power varies from 1745 MW to 1812 MW it is easy to monitor voltage collapse point by curves 1',2',3'. These curves are simulated by load flow using formulae (3). Therefore it is possible to avoid uncertainties and model inaccuracy in off-line calculation of transfer capability.
Another result which may be observed from Fig. 9 is the correct SVC size according to the criteria (2). The P-V curve 4 corresponds to loss of the line 330 kV Melitopol – Dzhankoy (most significant line). The P-V curve 5 corresponds to loss of the 350 Mvar SVC. Threshold active powers are equal for both cases. It proves that SVC size is optimal for this interface. The curve 6 corresponds to loss both elements (N-2): the line 330 kV Melitopol – Dzhankoy and the SVC.

5. Conclusion

The transfer capability determination in off-line mode and monitoring in on-line mode of transmission corridors with SVC and LS schemes are analysed.
As a measure to monitor transmission capability on-line, the distance to voltage collapse point is proposed. This distance may be obtained by monitoring on-line SVC output in Mvar. It allows avoiding calculations uncertainties and model inaccuracy in off-line mode.
The new approach to select SVC size is proposed. This approach is based on P-V curves analysis for different system conditions caused by failure of lines and SVC. The approach allows to rate SVC optimally for increasing total transfer capability of transmission corridors.

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