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THERMAL CAPABILITY OF 132 KV TO 400 KV EARTH SWITCHES

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PURPOSE AND SCOPE

This report addresses determining the continuous current carrying capability of earth switches on the National Grid electricity transmission network installed before a continuous duty was specified for all new installations.

All earth switches of indeterminate duty have been considered in this report.

PART 1 – REPORT DETAILS

1 INTRODUCTION

The reconductoring and hot wiring of many overhead circuits in recent years has had many benefits in terms of system operation flexibility and increased current carrying capability. Although these increases in power flow have been advantageous, there has been a necessary revision needed to maintenance procedures.

For a double circuit with one circuit on outage, the induced circulating current in the dead circuit is related to the current flowing in the live circuit; on L2 circuits the induced current is approximately 10% of that in the live circuit. As line ratings have been increased, through hot wiring or reconductoring, so accordingly have the induced circulating currents.

During the late 1990s problems were observed during the maintenance of certain overhead line routes. These problems included:

- a) Melting of nylon ropes.
- b) Overheating of drain earths.
- c) Damage to running blocks – wheels and bearings.

Subsequent investigation attributed these problems to the high-induced current in the dead circuit. In 1997 this problem was modelled and reported in TR(T)259. This work was subsequently re-examined in 2002/3 and is shown in Appendix A (prepared by John Hyde). This new study reaffirmed the previous work, and moreover, highlighted that the earth switches associated with these overhead line circuits are also subject to the same circulating currents. In the case of older models, these earth switches were not designed with this duty in mind. The conclusions of the MUNA study include the following statement:

"It has been recognised within National Grid that earth switches used on its network have not been tested in a manner that documents their strength and capability with regard to carrying continuous current. Although not the original intention of these studies the expected maximum continuous current that earth switches are expected to pass is readily obtained from the models. Paragraph 4.2 details the maximum continuous currents the earth switches are expected to carry. The worst case being 414.4 A.

A further study was run based on the following criteria:

- *Power Flow 3460 MVA (5000 A)*
- *Fault Level of 30 kA at both ends*
- *Balanced loading*

The maximum continuous circulating current in this case is 419.3 A. It is unlikely in the short term that National Grid will make extensive use of 5000 A rated switchgear on its system. It is unlikely, therefore, that under balanced system conditions a continuous current in excess of 420 A will be experienced on the National Grid system.

Using the IEC 60059 'R10' power series the nearest rating above 420 A is 500 A. This value gives significant headroom above that required and will also cater for any unbalanced conditions that may be encountered on the National Grid system. It is therefore suggested that earth switches for use on the National Grid Main Interconnected System be rated for a continuous current of 500 A."

Given the lack of test evidence for the continuous current capability of older earth switches and the above recommendations a test programme was undertaken to establish the capability of unproven earth switches.

2 TESTING

Table 1 lists the range and number of earth switches existing on the National Grid system. Given the maximum calculated induced current achievable under present design and loading conditions, a continuous 500 A current was chosen for the tests since this represents the worst case scenario with a significant margin of safety.

As full a range of earth switch designs were tested as practicable given the constraints of system outages. All testing was performed by Doble PowerTest Ltd. Further details of the testing regime and results can be found in Appendix B.

TYPE	OUTDOOR			INDOOR			TOTAL
	132 kV	275 kV	400 kV	132 kV	275 kV	400 kV	
Committee Design RCP + RD500	1238	115	1536	304	316	306	3815
Hapam RCP	45	45	130	0	0	15	235
Committee Design REP	61	0	0	20	140	0	221
GEC BEA 300	0	1702	0	0	0	0	1702
GEC Knee Type	0	0	5	0	0	0	5
Hapam Pantograph	0	11	64	0	0	0	75
Merlin Gerin Knee Type Disc	34	0	0	0	0	0	34
Rhuthal Panto Disc	5	0	7	0	0	0	12
GIS Single Break	0	27	37	56	47	393	560
TOTAL	1383	1900	1779	380	503	714	6659

Table 1 - Breakdown of earth switches on the National Grid system at the commencement of testing.

Table 2 shows that 8 earth switch designs (including 132, 275 and 400 kV models) were tested. These designs account for over 90% of the total earth switch population on the National Grid system, excluding GIS single break designs.

Table 2 shows that upon reaching thermal equilibrium, even under the severe testing conditions employed for this test, that the maximum contact temperature reached was only 84 °C. The average contact temperature recorded (excluding the measurements recorded at Daines) was slightly over 40 °C.

It should be noted that only one earth switch of each design has been tested and is assumed to be representative of that design: this has mainly been caused by the difficulties of obtaining outages. Nevertheless, taking the results as a whole, all the earth switches have responded in a similar manner tending to imply that none of those tested is unrepresentative.

3 CONCLUSIONS

The key facts from this work are:

- a) A testing programme has been undertaken that covers over 90% of National Grid's earth switch population.
- b) Tested earth switches were subjected to a current of 500 A for up to 2 hours (sufficient time to reach thermal equilibrium), which is in excess of the current predicted from modelling studies.
- c) The maximum recorded contact temperature was 84 °C.

The body of evidence indicates that the existing population of earth switches on the National Grid system has a capability in excess of 500 A. As such, the risk posed to the integrity of the earth switches by induced circulating currents during overhead line outages is minimal.

Site	Test Date	Doble PowerTest Ltd Report Number	Earth Switch Type	Voltage (kV)	Position Tested	Maximum Current Applied (A)	Maximum Temperature Recorded (°C)	Hottest Component
Castle Donington	17/6/03	1224	BEA 300	275	L23	486	44	Contact
Daines	26/8/03	1223	Committee design (AEI)	400	F22	41	+0.9 above ambient	
Sheffield City	27/11/03	1357	GEC RCP	275	H23	502	33	Contact
Knaresborough	10/12/03	1375	Hawker Siddely DE132	132	281	504	28	Contact
			Committee design (Hawker Siddely RD500)	275	S11B	511	84	Contact
Eakring	29/9/04	1753/EAKRING	GEC GD6A	132	N/A	500	57	Contact
							189	Earth/Frame joint
			Hapam SSPIII/RB/AM/420	420	N/A	506	19	Contact
			Hawker Siddely RD304	132	N/A	500	23	Contact

Table 2 - Details of the earth switches tested and maximum temperatures recorded.

4 FORMS AND RECORDS

Not applicable.

PART 2 - DEFINITIONS AND DOCUMENT HISTORY

5 DEFINITIONS

Not applicable.

6 AMENDMENTS RECORD

Issue	Date	Summary of Changes / Reasons	Author(s)	Approved By (Inc. Job Title)
1	October 2005	New issue	Simon Sutton Asset Strategy	John McKenzie Asset Stewardship Manager

PART 3 - GUIDANCE NOTES AND APPENDICES

7 REFERENCES

TR(T)259	Overhead Line Induced Voltages and Currents Study for 400kV Drain-Earth and Earth-Switch Specifications (P K Basak)
EP 145	Rationalisation of Overhead Line Designs - Engineering Panel paper 6 th December 2000 (Michelle Clark)
Seven Year Statement 2003	National Grid – Table B.2 – Existing and Planned Network: Circuit Parameters for Winter 2003.
MUNA	A Multiphase Unbalance Network Analysis Program (DJF Clark)

APPENDIX A - SUMMARY OF WORK UNDERTAKEN TO ASSESS THE DRAIN EARTH REQUIREMENTS ON CIRCUITS WITH LOWER RATED CONDUCTOR

A1 BACKGROUND

In April 1997 Engineering and Technology was charged with establishing the performance requirement of any new earthing equipment for Redwood conductor (2 x 850 mm²) on L6 type towers. Since in general the rating of overhead lines had steadily increased Engineering and Technology took the opportunity to assess the rating requirements of existing earthing apparatus. The issue regarding earthing equipment capability had also been driven, to some extent, by evidence of arcing on drain earth conductor clamps (in some cases the clamps had burnt off) and on overhead line stringing equipment.

This work concluded, inter alia, that the highest steady state circulating current likely to be 'seen' in earthing equipment is 446 A. Overhead line portable drain earths have a continuous current rating of 150 A. It is currently assumed therefore that three drain earths per phase are required to 'carry' this current. In practice each sub-conductor bundle must have the same number of earths attached to it, therefore, in the case of twin and quad conductors four earths per phase will be attached. This theoretically provides 600 A current carrying capacity.

The application of primary earth schemes to overhead lines has been termed a DrESS (Drain Earth Shorting Scheme). Using the earthing requirements highlighted above twelve earths for phase conductors and interconnecting earth lead bonds are required. This figure increases to eighteen earths for feed circuits at points where circulating current induced by two separate circuits can be additive. Tower earthing therefore is a resource intensive function and can take up to eight man-days per tower. To ensure, during maintenance, adequate provision was made for safety from the system and due to the immediate need for a solution to the problem of high circulating currents 450 A was taken as the assumed circulating current figure for all overhead line circuits.

A2 FURTHER STUDIES TO EVALUATE THE REQUIREMENT OF DRAIN EARTHS

In order to evaluate the rating requirement for earthing equipment Engineering and Technology used a software analysis package called MUNA [4] (Multi Unbalanced Network Analysis) for which a software model was constructed [1]. The model represented a double circuit overhead line with one side switched out. Various operating conditions and earthing arrangements were analysed and variations to 'standard' system conditions, such as tower footing resistances, were considered. The rating recommendation was based on a one rating fits all philosophy.

In the previous analysis [1] the maximum power flow in the in-service circuit was taken to be 3190 MVA. This is the currently accepted maximum power flow for twin Redwood conductor on L6 or L12 towers when tensioned for an operating temperature of 90°C [2]. Although quad Zebra (400 mm² ACSR) when strung on L6 towers for 75°C operation has a rating of 3420 MVA this is invariably limited by some other factor on the route i.e. cable sections or switchgear and protection ratings.

In practice the majority of circuits on the National Grid system have a rating that is substantially lower than that of twin Redwood. The National Grid Seven Year Statement [3] indicates that based on Winter, Spring/ Autumn and Summer ratings respectively, circuits with a rating of 2000 MVA or less account for 61%, 71% and 75% of all overhead/ overhead line and cable composite circuits on the England and Wales transmission system.

The level of circulating current induced in the isolated and earthed side of a double circuit route is related to the power flowing in the energised side. Therefore, bearing in mind the number of circuits with a much lower rating than that used in the previous studies and the level of resource required to apply a DrESS earthing scheme, a new model has been produced. The aim of the new studies is to ascertain a power flow below which only two drain earths per phase are required; increasing the efficiency of the earthing process.

A3 THE NETWORK MODEL

The model used for balanced power flows in the studies is shown schematically in figure A1. It is based on a nominal five kilometre 400 kV double circuit overhead line route with a tower spacing of 500 metres. The phasing arrangement is BYR on the energised side and RYB on the isolated and earthed side. Each tower is treated as having a ten-ohm resistance to earth and the terminal tower at each end has been connected directly to the substation earth mat. Power is injected at substation SND40 and taken at substation REC40. An earth switch is applied at each end of the circuit with their star points connected to the substation earth mat. The substation earth mats have a nominal resistance to earth of 0.2 ohms. Studies have been undertaken to assess the sensitivity of circulating currents to the assumed values.

For the case where unbalanced loading has been assumed a slightly different model is required this is shown schematically in figure A3. The impedance in yellow and blue phases was altered to simulate varying degrees of load unbalance from 5% to 20%. Otherwise the model remains as the balanced loading.

To obtain the required power flows on the balanced model the voltage angle was calculated using the formula shown below:

$$P = \frac{V_{SND} \cdot V_{REC}}{Z_{Line}} \cdot \sin \delta$$

This figure was then entered into the MUNA IN command.

To obtain the required power flow for the unbalanced conditions, assuming a short overhead line route length (5 km), the load was entered as an impedance calculated from the formula below:

$$Z_{phase} \Omega = \frac{V_{pu}}{MVA_{required}} \cdot Z_{base} \cdot 100$$

$$\text{where } Z_{base} = 1600 @ 400kV \text{ and } 756 @ 275kV$$

This figure was then entered into the MUNA Z command.

Overhead line models used have been either L6 at the highest ratings or L2 for the lower ratings. L2 tower construction results in higher circulating currents than L6 construction when all other conditions are identical. This is because of the reduced distance between phase conductors across the tower.

A4 STUDY RESULTS

Table A1 below shows the circulating currents in drain earths applied as shown in figure A2. In each case the figure represents the highest circulating current. Study results for selected cases are shown diagrammatically in figures B4 to B7.

Load (MVA)	% Load Unbalance	Max Drain Earth Current (A)
1710	0	214.7
	5	228.6
	10	238.3
	20	285.2
2000	0	251.0
	5	267.2
	10	278.8
	20	350.4
2240	0	285.0
2420	0	301.6
3190	0	375.7
	5	404.1
	10	422.9
	20	466.0

Table A1 – Maximum Drain Earth Currents. Note: 0% figures are with maximum fault level of 63 kA.

Table A2 shows circulating currents in the earth switches at both ends of the circuit when the circuit is isolated and earthed, via the earth switches at both ends.

Load (MVA)	% Load Unbalance	Max Earthing Device Current (A)
1710	0	221.1
	5	236.0
2000	0	258.5
	5	275.8
2240	0	285.0
2420	0	310.7
3190	0	380.5
	5	414.4

Table A2 – Maximum Earth Switch Currents. Note: 0% figures are with maximum fault level of 63 kA

The figures for the 3190 MVA power flows are based on L6 towers with 4 x 400 mm² conductor bundles. With the future use of gap conductor, which has a rating close to 3190 MVA, slightly higher circulating currents are observed. For 3100 MVA balanced power flow using L2 towers and earth switches at each end, all other parameters being equal, the maximum circulating current is 395.7 A. This represents an increase of around 4%.

The sensitivity of the studies to system strength at the Sending and Receiving end nodes was investigated for the balanced loading conditions, the results of which are detailed in Table A3.

L2 (2000 MVA) effect of System Strength on Circulating Currents (A) with Balanced Loads and Drain Earths Applied One Tower from Circuit End						
Fault Level (kA)	Earth	Earth-wire (mid point)	Red Phase	Yellow Phase	Blue Phase	Change in Drain Earth Current
30	158.3	261.0	166.0	84.8	254.3	1.15%
40	159.8	261.8	166.7	83.9	253.2	0.72%
50	161.3	262.6	167.4	83.3	252.3	0.36%
60	162.7	263.3	168.0	82.6	251.4	0.00%

Table A3 – Sensitivity of Circulating Currents to System Strength

Sensitivities to earth mat to earth resistance were also tested, the results being detailed in Table A4. Large percentage changes in earth mat resistance are required to introduce moderate changes in circulating current, however, it is not unreasonable for very large variances in earth mat resistance to occur across the country due to changing geological conditions.

L2 (1710 MVA) effect of Earth Mat Impedance on Circulating Currents (A) with Balanced Loads and Drain Earths Applied One Tower from Circuit End (63 kA fault level)						
Earth Mat Impedance	Earth	Earth-wire (mid point)	Red Phase	Yellow Phase	Blue Phase	Change in Drain Earth Current
0.2ohms	139.8	225.3	143.8	70.6	214.7	0.00%
0.5ohms	114.7	217.1	134.2	79	226.1	5.31%
1.0ohms	82.2	208.9	124.3	83.6	237.4	10.57%

Table A4 – Sensitivity of Circulating Currents to Earth Mat Impedance

In terms of relative percentage changes the effect of the substation earthing impedance is small, i.e. a ~10% change in Drain Earth current is brought about by a 400% change in Earth Mat impedance (see figure A8).