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Study and identification of short-circuit currents at the Complex Distribution Network SIDER-EL Hadjar (ex ArceloMittal-Algerie)

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Abstract

Because of an upcoming modernisation of the electricity distribution network in the SIDER EL-HADJAR steel complex, a new calculation of the short-circuit current must be taken into account. The objectives pursued in this article is to determine the precise values of the currents of maximum and minimum fault by each start 225, 63 and 15 kV of the distribution network to ensure the reliability of the existing system, on the other hand is to validate the sizing of the 63 kV bus bar follows the increase of the load of the transformer station P4 by replacing the 70 MVA transformer with a 120 MVA transformer and comparing the results to the old computation. The calculation of short-circuit currents is a key step in qualifying the equipment to withstand the thermal and electromagnetic effects. So it was question of appreciating the reliability of numerical computation of the currents of short-circuits which requires modelling and simulations with software NEPLAN V5.

Keywords: Initial short-circuit current, power supply system (SIDER-ELHADJAR), IEC 60909-0, peak value of short-circuit current, NEPLA software.

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1. Introduction

Faults of short-circuits in the power system cannot be avoided despite careful planning and design, good maintenance and thorough operation of the system. Influences from outside the system, such as short-circuits following lightning strokes into phase-conductors of overhead lines and damages of cables, the internal faults due to ageing of insulation materials. Short-circuit currents therefore have an important influence on the design and operation of equipment and power systems. currents flowing through earth can induce impermissible voltages in neighbouring such as communication and power circuits, oscillations of generator units which will lead to oscillations of active and reactive power as well, thus causing problems of stability of the power transfer which can finally result in system black-out. Therefore the short-circuit depends on various parameters, such as the voltage level, the impedance at the fault point, and requires a detailed knowledge of the parameters of the network [1–5].

2. Mathematical equations

2.1. Analytical method

The method used is the impedance method, which determines the short-circuit current value at any point in the network by summing the resistance and reactances of the fault loop from the source to the point of failure and calculate the equivalent impedance. The values of the short-circuits are calculated by applying the equations:

$$I_{cc3} = U / \sqrt{3} Z_{cc} \tag{1}$$

$$I_{cc2} = 3 / \sqrt{2} I_{cc3} \tag{2}$$

U: Voltage between phases at fault point

Z_{cc}: Short circuit impedance

I_{cc3}: Three-phase short-circuit current

I_{cc2}: Two-phase short-circuit current

The fault giving the maximum short-circuit current is assumed to be three-phase and generally located at the start of the fault, giving the two-phase fault giving the minimum short-circuit current at the end of line [6, 7].

2.2. Numerical method

The behaviour of an electrical network during a short circuit can be represented by an equivalent network composed of a voltage source before the fault and impedance Z_{ki} for the sequence of the direct, inverse and homopolar system at the point of fault, the symmetrical components are only connected to the location of the fault. The equations related to the type of defect:

Three-phase fault

$$I_{k1} = U_k / Z_{k1} = 0 \tag{3}$$

$$I_{k2} = U_k / Z_{k2} = 0 \tag{4}$$

$$I_{k0} = U_k / Z_{k0} = 0 \tag{5}$$

Two-phase fault

$$I_{k1} = U_k / Z_{k1} + Z_{k2} \quad (6)$$

$$I_{k2} = 0 \quad (7)$$

$$I_{k0} = 0 \quad (8)$$

U_k Voltage before fault at node k

Z_{ki} Impedance of the network to the faulty node of the direct, inverse and homopolar system.

2.3. Calculation algorithm

After modelling the network studied, the calculation of the parameters is done in four stages:

- Calculation of the voltage equivalent to the fault point.
- Determination and summation of the direct, inverse and homopolar equivalent impedances at the point of failure.
- Calculation of the initial short-circuit current using the symmetrical components.
- Determination of other quantities characteristic:
  - i_p : The peak value of the short-circuit current.
  - i_b : The effective value of the cut-off symmetrical short-circuit current.
  - i_{cc} : The aperiodic component.
  - i_{th} : The thermal resistance.
  - i_k : RMS value of the permanent short-circuit current.

2.3.1. Equivalent voltage calculation method for maximum short-circuit currents

The calculation of maximal short-circuit current is the main design for the rating of equipment to withstand the effects of short-circuit currents (thermal and electromagnetic effects). We used the IEC60909 2001 standard. This standard applies to all radial and meshed networks up to 550 kV. The calculation method is based on THEVENIN theorem, which consists in calculating a voltage source equivalent to then to determine the current at that same point. All power supplies are replaced by their direct, inverse and zero-sequence impedances by neglecting all the admittances and capacities of the lines. The voltage equivalent to the point of failure is equal to $c^*Un/\sqrt{3}$ with *C*, is a voltage factor whose introduction into the calculation is necessary to take into account [8, 9]:

- Voltage variations in space and time.
- Possible change of transformer plug.

2.3.2. Method of calculating the minimum short-circuit current

The calculation of the minimum short-circuit current is necessary for the design of the protection systems and the minimum setting of the protection relays. For this, we used the power distribution superposition method, taking into account the real voltages just before the defect, which are calculated according to the Newton–Raphson method.

The determination of the maximum and minimum short-circuit current is therefore not as simple as it could be seen at this stage [10].

2.4. Newton–Raphson algorithm

This algorithm starts from the error equation for the node i of the network.

$$\Delta S_i = (P_i - jQ_i) - U_i^* * \sum_{k=1}^{i} Y_{ik}^* * U_k^* \quad (9)$$

The complex voltage U_k must be found such that the error becomes zero.

Pi and Qi are the active and reactive power predefined. Y_{ik}^* is an element of the matrix *Y* of the *i*th line and the *k*th column. The solution of this error equation above consists of three steps:

1. Calculation of the error of the power using the voltages of each node

$$\Delta S_i = S_{\text{vor}\,i} - S_{\text{ber}\,i} \quad (10)$$

2. Calculation of the voltage variations for each node with the Jacobean matrix J

$$\Delta U = J^{-1} * \Delta S \quad (11)$$

3. Calculation of the voltages at the nodes

$$U_{\text{neu}\,i} = U_{\text{alt}\,i} - \Delta U_i \quad (12)$$

These three stages of iteration start with *u* = 1.0 pu continue until the convergence criterion is reached

$$\varepsilon = |\Delta S_i| \quad (13)$$

2.5. Network modelling studied

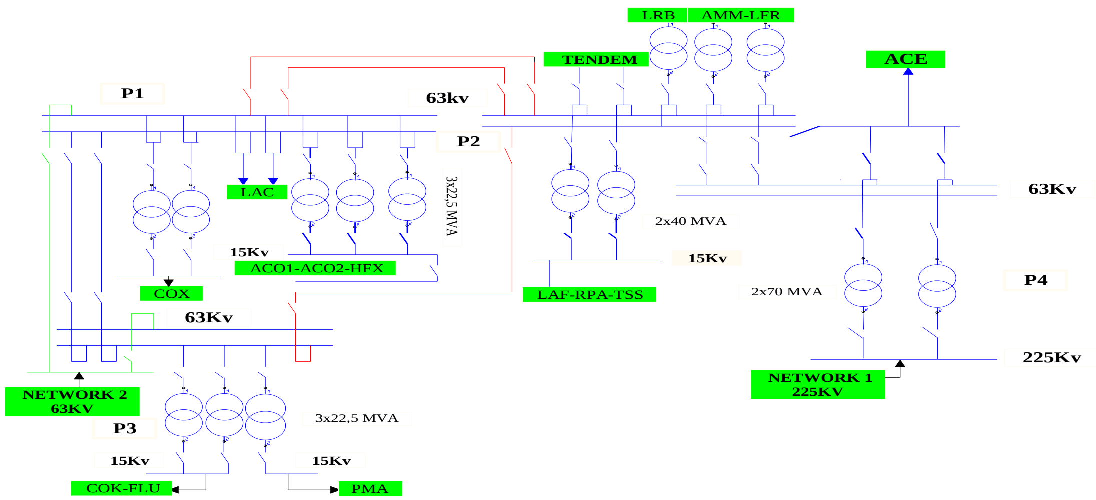

Figure 1. Sider-El-hadjar network single-wire diagram

2.6. Representation of transformer station P4

The SIDER-El-hadjar Figure 1 is the network that supplies three transformer stations from two different power sources, two of 63 kV (P1, P3) and the other of 225 kV (P4) [11–15].

Calculation evaluations mainly concern the following operating configurations:

1. Operating mode N-1: power supply network 220 kV + 63 kV.
2. Operating mode N-2: power supply 225 kV (contingency of a 63 kV arrival P1).
3. Operating mode N-3: power supply network [225 kV + thermal power plant (GT)].

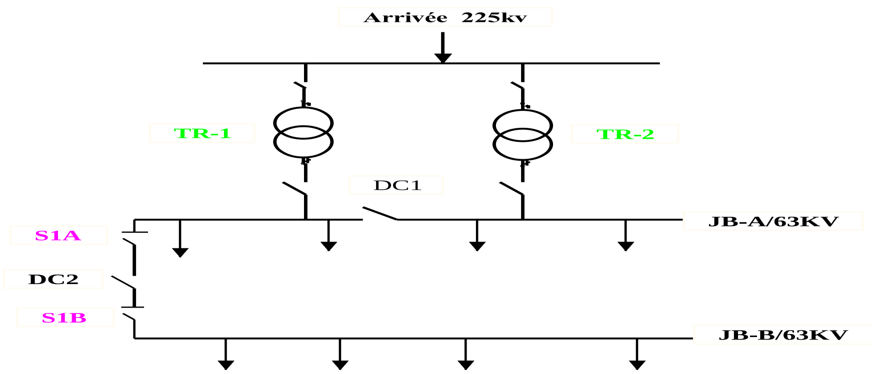

Figure 2. Transformer station P4

The transformer station P4 (Figure 2) has two bus bars (JBA, JBB), supplied by two transformers HTB/HTA named TR1 of 120 MVA power and TR2 of 70 MVA power, in normal operating mode, DC1 coupling being closed the transformers TR1 and TR2 feed the bus bar A. The P4 transformer station has four (4) starts: two to ACE, two to P2 transformer station.

3. Simulation of the model by software NEPLAN

3.1. Maximum current on 63 kV bus bar

The two transformers are coupled in parallel to the bus bar **A** 63 kV and all the sends are connected to the same bus bar **A**, in this case the maximum current output by the two transformers is 1916 A. Even if the sends are connected to the Bus bar **B** through the coupling circuit breaker (DC 2) the total current produced by the two transformers in parallel is 1916 A.

3.1.1. Analysis

The bus bars **A** and **B** are sized; they are able to withstand a current of 1916 A. The disconnectors and coupling circuit breaker being sized at 1250 A, it will also not be able to withstand a current of 1916 A.

3.2. Power balance

The overall power of the site is: 1 + *j*0.607 distributed over the three station breaks down as follows:

Name of substation	*U* (pu)	*P* (pu)	*Q* (pu)	*S* (pu)
P4	1.02	0.7016	0.5377	0.883
P1	1.05	0.154	0.033	0.157
P3	1.05	0.148	0.0295	0.1501

Table 1 shows the exchange of real and simulated power between the different elements of the network.

Table 1. Comparison between real and simulated consumption

Name of substation	Consumption real			Consumption simulated			Deviation %	
	p (pu)	Q (pu)	cos α	p (pu)	Q (pu)	cos α	p (pu)	Q (pu)
P1	0.154	0.033	97.8	0.152	0.0331	97.7	0.002	0.0001
P3	0.148	0.0295	98.05	0.146	0.0298	98	0.002	0.0003
P4	0.7016	0.5377	79.3	0.7003	0.8675	79.2	0.0013	0.3298

3.2.1. Analysis

The power factor at the connection points P1 and P3 with the Network 63 kV is greater than 0.8; Except the P4 station or it is lower because there is a significant overload. In addition it would be interesting to distribute the load more equitably on the three arrivals or to add a transformer of 225 kV/63 kV to the south station (P4) in order to avoid the overload.

In our simulation all the loads work at the same time which explains in case of loss of one of the two arrivals 63 kV the transformer 120 MVA of the station P4 would not manage to take the receiver. In this case it would be necessary to increase the power of the station 220 kV.

3.3. Calculates the maximum short-circuit currents

The following tables show the thermal resistance of the different bus bars to be compared with the maximum short-circuit current calculated for different operating configurations.

Table 2. Three-phase short-circuit current before reconfiguration

Substation	Bus number	I_{cc3} (kA)	ip (kA)	i_{th} (kA)
P4	JB1-P4	17.50	49.52	20.19
	JB2-P4	9.82	26.56	10
P1	JB1-P1	11.66	29.81	11.75
	JB2-P1	14.78	38.91	14.95
P3	JB1-P3	11.59	29.54	11.68
	JB2-P3	15.94	33.14	15.97

Table 3. Three-phase short-circuit current after reconfiguration

Substation	Bus number	I_{cc3} (kA)	*ip* (kA)	i_{th} (kA)
P4	JB1-P4	17.50	49.52	20.19
	JB2-P4	12.60	34.55	12.93
P1	JB1-P1	11.66	29.81	11.75
	JB2-P1	14.78	38.91	14.95
P3	JB1-P3	11.59	29.54	11.68
	JB2-P3	15.94	33.14	15.97

Table 4. Contingency of arrival P1

Substation	Bus number	I_{cc3} (kA)	*ip* (kA)	i_{th} (kA)
P4	JB1-P4	17.50	49.52	20.19
	JB2-P4	12.60	34.55	12.93
P1	JB1-P1	12.05	32.03	12.20
	JB2-P1	14.92	39.76	15.12
P3	JB1-P3	11.59	29.54	11.68
	JB2-P3	15.17	39.82	15.34

Table 5. Three-phase short-circuit current with contribution from GT

Substation	Bus number	I_{cc3} (kA)	*ip* (kA)	i_{th} (kA)
P4	JB1-P4	17.75	50.14	20.47
	JB2-P4	13.50	36.84	13.80
P1	JB1-P1	12.94	34.34	13.11
	JB2-P1	19.50	51.46	19.73
P3	JB1-P3	2.30	5.45	2.31
	JB2-P3	17.69	38.39	17.74

Table 6. Range of short-circuit currents by station departure

Substation	Bus number	Actual value minimal (kA)	Actual value maximum (kA)
P4	JB1-P4	1.157	17.50
	JB2-P4	1.157	12.60
P1	JB1-P1	1.157	12.05
	JB2-P1	1.157	14.92
P3	JB1-P3	1.157	11.45
	JB2-P3	1.158	15.11

3.3.1. Analysis

By analysing the results of Tables 2, 3 and 4, it will be noted that the actual maximum short-circuit current is greater. The maximum short-circuit current value is 9.82 kA for the current network and 12.60 kA after reconfiguration. Table 5 shows the contributions of the GT to the increase in the maximum short-circuit current. Table 6 gives the range of true values of the short-circuit currents according to the different starts of each station.

4. Conclusions

The following conclusions can be drawn from the various simulation tests:

1. In our article, IEC60909-0 is used to calculate different types of short-circuit current in a power system. Our power system is divided into several different voltage levels, or calculations are made for short-circuit on the levels of 15, 63 and 225 kV. Five different cases have been set up to evaluate the system, so that Maximum and minimum currents could find.
2. The 225 kV-rated bus bars have a good resistance to the maximum short-circuit current.
3. The existing 63 kV bus bars are able to withstand the new maximum short-circuit current of 12.60 kA following the replacement of the 70 MVA transformer by a 120 MVA transformer.
4. In this configuration, the disconnectors and coupling circuit breaker must be replaced. Depending on the exchanges with the SIDER operators, this full-load configuration is not used. However, an operating procedure should be set up in order to avoid overloading.
5. The insertion of the decentralised production (GT) has negative consequences on the exploitation of the networks of distribution in particular, the plan of voltage can be modified by the presence of GT, to the point the voltage risks to exceed the limit, also the protection plan may also be affected by a high rate of short-circuit current so selectivity is questioned.

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