SHORT-CIRCUIT CURRENTS INFORMATION EXCHANGE BETWEEN DSO AND TSO, AN APPROACH FROM THE PORTUGUESE DEMONSTRATION OF THE ONENET PROJECT

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ABSTRACT

The short-circuit current is one of the most important security operational parameters. With the increased penetration of DERs, it is crucial to frequently and periodically monitor it, ideally every 24 hours and with high granularity (e.g., 30 minutes). This paper develops a short-circuit computation methodology to calculate the complete short-circuit current in the TSO/DSO interface nodes (extra high voltage/high voltage (EHV/HV) substations), which could be used for operational planning purposes, considering the active contributions to the short-circuit current originating from both transmission and distribution networks. A TSO-DSO coordination procedure is presented to obtain the day-ahead short-circuit currents forecast. Moreover, two real cases are provided as examples for validation of the demonstrated procedures.

I. INTRODUCTION

A short-circuit is a fault condition that occurs when a low resistance connection is established, allowing a large amount of electrical current to flow. This can be caused by various factors, including equipment failures, lightning strikes, loss of insulation, overload or human error. Short-circuit current (Isc) calculations are a type of electrical analysis that allow estimating the maximum amount of current that can flow through an electrical system, under a given fault condition. These calculations are fundamental for designing and analysing electrical power systems, particularly for Transmission System Operators (TSOs) and Distribution System Operators (DSOs). They are used to determine the fault current levels and equipment ratings at various points in the system and to ensure that it can safely handle fault conditions and allow the grid operators to assess the equipment rating adequacy and protective device settings. The fault clearing devices, such as circuit breakers and fuses, are designed to interrupt the fault current flow and prevent system damage. The ratings of these devices must be selected carefully to ensure that they can interrupt the maximum fault current that can flow through the lines/transformers as determined by the short-circuit calculations. Monitoring the Isc forecast allows TSOs and DSOs to ensure that the system is operating safely and efficiently, take appropriate action in the event of a fault, maintain system reliability, security of supply, and optimum use of ancillary services.

With the increasing amount of DERs (Distributed Energy Resources) in the grid, some new challenges arise, namely the Isc increase due to the raise of machines in service connected to the grid that actively contribute to the Isc. This becomes more critical when we consider the TSO-DSO interface substations, in which the operators do not have full visibility of all the assets connected in the upstream and downstream network, which contributes to the Isc increase at the TSO-DSO interface nodes. In that sense, TSO-DSO coordination is fundamental to accurately forecast the Isc in the interface between operators' (EHV/HV substations).

In this paper, we aim at capturing the daily short-circuit dynamics at the TSO-DSO interface considering the exchange of information between operators to maximise the accuracy of the forecast. The Portuguese power system was used in the simulations and a RESTful web service architecture was built to exchange this data between the Portuguese TSO (REN) and the main DSO in Portugal (E-REDES).

The paper is organized as follows: Section II presents the importance of TSO-DSO coordination for the accurate Isc calculation. Section III illustrates the case studies and the methodology followed, Section IV shows the simulation results and discussion, and lastly, Section V draws conclusions from the work carried out.

II. TSO AND DSO COORDINATION

Several areas of interest can be identified where coordination between system operators is beneficial: for market procurement, planning or operation purposes. This paper focuses on the Isc forecast at TSO-DSO interface nodes.

The continuous integration of DERs connected to the distribution grid, results in an increasing Isc contribution observed by the SOs (system operators) in fault events. Accounting for this contribution (in addition to the contribution of the TSO) allows more accurate planning of grid assets (transformers, cables, switchgear). Coordination between SOs is required since there is no way for the TSO to know about the assets connected to its interconnected DSO. Similarly, the DSO does not have the information needed to determine the short-circuit contribution from the transmission network. The main reasons for this coordination are i) Accurate dimensioning of substation equipment, ii) Correct settings of substation protection, automation and control systems, iii) Equipment purchase/cost optimization.

The correct Isc estimation has a high impact on the cost of the equipment. Many pieces of equipment, such as circuit breakers, have their short-circuit rating, which is the maximum current it can clear in a fault situation, chosen from standardized values such as 25 kA, 31.5 kA, and 40 kA [1], among others. These values can then be endured for a specific time, such as 1 s or 3 s. A circuit breaker that can endure 25 kA for 1s can be 30 % less expensive than one that can endure 31.5 kA for 3 s for certain voltage levels [1]. The overall cost can be quite different considering multiple circuit breakers and other switchgear from a substation, including power transformers, thus, important savings can arise from a proper equipment selection. For power transformers, if a short-circuit test is demanded, and if the current is not correctly estimated, it may fall short of what it was expected in terms of test, or the transformer can be over dimensioned, greatly decreasing its lifetime, since such tests are very demanding. In Portugal, the TSO uses 31.5 kA for HV circuit breakers, while the DSO uses 25 kA rating for their circuit breakers.

Various electrical parameters are required to characterize how the transformer withstands stresses in healthy operation and fault conditions. They are other decisive factors in the choice and setting of protection devices, such as the short-circuit voltage (Vsc). This enables calculation of the current absorbed by the primary in case of short-circuit across the secondary's terminals. This element is a direct input to be considered in the dimensioning of the transformer. On the one hand, high Vsc limit the short-circuit power on the secondary side. On the other hand, if it is higher, it will increase the electric losses of the transformer and decrease the available secondary voltages when the transformer is in service. Typical Vsc values range from 4 % to 6 % in MV/LV transformers depending on their rated power or even higher than 10 % in HV/MV and 15 % at EHV/HV transformers.

Regarding the substation protection system, many characteristics and functions can be chosen from a list of parameters to which the relays can react upon. It depends on what the protections are monitoring, their location and how sophisticated they are. Settings for line bay protection, bus bar protection, and transformer bay protection often require the Isc estimation, so that in case the Isc value is in fact a function being used, the protection can react in time and understand what abnormal values are. The correct Isc estimation also impacts the operation of the substation itself. The TSO may take actions such as opening the coupling busbar bay, thus reducing the contribution of a set of lines to a foreseen undesired high Isc value. In other scenario, it may prefer a transformer bay to dispatch or decide that several transformers can work together.

The operational solution to reduce the Isc values at HV level (interface bus) is to open the coupler circuit breaker to increase the Thévenin impedance seen at the HV busbar. Since this solution increases the N-1 risk, another option is to close the coupler circuit breaker, but with instantaneous trip of the coupler to immediately reduce the Isc in case of an HV fault in the vicinity. For a long-term solution, to guarantee lower Isc values, additional reactances are put in place (series) next to the transformer (EHV/HV) in the HV side to limit the three-phase fault, or a shunt reactor is placed on the neutral to the ground also in the HV side to limit the phase to ground faults.

The TSO-DSO interface is the power transformer between transmission and distribution networks and defines the boundary between TSO and DSO operating areas. In some countries, the DSO owns these transformers (for example, Spain, France, Ireland, Sweden, and USA), meaning that the DSO has only visibility of the contributions coming from the EHV/HV transformer downwards. On the other hand, in some countries, these transformers are owned by the TSO (for example, Portugal, Belgium, and China), meaning that the TSO has only visibility of the contributions coming from the EHV/HV transformer upwards. In both cases, the overall Isc value depends on the Isc in the transmission and distribution networks which is not readily available for DSOs and TSOs in the mentioned countries, respectively. In these cases, cooperation between the TSOs and neighbour DSOs is necessary to properly assess the Isc values and keep the transformers operating safely [2].

In this paper, a short-circuit computation methodology is developed, and a TSO-DSO coordination scheme is presented, allowing a better Isc forecast at the TSO-DSO interface focusing mainly on the operational planning enhancement.

III. METHODOLOGY AND CASE STUDIES

This paper describes a process to compute the forecast and exchange of the Isc values in the interface nodes (EHV/HV substations) that could be used for operational planning purposes. The contributions from transmission and distribution connected generators are considered for the Isc calculation. The automatic sequence fault calculation method was used, focusing only on transient three-phase symmetrical short-circuit. The data exchanged has a timespan of 24 hours, a granularity of 30 minutes and is refreshed every 24 hours.

The Isc calculation follows an automatic structure and method that was developed and is to be integrated into the pre-operational planning of the SOs to improve the overall efficiency of the process. The Isc forecast needs to be performed after the wholesale market closure time, to include the market results (generation profile) in the simulations. The TSO then creates the network data file with this information for all the simulation periods and runs a power flow using, for example, the Newton-Raphson solution method. From the DSO side, the power flow is run by DPLAN[1]. The methodology used by the TSO for the Isc estimation is the automatic sequence fault calculation. The DSO used the same principle to calculate the distribution level contributions.

The 60 kV bus bars in the EHV/HV substations are the TSO-DSO interface and are owned by the TSO. In the TSO's network simulation model, the active distribution system is reduced and modelled as one equivalent generator and load at the interface bus bar. In the DSO's network simulation model, the active transmission network is reduced and modelled as one equivalent generator with a given short-circuit power.

To allow the communication and exchange of data between both parties, a data exchange platform (DEP) was developed, one for the TSO (TDEP), another for the DSO (DDEP), which is a cloud system that serves as a gateway between the internal systems of the DSO and TSO with other possible external entities. The two DEPs are supported by a GUI (frontend-layer), which allows the visualization of the data exchanged, and a set of APIs (backend-layer), responsible for the exchange and management of the data. The short-circuit data is transferred between the TDEP and DDEP through XML files and is structured in the fields and sub-fields presented in Table 1.

Table 1 - Fields, sub-fields and type of data shared between the TSO and DSO platforms

Field	Sub-field 1	Sub-field 2	Type
Sender	-	-	(string)
Time of creation	-	-	(string date-time)
Start time	-	-	(string date-time)
End time	-	-	(string date-time)
BUS-ID-ARRAY	BusID	-	(string)
	TIME-ARRAY	Start Time (of Forecast)	(string date-time)
		Contribution from EHV network (TSO)	(number float)
		Contribution from HV network (TSO)	(number float)
		Contribution from active HV network (DSO)	(number float)

To obtain the day-ahead Isc forecast in the interface, the TSO firstly computes the Isc only considering the contributions from its grid, calculated considering the expected generation profile from the wholesale market results. Then, these values are exchanged with the DSO to compute the final Isc value for each EHV/HV substation, by adding the contribution from the expected generation profile at the distribution level. The process finishes when both operators reach the final value, which include both Isc contributions in the TSO-DSO interface. A visual representation of the whole process is presented in Figure 1.

With the participation of the Portuguese TSO (REN) and main DSO (E-REDES), the authors were able to apply this methodology to study the entire Portuguese TSO-DSO interface, composed of 89 substations, among which, 63 EHV/HV substations are connected to the DSO. The case studies selected for this paper are the SS1 and SS2 substations, the first located in the northeast and the latter in the south of Portugal. They were selected due to their DERs mix and topologies, making them interesting to analyse the impact of the active short-circuit contributions from the distribution side in the TSO-DSO interface.

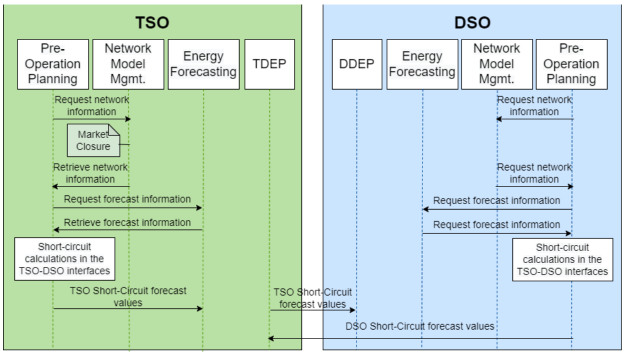

Figure 1 – Short-circuit sequence diagram for information exchange between TSO and DSO

The main characteristics of the two substations selected are presented in Table 2. Note that the generation installed capacity at the distribution side is the aggregate value of assets connected at the HV and MV levels and from the transmission side corresponds to the aggregated value from the private lines connected to the HV bay from which only the TSO has visibility.

Table 2 – Case studies: TSO-DSO substations details [3][4]

Injector	Connected resources			Total
SS1	Lines	EHV		7 lines
		HV		5 lines (3 private)
	EHV/HV Transformers	Number		3
		Power		3 x 126 MVA
	Generation	TSO	Wind	149.4 MVA
		DSO	Hydro	59.8 MVA
			Wind	128.4 MVA
	Circuit Breakers	DSO		25 kA
		TSO		31.5 kA
SS2	Lines	EHV		8 lines
		HV		5 lines
	EHV/HV Transformers	Number		2
		Power		2 x 170 MVA
	Generation	DSO	Wind	145.6 MVA
			PV	54.1 MVA
			Hydro	2.3 MVA
			Biogas	1.8 MVA
			Cogeneration	5.3 MVA
	Circuit breakers	DSO		25 kA
		TSO		31.5 kA

Other relevant piece of information is presented in Table 3, which is the maximum Isc foreseen in the transmission network development and investment plan (PDIRT) 2022-2031 [5], that is updated every 2-years. One annex has the

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[1] DPLAN – E-REDES Network Planning Tool.

foreseen maximum three phase Isc evolution for all the TSO buses, for different time horizons. The maximum value on each bus is determined, per year, from the maximum value of the relevant peak, valley and off-peak network scenarios simulated for each year, for two types of weather regimes (wet and dry), and for winter and summer seasons, retaining the highest value determined between them. Therefore, it is interesting to cross check these planning values with the ones obtained from the simulations carried out to assess if by considering the DSO contributions the TSO long-term planning forecasts can be affected.

Table 3 – Maximum three phase Isc foreseen for 2022 in PDIRT

Substation	Voltage (kV)	Maximum three phase Isc (kA)
SS1	60	23.6
SS2	60	14.5

In the next section, a set of results from the simulation carried for these two case studies is presented and the findings discussed.

IV. SIMULATION RESULTS AND DISCUSSION

In this section, the simulations results are presented, firstly for SS1 substation and lastly for SS2. Our main goal is to assess the impact of the distribution level contributions to the total Isc value at the interface bus.

From Figure 2 one can see that Isc values for the SS1 substation on the 20th of November 2022 do not surpass the maximum value from PDIRT and are lower than the short-circuit ratings of circuit breakers (31.5 kA). The maximum value of the total contribution is approximately 94 % of the maximum value from PDIRT. The lowest percentage contribution from the DSO network is 6.98 % (in hour 21:00), when the contribution from the DSO network is the lowest and equal to 1.50 kA and the contribution from the TSO (both step-down transformers and 60 kV private lines, connected to the TSO bay) is the highest and equal to approximately 20 kA.

The highest percentage contribution from the DSO network is 13.06 % (in hour 08:30), when the contribution from the DSO network is the highest and equal to 2.82 kA and, at the same time the contribution from the TSO (both transformers and 60 kV private lines, connected to the TSO bay) is the lowest and equal to approximately 18.8 kA. The contribution from the 60 kV lines, owned by the private entity (from which only the TSO has visibility), falls in the range from 9.2 % to 10.8 % of the total contribution from the TSO.

Another finding worth mentioning is that the total Isc value is close to the DSO short-circuit rating (25 kA). Given the fact that the value is measured at the TSO-DSO interface, it would decrease when reaching the MV/LV substations, as the lines contribute to the Isc reduction. Nevertheless, in situations where the total Isc is greater, actions such as opening the tie-breakers or transferring producers to another injection point can be considered, or even the possible substitution of these circuit-breakers.

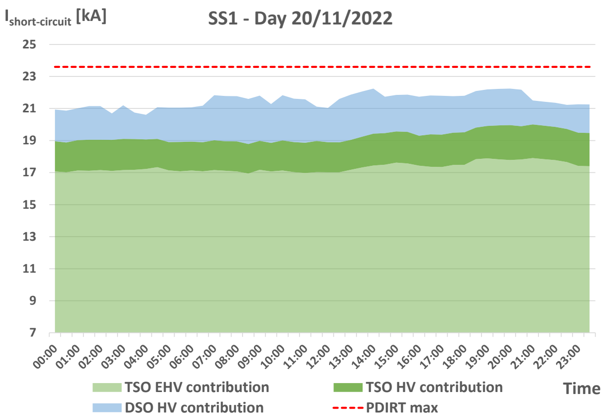

Figure 2 – Isc values for SS1 substation on 20/11/2022

Figure 3 shows the Isc values on the 19th of November 2022 for the SS2 substation at the 60 kV TSO-DSO interface bus and the respective PDIRT maximum value. In 5 periods during the day, the total Isc surpasses the maximum value from PDIRT (at 10:00, 11:00, 12:00, 13:00 and 16:30). The maximum Isc occurs at 11:00, correspondent to 14.63 kA which is less than 1 % above the maximum value from PDIRT (14.5 kA). Nevertheless, this value is far from the short-circuit ratings of the TSO and DSO circuit breakers (31.5 kA and 25 kA, respectively).

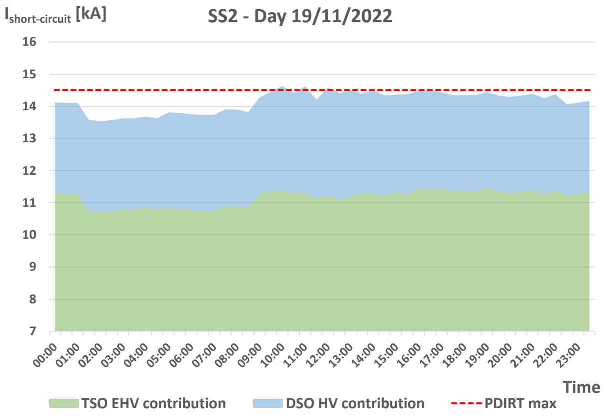

Figure 3 – Isc values for SS2 substation on 19/11/2022

The lowest percentage contribution from the DSO network is 20 % (at 23:30) and occurs during the off-peak period (from 22:30 until 04:30) when the contribution from the distribution side is the lowest and equal to 2.83 kA. Due to the large amount of solar distributed generation integrated within the DSO area correspondent to the SS2 substation, the DSO short-circuit contribution is higher during the peak sun hours given that more PV panels are in service. The highest percentage contribution from the DSO network is 22.96 % (at 13:00) with a contribution of 3.33 kA. The contribution from the DSO network is highest (in value) and equal to 3.34 kA at noon. The Isc values computed are far from the circuit breakers ratings, so, in this case, it can be confirmed that the security of the grid assets is ensured by the current TSO and DSO short-circuits breakers, having no need of special operational planning measures to control the short-circuit power.

The following table summarizes the main findings from the short-circuit simulations analysis of the two case studies.

Table 4 – Summary of the case studies short-circuit simulations

Case study	Contributions					
	TSO EHV range		TSO HV range		DSO HV range	
SS1	kA	%	kA	%	kA	%
	[16.95 to 17.91]	[78.40 to 83.57]	[1.76 to 2.17]	[8.27 to 9.78]	[1.50 to 2.82]	[6.98 to 13.06]
SS2	kA	%	kA	%	kA	%
	[10.70 to 11.46]	[77.04 to 80.00]	0	0	[2.83 to 3.34]	[20 to 22.96]

The results from these two case studies highlight the importance of considering the DSO short-circuit contributions in the TSO-DSO interface. In the SS2 substation, without considering the DSO active contribution, the PDIRT maximum Isc forecast value would not be violated. In this substation the percentage DSO contribution from the total Isc value on the interface fits within 20 % and 22.96 %. In SS1 substation, the contribution from the DSO is less relevant, however, its maximum value represents 13.06 % of the total Isc value in the TSO/DSO interface.

From the results it is clear that with the coordination process presented for exchanging the Isc contributions between system operators with respect to the TSO-DSO interface, an improvement can be achieved in the reliability of the total Isc values determined for operational planning purposes. This way, the operational teams can forecast the day-ahead Isc values with higher accuracy and thus avoid unexpected Isc peaks in the TSO-DSO interface, that could be caused by generation of which the SOs have no visibility.

Although the joint contributions for both case studies are still not a burden from the circuit breaker ratings point of view, the surpassing of PDIRT maximum values (for SS2 substation), show the added value in the consideration of both contributions for asset planning purposes. This is especially true considering that contributions from the distribution side are expected to rise substantially with increased DER penetration.

V. CONCLUSIONS

This paper establishes and tests a process to compute and exchange the Isc data in the TSO-DSO interface nodes (EHV/HV). Both contributions were determined and added to calculate the overall TSO-DSO short-circuit contribution. The Portuguese power system was used as a case study, comprising 63 EHV/HV substations connected to the DSO, and a RESTful web service architecture was built to exchange the data between the Portuguese TSO and main DSO. For results analysis, two substations were selected, the SS1 and SS2 substations, the first located in the northeast and the latter in the south of Portugal.

The SS2 substation turned out to be a very interesting case study given its high DER installed capacity. In this substation a maximum DSO contribution of almost 23 % was observed, considering the total Isc value in the TSO-DSO interface, which cannot be neglected. In the SS1 substation, the contribution from the DSO is not as noteworthy as in SS2, however, considering it for operational and planning purposes can increase the reliability in the total Isc forecast.

Although the results for both substations still do not pose a security risk for the TSO and DSO networks, the instantaneous joint contributions are sometimes above the maximum Isc values foreseen in the TSO network investment plan (PDIRT). Given that the distribution level contributions are expected to grow significantly in the coming years with increased penetration of DER, the coordination process described in this paper would allow a more accurate Isc forecast at the interface level and, consequently, a more accurate planning of grid assets and enhancement of the operational activities.

VI. REFERENCES

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VII. ACKNOWLEDGEMENTS

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