METHOD FOR DETERMING DYNAMIC SHORT CIRCUIT WITHSTAND CAPABILITY OF INSTALLATIONS IN MESHED CABLE MV-NETWORKS, DURING SWITCHING ON A FAULT

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ABSTRACT

Stedin is the Distribution Grid Operator in the western part of the Netherlands and is known to be a "slim network operator" which means that it is only responsible for managing the gas and electricity networks. In this paper a method will be described with which Stedin proved that the dynamic short circuit withstand capability of the installations in the Medium Voltage (MV)-rings can dynamically withstand the immediate occurring fault current after switching on a fault.

INTRODUCTION

Major power system disturbances and outages have a significant economic and social impact and the security of supply becomes a more and more important issue. Hence outage times should be as short as possible.

In the Stedin service area fault restoration is done via a third party service provider. At this moment during an outage fault localization takes place and after finding the faulted cable, cable testing is done first before the network is re-energized. This is very time consuming and increases the outage time as well as the contribution to the customer minutes lost.

In order to keep the outage time as short as possible Stedin has investigated if the cable testing can omitted during fault restoration. However, this introduces a risk of switch onto a fault. It sometimes occurs that the wrong cable section gets isolated and the fault is still present somewhere in the MV-ring. If in this case switching actions take place, there will be switched on a fault. This means that a fault current goes through the installation immediately after switching. To convince the service provider that the cable testing during fault restoration can be omitted without sacrificing the personal safety Stedin has studied the impact of switch onto a fault at the normally open point in Medium Voltage networks (MV-networks). The results of this study is discussed in this paper.

Problem Approach

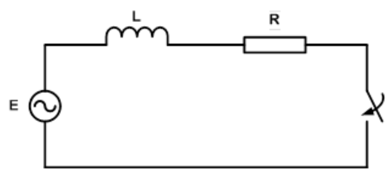
The MV-network of Stedin can be divided into approximately 170 distribution grids operated at a voltage level of 23, 13 or 10 kV). The first step in this project is to collect all the data of all the different types of MV-installations in these distribution grids. This project only focusses on the dynamic withstand capability of the installations. Then, 170 distribution grids are analysed and the critical distribution grids are identified. For these critical grids hold that the total amount of short circuit power (S_k) on the primary HV/MV substation exceeds the rating of the MS-installation with the lowest dynamic withstand capability. In the Stedin area 52 distribution grids turned out to be critical networks.

The evaluation of the above mentioned critical grids will be explained in this paper. It will be shown that within each critical grid a critical distance can be determined in which the dynamic withstand capability of the MS-installations might be exceeded. Because re-energizing a network after a fault is done by closing the normally open point (NOP). In this case there is a chance of switching onto a fault hence the most critical situation occurs when a NOP is located within this critical distance. The evaluation of the withstand capability of the NOP's within the critical distance will also be explained.

BACKGROUND THEORY

Switching on a Fault

Switching on a fault occurs when the switch closes into a short-circuited line or underground cable. This can most simply be represented by Figure 1, where a sinusoidal voltage is switched on to a series connection of an inductance (L) and resistance (R).



With:
$E=E_{max}\sin(\omega t+\varphi)$

Figure 1: *sinusoidal voltage source is switched on to a RL series circuit*

Applying Kirchhoff's voltage law gives the following differential equation:

$$E_{max}\sin(\omega t+\varphi) = Ri + L\frac{di}{dt} \tag{1}$$

t is zero at the time of applying the voltage and α determines the magnitude of the voltage when the circuit is closed.

The solution of this equation is:

$$i = \frac{V_{max}}{|Z|}\left[\sin(\omega t + \alpha - \theta) - e^{-\frac{R}{L}t}\sin(\alpha - \theta)\right] \quad (2)$$

Where: $|Z| = \sqrt{R^2 + (\omega L^2)}$ and $\theta = tan^{-1}(\omega L/_R)$

The *dc component* of the current decays exponentially with a time constant $L/_R$. The first term of (2) is the steady-state short circuit of constant amplitude [1]. The second term of (2) is the decaying DC-component which gives, together with the steady state current, the highest current value. This value occurs within the first period of the short circuit current and is called the peak current i_p. The peak value of the current can reach a value of about two times the steady state fault current value.

i_p and the maximum short circuit power $S_k^"$ are related in the following way [2]:

$$i_p = \kappa \cdot \sqrt{2} \cdot I_k^" \quad (3)$$

$$S_k^" = U_{nom} \cdot I_k^" \cdot \sqrt{3} \quad (4)$$

κ is called the impulse factor. In this project the short circuit takes place in passive distribution grids far from large scale generation. The short circuit current value doesn't really decrease due to the impact of synchronous generators, hence the following can be assumed: $I_k = I_k^"$ $\Rightarrow S_k = S_k^"$

The shape of the transient current is shown in Figure 2.

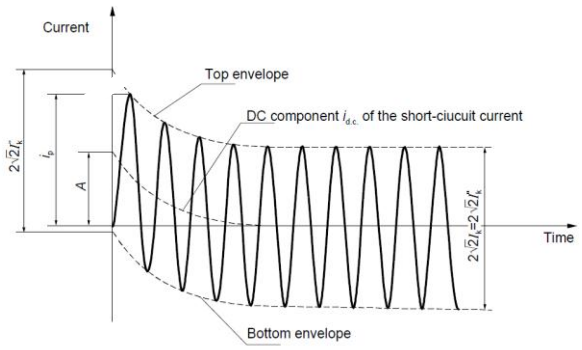


Figure 2: *Shape of the short circuit current in distribution grids [2]*

To find out if the MV-installations can withstand this transient current, the maximum or peak value (i_p) of the current must be known. As can be seen in figure 2 i_p can theoretically be $i_p = 2\sqrt{2}I_k$. According the IEC 60909 the value of ip can be calculated by applying an impulse-factor (κ) [2]. Usually kappa is chosen at 1,8. In this project this value is applied as well [2]. Hence, in total for the peak value holds $i_p = 2{,}5I_k$.

Critical Distance

Not all MV-installations within the MV-rings are critical. To create a general overview of the critical areas within the distribution grids, a method which is based on typical curves which show the development of the short circuit power (S_k) at various locations along the feeder. A distinction is made for different cable types and various values of the short circuit power in the substations. S_k as function of the cable length for different cable types, can be derived as follows:

$$S_k = \frac{U_l^2}{(Z_{gr} + l \cdot z_{cable})} \quad (5)$$

In (5) Z_{gr} is the grid impedance in Ω, *l* the cable length in km, z_{cable} the cable impedance in Ω/km and U_l the line voltage in kV.

With the above formula typical curves are made where the decrease of S_k (MVA) at the HV/MV substation is plot as function of cable type and cable length (km). In Figure 3 an example of such a plot is shown for a 95mm^2 CU GPLK cable and different values for S*k* (100, 200, 300, 400 and 500 MVA resp.).

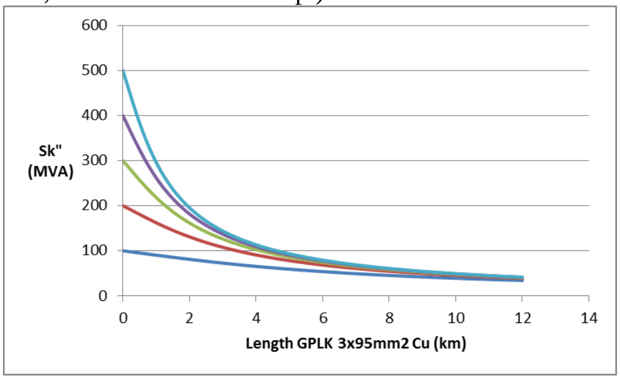


Figure 3: *Decrease of Sk (MVA) along the length (km) of a 95 mm^2 CU GPLK cable in a 10 kV distribution grid*

From these plots it is clearly seen at what distance from the HV/MV substation along the cable, the value of S*k* is still significantly high enough to possibly exceed the dynamic withstand capability of the MV-installations. In this project this distance is called the *critical distance*.

PROJECT ANALYSIS

Critical networks and critical distances

In the Stedin distribution network the MV-installation with the lowest dynamic withstand capability (I_k'') is an EATON-HOLEC COQ with I_k'' = 8,7 kA = ± 150 MVA. With this information the critical distribution grids can be found. These are the grids in which the value of S_k on the HV/MV-rail exceeds 150 MVA. From the total of about 170 distribution grids in the Stedin network, there were 52 critical distribution grids. These consisted out of 49 distribution grids operated at 10 kV and 3 distribution grids operated at 13 kV.

Evaluating and analysing all the MV-installations in these critical grids will cost a significant amount of time and investments. However, by determining the critical distance, the whole critical area can be narrowed down to the evaluation of a certain radius only. An example of determining such a critical distance is shown in Figure 4. In the example the critical distance is determined in a group of 10 kV distribution grids with the value of S_k at the busbar of the primary substation varying between 200 and 300 MVA. Because the weakest installation in the 10 kV distribution grid has a short circuit capability of 150 MVA in this project, the boundary is chosen at this value. The critical distance is the largest distance formed by the intersection of the boundary value and the S_k values. In this example the critical distance is 2.2 km.

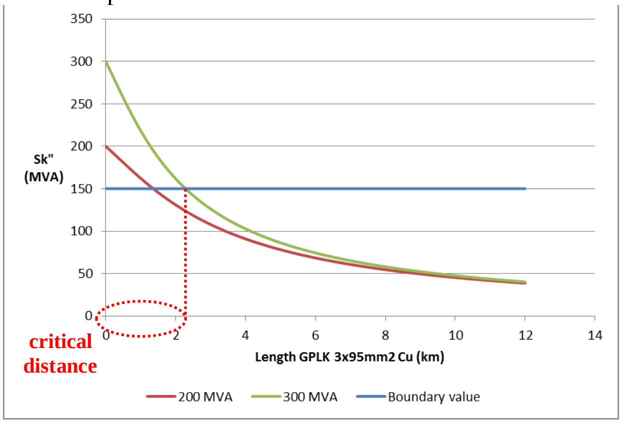


Figure 4: *Determining the critical distance in different grids with S_k on the HV/MV rail between 200 MVA and 300 MVA and MV installations along a 95 mm^2 CU GPLK cable in a 10 kV distribution grid*

A critical distance of 2.2 km means that the dynamic withstand capability of all MV-installation within the first 2.2 km can be exceeded when a 95 mm^2 CU GPLK cable is applied in the 10 kV distribution grid with a S_k of 300 MVA at the busbar of the primary substation. A summary of all the critical distances found for the 52 critical distribution grids is given in Table 1.

Table 1: *Summary of all critical distances for the 52 critical grids*

Cable Type	Critical Distance
3 x 50 mm2 Cu GPLK	1,2 km
3 x 95 mm2 Cu GPLK	2,1 km
150 mm2 AL XLPE	1,8 km
240 mm2 AL XLPE	2,2 km

Analysis of the Normal Open Points (NOP's)

In case of switching within MV-rings after short circuits, most of the switching takes place at the NOP's. These installations may thus easily be subjected to switching on a fault and this makes them the most severe MS-installation locations within the critical distance. The analysis of the NOP's is done in 3 steps. These steps will be explained and are summarized in the flow chart of Figure 6.

Step 1. In a critical network, all outgoing fields of the HV/MV substation need to be evaluated to asses if there are NOP's available within the critical distance. After evaluating the 52 critical distribution grids of Stedin, it seems that 377 NOP's are situated within critical areas.

Step 2. The dynamic withstand capability of the NOP's within the critical distance must be compared with the total *Sk* on the HV/MV rail in the concerning grid section. If the dynamic withstand capability of the MV-installation is exceeded, a priori this installation becomes critical. If not, the installation is eliminated from the analysis, because it is then assumed that the installation can withstand the occurring fault current peak during switching on a fault in the concerning grid. The evaluation of the 377 NOP's mentioned in step 1, resulted in 206 critical MV-installations.

Step 3. At the exact location of the critical MV-installation the actual fault peak current (i_p) can be different than the short circuit level at the busbar of the primary substation. Hence the local short circuit power at the NOP must be calculated. A short circuit in the critical installation demonstrates the highest current value in case of switching on a fault , because the faulted cable section will most likely be situated at a certain distance from the installation. Because NOP's are mostly situated within MV-rings, it must be taken into account during calculation that switching on a fault can occur in two possible ways. The difference is the actual location of the normally open point. This difference determines which feeder part is supplying the fault current. These feeder parts can have a different feeder length and hence the fault current can be different. This is shown in Figure 5. The possibility that causes the largest i_p is used for further analysis.

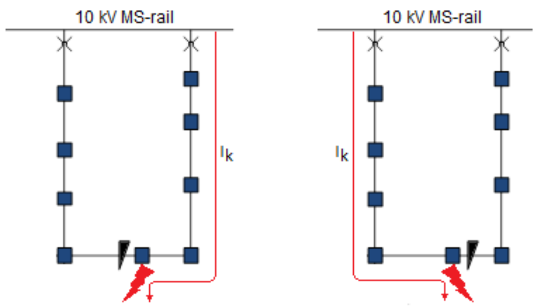


Figure 5: *Possibilities of short circuit analysis to determine the highest i_p in a MV-installation*

If step 3 results in an i_p that exceeds the dynamic withstand capability of the MV-installation, the installation will not withstand switching on a fault and must be replaced immediately.
In this project these calculations are simulated in the network simulation program Vision. Applying this analysis to the 206 critical installations mentioned in Step 2 showed that all the NOP's in the MV-grids of Stedin can withstand switching on a fault.

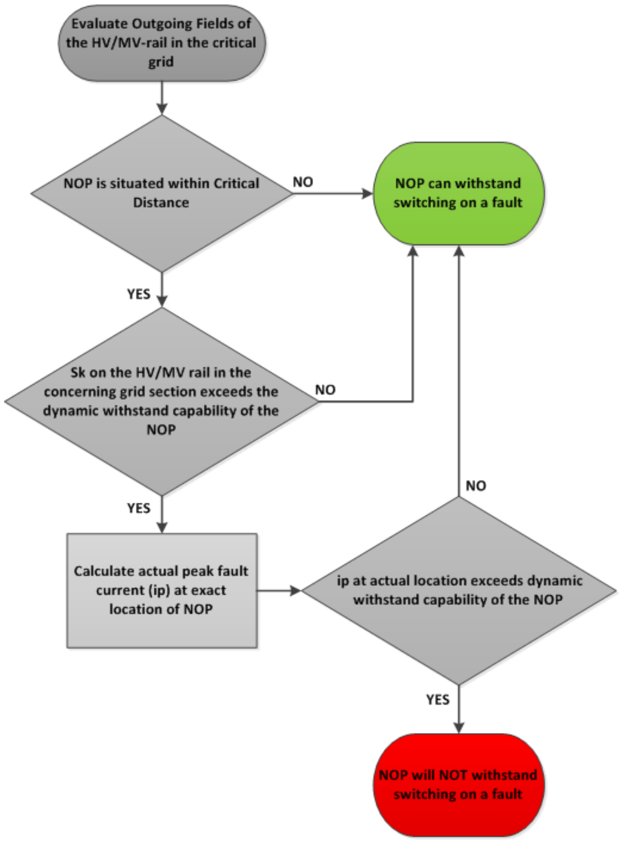


Figure 6: *Flow chart of the steps that need to be taken to analyse whether NOP's can withstand switching on a fault*

LESSONS LEARNED

By knowing that all the NOP's within the Stedin MV-network can withstand occurring peak currents during switching on a fault, Stedin can convince the third party that the time consuming verification method before switching is not necessary anymore, thereby reducing outage times. However, all safety precautions during switching actions still need to be followed.

To maintain this situation in the grid, future network designs need to take into account the critical area in which the dynamic withstand capability of MV-installations can be exceeded during switching on a fault. A possibility to take this into account is by making a standardisation for network design in which the company only allows MV-installation with dynamic withstand capabilities higher than a certain standardized value in each voltage level of the network.

CONCLUSIONS

This method proves that the dynamic short circuit withstand capability of the installations in the MV-rings can dynamically withstand the immediate occurring fault current after switching on a fault. It is a cost effective way which did not require a lot of manpower and investment. Before applying this method the necessary data of all installations needed to be available. It is also important that during calculations, the networks (cable lengths, installation details and network structure) need to be programmed correctly. Calculating a wrong current value may have disastrous effects on human safety. Therefore, even though the company proves that all MV-installations can withstand switching on a fault all safety precautions during switching actions still need to be followed.

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