OPTIMIZATION OF OVERVOLTAGE PROTECTION OF DISTRIBUTION NETWORKS

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ABSTRACT

Along with increasing importance of power quality the effect of overvoltage protection to short interruptions and voltage dips is of great importance. With advanced reliability analysis tool integrated to network information system, the effect of protection can be studied. The calculations which have been done shows that the investments on increased overvoltage protection is extremely profitable if theshort interruptions and voltage dips are taken into account as outage costs.

INTRODUCTION

The overvoltage protection of distribution networks is quite challenging task. The traditional reason for overvoltage protection has been prevention of failure of expensive components like transformers. Along with increasing importance of power quality the effect of overvoltage protection to short interruptions and voltage dips is of great importance. This means that overvoltage protection should be deeply modeled and analysed as part of reliability based network analysis. For example, selection of using surge arresters instead of spark gaps in transformer protection is not necessary based on the transformer itself but the consequences of short interruption and voltage dips due to arcs in spark caps. This paper presents different types of strategies which can be applied in overvoltage protection planning. Additionally ,the paper describes studies which have been done using the reliability analysis tool in optimization of overvoltage protection.

OVERVOLTAGES AND OVERVOLTAGE PROTECTION

Lightning overvoltages

Lightning can cause transient overvoltages on transmission and distribution networks by direct strokes to current conductors, by back flashovers or by induction from the strokes to objects next to the overhead line. Induced overvoltages don't usually cause failures of equipment or other harm in networks of high system voltage ($U_s > 52$ kV) but in distribution networks ($U_s \leq 36$ kV) their amplitude is high enough (maximum approximately 400 – 500 kV) to cause problems. The main factors influencing the amplitude of the induced overvoltage are the magnitude of the return-stroke current, the speed of the return-stroke, the distance between the stroke position and the line, the height and the configuration of the conductors and the resistivity of the soil between the stroke position and the line [1,2]. Due to the shielding effect of the nearby objects (trees, masts, buildings) a major part of the harmful transients in Finnish distribution networks (U_s = 24 kV) are induced overvoltages. Hence, they are the most interesting object in overvoltage protection investigations concerning distribution networks.

Overvoltage protection

Mainly three types of devices are used for overvoltage protection in distribution networks: spark gaps, surge arresters (old type gapped silicon-carbide arresters or modern gapless metal-oxide arresters (MOAs)) and current limiting arresters (CLA, a series connection of a "small" MOA and a spark gap). Shielding wires over the lines are used rather seldom in distribution networks due to the increasing risk of back-flashovers, which in turn is a consequence of difficulties to achieve good groundings of the shielding wires along the line. If shielding wires are used (with good groundings), they can decrease also the amplitudes of induced overvoltages by 20-40 % [3].

Alternative strategies for overvoltage protection

Traditional protection

In Finland small distribution transformers (below 200 kVA) are traditionally protected with spark gaps, and bigger ones with surge arresters. Spark gap protection demands special transformers, which have to be tested with chopped, deep front lightning impulse voltages. The costs of spark gap protection itself are rather low but, on the other hand, the transformer costs are higher due to the special transformers. The only target of this traditional strategy has been to protect transformers and other equipment (e.g. cable terminations) against lightning. Lightning overvoltages in distribution networks usually cause all the spark gaps of the three phases to ignite, which leads to three phase short-circuit (usually with ground connection) and hence to reclosing operations of the feeder. In addition, voltage dip will occur in all the feeders connected to the same bus bar in the substation. The deepness of the dip depends on the position (short-circuit current value) of the sparking gaps and the voltage stability of the network feeding the bus bar.

”Full” protection

Recently, many utilities in Finland have started programs to change the spark gaps to current limiting arresters (CLAs). The main targets of this action are to improve the protection level for equipment and, particularly, to decrease the amount of short interruptions and voltage dips due to the arcs in spark gaps. Short interruptions due to the reclosing operations and, recently, voltage dips, have been considered more and more harmful by the users of electricity.

Full protection strategy means that all small transformers (below 200 kVA) are protected with CLAs and all big transformers (≥ 200 kVA) are protected with surge arresters.

Partial protection

Partial protection strategy means that all small transformers (below 200 kVA) are protected with CLAs and all big transformers (≥ 200 kVA) are protected with surge arresters to a certain distance from the substation. The distance is determined so that the minimum residual voltage (during a three phase short-circuit) is approximately 70 % of the nominal voltage. The rest of the feeder is protected using the traditional strategy. The aim of this partial protection strategy is to prevent deep voltage dips to occur.

NETWORK STUDIES

This section presents some results of the studies, which have been done using data of one Finnish utility. The main idea is to compare the different overvoltage strategies by calculating the total long-term costs. Before the studies the software tool used is briefly presented.

Reliability analysis software

At Tampere University of Technology models for reliability based network analysis have been developed and implemented as part of a network planning software. First version of the reliability analysis was developed already in 1980s and it has been used e.g. for studying the optimal number and location of remote controlled disconnectors. In the earlier analysis, failure rates were constant for similar components (e.g. 6 failures per year and per 100 km for all overhead lines) without taking into account any other factors influencing to the reliability of the components. In reality, the operational environment affect to the failure rate. In the developed more advanced reliability based network analysis failure rates are based on the “partial failure rates” due to certain failure causes. E.g. for a transformer the overall failure rate for permanent faults is a sum of partial failure rates due to lightning, animals and other fault causes. Partial failure rates are, in turn, dependent on one or more weight factors. For example the partial failure rate due to wind and/or snow for overhead lines is dependent on the surroundings of the line (forest, field or next to road) and on neutral earthing method of the overhead line feeder. Defined partial failure rates and weight factors are based on failure statistics collected from several network utilities and Finnish failure statistics. In addition to statistics, engineering judgment was used when enough adequate failure data was not available.
The reliability analysis in radially operated distribution networks is quite straightforward, but the difficulty is in the determination of the outage time in different parts of the network. Some parts of the network can be restored in few minutes by using remote controlled disconnectors, but some other parts must be restored manually, which will take some tens of minutes. In a fairly small part of the network the outage time is the same as the real repair time. In the reliability model several different switching times are applied and each outage time depends on how faulted component, load point and remote controlled and manually operated disconnectors are situated.
The reliability analysis results in the expected number and duration of outages each load point in the network as well as the overall reliability indiced (SAIFI, SAIDI, CAIDI and MAIFI). The load point specific information can further be used as an input for outage cost modelling. The evaluation of the outage costs experienced by customers is based on the value of non-distributed energy, which is determined by outage cost parameters of different customer groups. Costs like losses in production are taken into account in definition of inconvenience costs for a customer. In this connection customers are divided into five groups: residential, agricultural, industry, public and commercial. The outages are divided into four categories: long fault interruptions, planned maintenance outages and short auto-reloclosing occurrences (i.e. < 1 second and < 3 minute). The cost model has two parameters that ascribe a cost to the interrupted demand, A [€/kW], and to the unsupplied energy, B [€/kWh]. For the auto-reclosings there is separate values. Table I shows the input data for the outage cost definition described in more detailed in [4].

TABLE 1. The reliability worth parameters

	Unexpected		Planned		High-speed AR	Delayed AR
	A	B	A	B	A	A
Residential	0.36	4.29	0.19	2.21	0.11	0.48
Agriculture	0.45	9.38	0.23	4.80	0.20	0.62
Industry	3.52	24.45	1.38	11.47	2.19	2.87
Public	1.89	15.08	1.33	7.35	1.49	2.34
Commercial	2.65	29.89	0.22	22.82	1.31	2.44

In addition of the reliability analysis the software calculates the expected number and the depth of voltage dips for each load point. In order to include the dips also to the overall cost calculation the cost of dip should be evaluated. Because a deep voltage dip is like short interruption from a customer point of view it is natural to use the cost of fast autoreclosing also to dips. In the studies presented below the dips in which the residual voltage is less than 60 % causes the same cost as the short interruption due to fast-auto-reclosing. One cost model for voltage dips is also presented in [5], but using those values in our example utility the €/dip values would have led to extremely higher dip cost comparing with the auto-reclosing events.

The developed reliability based network analysis has been implemented into a network planning software. In the implementation network information system (NIS) with interface to customer information system (CIS) has been used as a platform. The basic idea of the developed modern reliability based network analysis is depicted in more detail in reference [6].

Alternative network studies

Using the software tool , several network studies have been carried out. In the part of network under study there is network fed by one primary substation (110/20 kV). There is four urban feeders and four rural feeders. Initially the urban feeders were totally protected by surge arrested, while in the rural feeder only the bigger transformers (≥ 200 kVA) have been protected by surge arresters. The alternative choice for the overvoltage protection is using arresters in all the transformers in that case the protection of small transformers would be done using CLAs. That strategy has proven to be beneficial in studies presented in [7], and is also used nowadays in Vattenfall as a part of boosted maintenance of distribution transformer substations. Boosted maintenance means addition of improved overvoltage and animal protection during the periodical maintenance of the secondary substation. In Koillis-Satakunnan Sähkö, partial protection strategy have been chosen in order to reduce the harm due to voltage dips.

The result of the study are presented in table II and in figure 1. The study period was 20 years, which has been evaluated to be the use time of CLAs. In the table II the costs due to ligthning has been also separately presnted in order to show their portion of the different components of the outage cost. As can be seen. The effect of costs due to lightning is remarkable regarding with short interruptions and dips, but quite minor regarding with permanent interruptions. However the direct costs due to transformer failures is not taken into account in the study.

TABLE I1. The result of the study

	Traditional protection	Full protection	Partial protection
Permanent faults	1005.65	997.89	1002.28
Permanent faults (lightning)	22.09	14.33	18.72
Short interruptions	998.48	663.34	896.29
Short interruptions (lightning)	433.94	98.8	331.75
Voltage dips	733.7	471.77	471.77
Voltage dips (lightning)	361.78	99.85	99.85
Investments	-	103.8	45.6
Total	2737.83	2236.80	2415.94
Total (lightning)	817.81	316.78	495.92

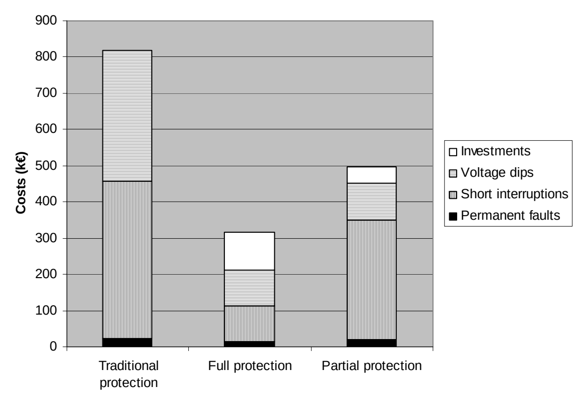

Figure 1. Outage costs due to faults caused by lightning and investments to the overvoltage protection

The result of the study shows that adding arresters is very profitable in both strategies. The full protection should be the goal, but the partial protection gives the rule to be used in the priorisation of the improved protection: The installation of the CLAs should be started from the beginning of the feeders of the most important primary substation.

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