Reliability of Transmission Links consisting of Overhead Lines and Underground Cables

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***Abstract*—Underground cables will be applied more often within new connections of the Extra-High-Voltage (EHV) transmission network. As EHV underground cables are a relatively new technology, not much is known about their behaviour in large transmission networks. Underground cable connections (consisting of cables, joints and terminations) are in general less reliable than traditional overhead lines, mainly because of their much longer repair time. This can negatively influence the reliability of the transmission network as well. It is therefore of interest to study the reliability of underground cable connections in detail. This paper concentrates on the reliability of EHV underground cable and overhead line connections. Based on actual failure statistics of individual components, the reliability of a connection is analysed, it is studied which factors are of influence and what measures can be taken to improve the reliability. An optimised cable repair process and a configuration with additional disconnectors are two solutions.**

***Index Terms*—power system reliability, reliability evaluation, transmission networks, underground cable connections**

NOMENCLATURE

EHV	Extra-high voltage (380/220kV in the Netherlands).
TSO	Transmission System Operator
c_{cc}	dependent failure factor [-].
f_c	failure frequency of an underground cable (single circuit, one cable per circuit phase) [/cctkm·y].
f_{c1}	failure frequency single cable circuit [/y].
f_{c2dep}	failure frequency of dependent double circuit failures in cable connections [/y].
f_{c2ind}	failure frequency of independent double circuit failures in cable connections [/y].
f_j	failure frequency of a single joint [/comp·y].
f_l	failure frequency of an OHL circuit [/cctkm·y].
f_{l1}	failure frequency of a single overhead line circuit [/y]
f_{l2dep}	failure frequency of dependent double circuit failures in overhead lines [/y].
f_{l2ind}	failure frequency of independent double circuit failures in overhead lines [/y].
f_{pc1}	failure frequency of a partially-cabled circuit [/y].
f_{pc2dep}	failure frequency of dependent double circuit failures in partially-cabled connections [/y].
f_{pc2ind}	failure frequency of independent double circuit failures in partially-cabled connections [/y].
f_t	failure frequency of a single termination [/comp·y].
l_c	total cable circuit length [km].
l_{cp}	cable part (between joints) length [km].
l_l	total overhead line length [km].
l_{total}	total connection length [km].
N_c	number of embedded cable sections [-].
n_i	number of individual cables per circuit phase [-].
r_c	repair time of a cable [h].
r_j	repair time of a joint [h].
r_l	repair time of an overhead line [h].
r_t	repair time of a termination [h].
U_{c1}	unavailability of a single cable circuit [-].
U_{c2dep}	unavailability of dependent double circuit failures in cable connections [-].
U_{c2ind}	unavailability of independent double circuit failures in cable connections [-].
U_{l1}	unavailability of a single overhead line circuit [-].
U_{l2dep}	unavailability of dependent double circuit failures in overhead lines [-].
U_{l2ind}	unavailability of independent double circuit failures in overhead lines [-].
U_{pc1}	unavailability of a partially-cabled circuit [-].
U_{pc2dep}	unavailability of dependent double circuit failures in partially-cabled connections [-].
U_{pc2ind}	unavailability of independent double circuit failures in partially-cabled connections [-].
U^*	annualised (to hours/year) unavailability [h/y].
$\lceil x \rceil$	ceil function (rounding to nearest integer to infinity).

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I. INTRODUCTION

UNDERGROUND Extra-High-Voltage (EHV) cables are becoming more popular for the extension of existing transmission grids in densely populated areas. The main drivers for this are the visual impact of high-voltage towers on the landscape and health concerns related to electromagnetic fields. Whereas there is much experience with cables at HV