TR A5721

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Electrical Rating of DEH for Rigid Steel Risers

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November 2002

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TECHNICAL REPORT

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Enterprise No.:
NO 939 350 675 MVA

SUBJECT/TASK (title)

Electrical Rating of DEH for Rigid Steel Risers

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CLIENTS(S)

CSO, Statoil, Norsk Hydro, Totalfinaelf, Nexans Norway

TR NO.	DATE	CLIENT'S REF.	PROJECT NO.	
TR A5721	2002-11-06	Vidar Halvorsen, CSO	14X135	
ELECTRONIC FILE CODE		RESPONSIBLE (NAME, SIGN.)	CLASSIFICATION	
021106JKL11227		Gunnar Klevjer	Unrestricted	
ISBN N0.	REPORT TYPE	RESEARCH DIRECTOR (NAME, SIGN)	COPIES	PAGES
82-594-2382-0		Hallvard Faremo		15
DIVISION		LOCATION	LOCAL FAX	
Electric Power Technology		Sem Sælands vei 11	+47 73 59 72 50	

RESULT (summary)

In two reports on Duplex risers [1] and Carbon risers [2] the calculated system impedance, heat generation and current distribution are compared with measured values. The tests are performed on a scaled model at 400 Hz. The calculations are based on the results for two-dimensional cuts for different spacing between risers. The calculations are in good accordance with the measurements.

These results are used to establish calculation methods for DEH of single and neighbouring risers using modified two-dimensional finite elements simulations at 50 Hz.
Tests and calculations have been performed on different grounding alternatives. The rating is referred to the grounding alternatives:

- Single point grounded system.
- Two point grounded system without intermediate electrodes (anodes) along the risers.
- Two point grounded system with intermediate electrodes (anodes) along the risers.

This report gives a summary of the principle for rating of 50 Hz DEH system for neighbouring risers with spacing topside between from 1,7 to 5,6 m and subsea from 1,7 to 14 m.

KEYWORDS

SELECTED BY AUTHOR(S)	Carbon and Duplex	Electrical heating
	Calculations	Neighbouring risers

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1 INTRODUCTION

Methods for electrical and thermal rating of DEH with single and parallel flowlines are qualified based on two-dimensional numerical simulation, [3]. In a system of two or more neighbouring risers the spacing increases from minimum topside to maximum at the subsea end, i.e. it is three-dimensional. As three-dimensional electromagnetic simulations at present not are sufficient developed for riser applications, methods based on two dimensional calculation methods must be applied.
To qualify the calculation methods measurements have been performed on risers of Duplex and Carbon on a scaled model at 400 Hz and the geometry and impedances are converted to 50 Hz equivalent. The scaled tests were performed at 400 Hz for a spacing topside from 0,6 m to 2 m and from 0,6 m to 5 m subsea. The geometric scaling factor between 400 Hz and 50 Hz is 1:2,83 (square root of the ratio between 400 Hz and 50 Hz).
In the reports on Duplex risers [1] and Carbon risers [2] the calculated system impedance, heat generation and current distribution are compared with measured values. The calculations are based on the results for two-dimensional cuts for different spacing between risers.

The field tests include both parallel risers and risers with different individual spacing topside and subsea. For Duplex steel risers the tests comprise max. 3 risers and for Carbon max. 2 risers. Distances between risers in the scaled configuration corresponds to following spacing at 50 Hz (**Figure 1.1**):

- Topside: 1,7 and 5,6 m.
- Subsea: 1,7 and 14 m.

Tests have been performed on different grounding alternatives:

- Single point grounded system.
- Two point grounded system without intermediate electrodes (anodes) along the risers.
- Two point grounded system with intermediate electrodes (anodes) along the risers.

The results are used to establish calculation methods for risers using modified two-dimensional finite elements simulations. This is a main objective of the DEH riser qualification programme.

For risers with two point grounding (with and without intermediate electrodes) only single phase power system can be used.

The system impedance and thermal rating depends on the riser configuration, grounding alternatives, application of intermediate anodes and if the heating is supplied on a single riser or simultaneously on neighbouring risers. The thermal rating of the heating system is determined by the minimum riser current. A piggyback cable is required for each riser to be heated. The neighbouring effect is not sufficient for heating, but influences the system impedance.

For electrical rating of DEH for risers that are shorter than 5 km at 50 Hz, it is only necessary to consider the series impedance. For risers with DEH operating at higher frequencies it can be necessary to take into account the parallel capacitances. For a practical installation it must be examined if an increased frequency is feasible. At higher frequency the system current is reduced and therefore a smaller cross section can be used. In addition the neighbouring effect, induced currents, induced voltage and the problem with stray currents through structures will be reduced.

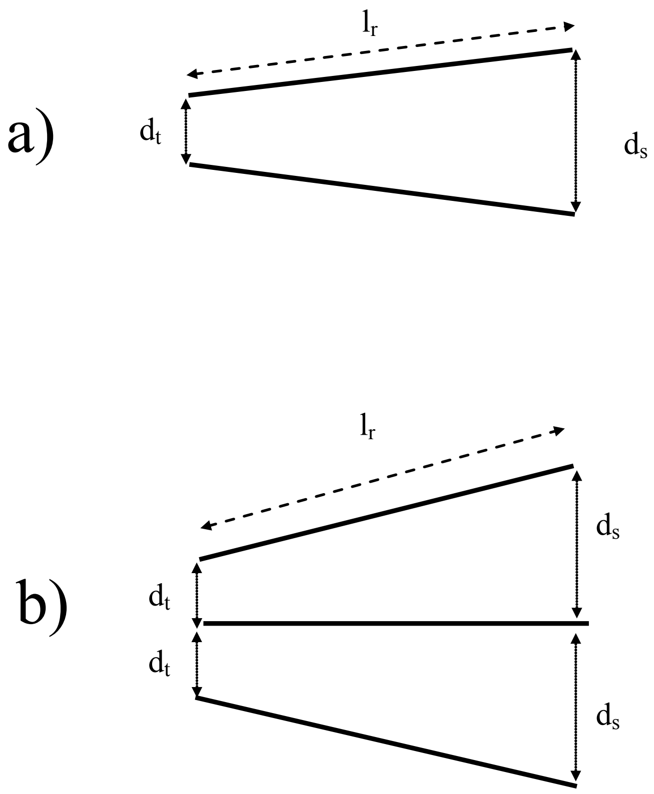

Figure 1.1: The test set-ups for risers with different spacing topside and subsea. For Duplex steel risers the tests comprise max. 3 risers and Carbon max. 2 risers The distances between risers in the scaled configuration corresponds to a spacing topside (d_t) from 1,7 to 5,6 m and from 1,7 to 14 m subsea (d_s) at 50 Hz.

2 ELECTRICAL AND MAGNETIC PROPERTIES

Table 2.1 shows the measured electrical and magnetic data for Duplex, Carbon and the resistivity for copper and seawater used in the calculations for comparison with measurements in [1, 2]. The permeability is dependent of the magnetic field and must therefore be correlated to the current. An alternative is to represent the magnetic characteristic with a B/H – relation. This will improve the accuracy of the simulations, but requires extensive measurements and fabrication of special specimen from the actual steel materials.

Table 2.1: Electrical and magnetic data. 1) The effective relative permeability is given from [1, 2]. The value of the permeability is correlated to the current.

Material	Resistivity at 20°C [$\Omega mm^2/m$]	Temperature coefficient of the resistivity [1/°C]	Relative effective permeability
Duplex	0,8	0,00873	30 – 60 [1)]
Carbon steel	0,2	0,00324	150 – 450 [1)]
Cable copper conductor	0,0172	0,00393	1
Seawater	$0,3 * 10^6$	-	1

3 REQUIRED GENERATED HEAT IN THE RISER

The required generated heat in the riser is determined by the required temperature rise of the steel riser and the thermal data for the riser insulation.

The average thermal conductivity, γ, for the riser insulation is related to the overall heat transfer coefficient, U, with reference to the inner diameter of the steel riser is determined by:

$$U = 2 \cdot \gamma / (id_{st} \cdot \ln(OD_{ins} / OD_{st})) \quad \text{(Equation 3.1)}$$

OD_{ins} - outer diameter of the insulated riser
OD_{st} - outer diameter of the steel riser (inner diameter of riser insulation)
id_{st} - inner diameter of the steel riser

The thermal resistance of the riser per length, R_T, is:

$$R_T = \ln(od_{ins} / od_{st}))/ (\gamma * 2 * \pi) \quad \text{(Equation 3.2)}$$

Based on the required riser temperature, the required heat development is determined by:

$\theta_p - \theta_s = R_T * P_p$ (Equation 3.3)

θ_p - Required temperature of the steel riser [^{o}C]
θ_s - Temperature of seawater [^{o}C]
P_p - Required heat development in the riser [W/m]

Equation 3.3 assumes a uniform heat development in the steel riser. For a DEH installation the heat development varies within the cross section of the steel riser, and the value obtained by finite element simulations will therefore differ from calculations by **Equation 3.3**.

The thermal model for the riser with piggyback cable used in the finite element simulations is shown in **Figure 3.1**. In these calculations specific values of the thermal insulation must be specified. If the U-value is given the thermal conductivity can be calculated from **Equation 3.1**. The thermal and electromagnetic simulations of the DEH configuration can be combined in order to include the temperature dependency for the electrical resistivity of the conductors (steel riser and copper conductor materials). In these calculations the cable temperature is determined. The cross section must be adjusted to comply with the max. allowable cable insulation temperature.

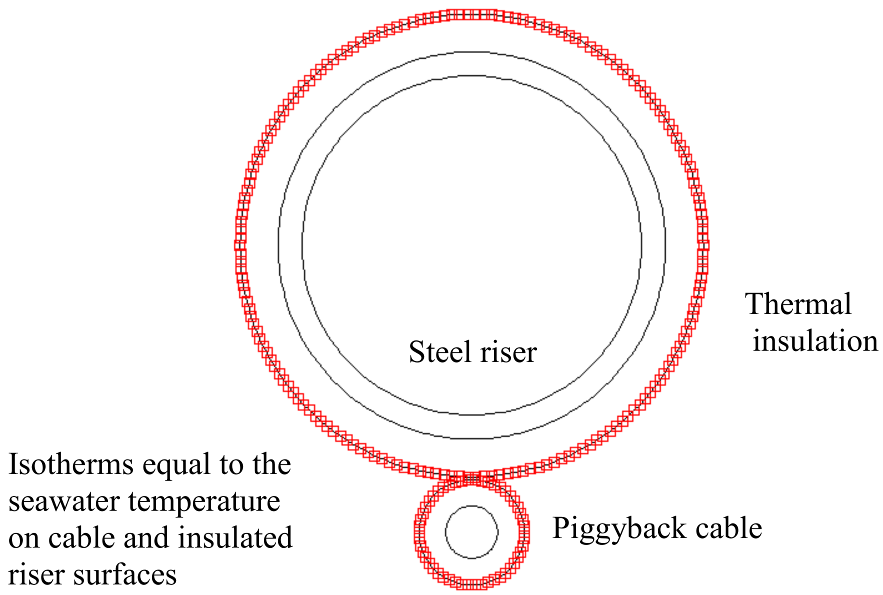

Figure 3.1: Thermal model for riser with piggyback cable. The outer surface of riser and cable is represented by an isotherm of temperature equal to the seawater temperature.

4 RATING OF SINGLE POINT GROUNDED RISER

For single point grounded system the risers are grounded only at the subsea end. The max. voltage of riser and cable is at topside. The riser insulation and topside riser termination must be qualified for the relevant voltage.

Both tests and calculations confirm that the neighbouring effect to other risers can be neglected for piggyback configuration, i.e. the system cable is clamped to the riser. The riser current, which determines the thermal rating of the heating system, is equal to the piggyback current. It is assumed that the piggyback cable has no armouring or metallic screen. (In case of armouring and screen these must be single point grounded and for this case the induced voltage must be considered).

By finite element calculations, the electrical parameters can be determined for a simplified model neglecting the other risers and seawater. **Figure 4.1** and **4.2** illustrate the model for a Duplex riser. For this case it is sufficient to restrict the model to an area with a radius of 10 m and common center with the riser. This circle is used as the boundary conditions with constant vector potential and the magnetic field equal to zero. For electrical components the elements in the model is related to the depth of penetration. In general the first element from the surface should be chosen less than the depth of penetration and the next elements with increasing length.

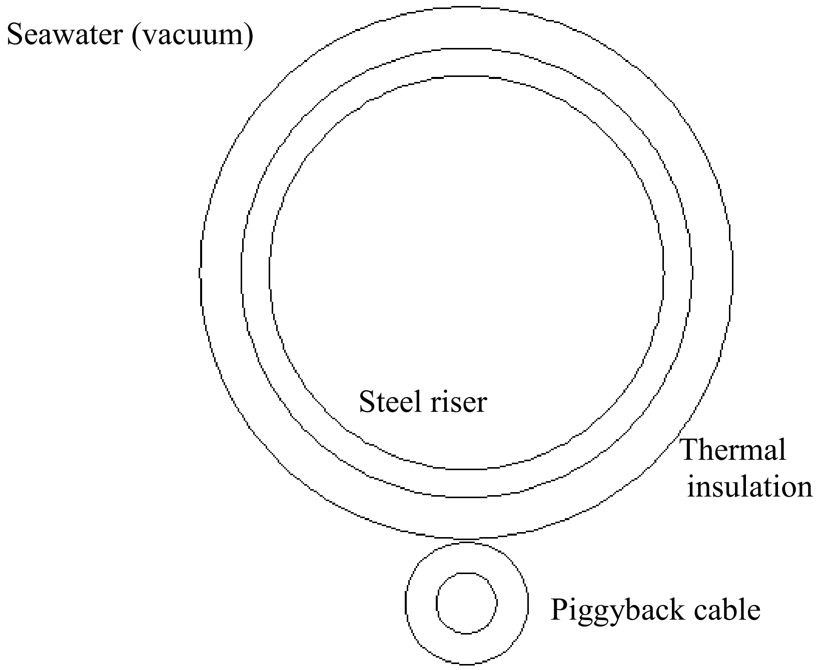

Figure 4.1: Electromagnetic model of single point grounding of Duplex risers.

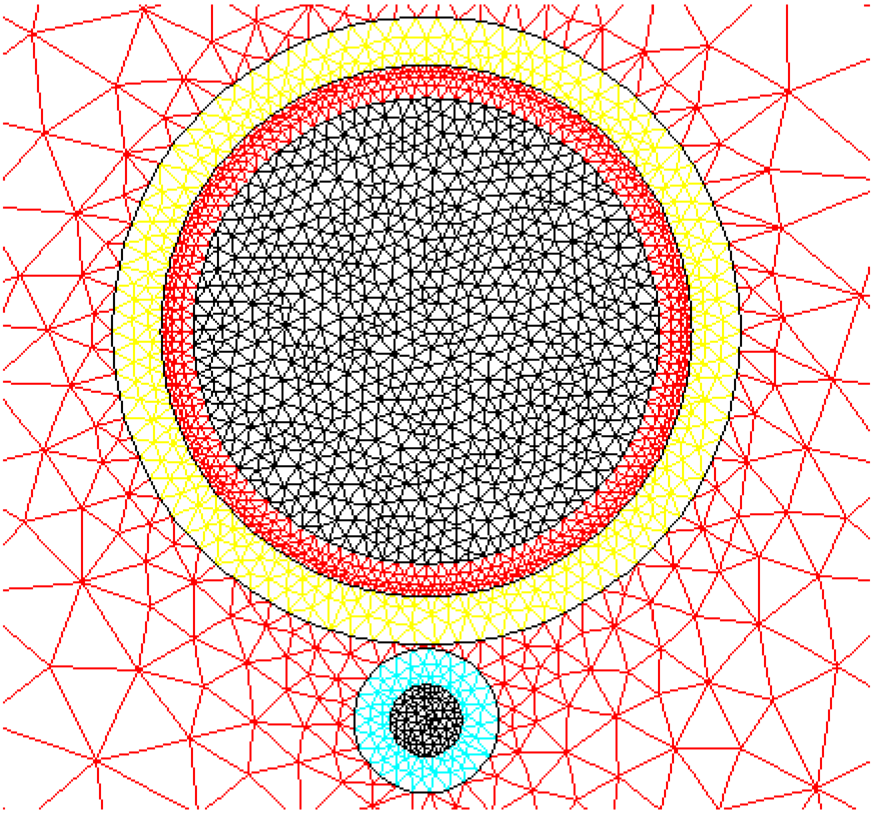

Figure 4.2: The mesh for a part of the model close to the riser in Figure 4.1.

In order to determine the required current to heat the riser combined electromagnetic (**Figure 4.1**) and thermal calculations (**Figure 3.1**) can be performed. **Table 4.1** shows the input data and the parameters that can be obtained from the simulations.

Table 4.1: Calculated parameters for DEH of single point grounding system derived from finite element simulations.

Parameter	Symbol	Comments
System current	I	Input
Generated heat in riser	P_r	Calculated
Generated heat in cable	P_c	Calculated
Voltage drop of piggyback cable	U_c	Calculated
Voltage drop of riser	U_r	Calculated
Single phase terminal voltage	U	Calculated voltage between riser and cable
Active power	P	Calculated
Reactive power	Q	Calculated
Temperature conditions	-	Calculated field plot. The temperature conditions must comply with the target riser temperature

The system impedance, Z_r (complex), is the ratio between single phase terminal voltage and system current:

$Z_r = U/I$ (Equation 4.1)

Power system requirements

The requirements for the topside power supply can be obtained directly from the finite element simulations:

- U – single phase terminal voltage
- I – system current
- P – active power
- Q – reactive power

A single phase system is used for heating. Each riser can have separate transformer. Capacitor bank for reactive compensation and single to three phase symmetric conversion may be required, [4].

5 RATING OF RISERS WITH TWO POINT GROUNDED SYSTEM WITHOUT INTERMEDIATE ELECTRODES (ANODES) ALONG THE RISERS

For two point grounding all risers have to be considered both for heating of a single riser and simultaneous heating.
To determine the impedance calculations for parallel riser are performed as a function of the spacing between the risers, see **Figure 5.1**. The impedance for the riser with different spacing topside and subsea is defined as a mean value of the impedances for the relevant soacings. The mean impedance defines an **equivalent spacing** (parallel risers), see **Figure 5.3**. Calculations at this spacing are used to determine the parameters for the DEH riser system at 50 Hz. The calculations cover spacing topside from 1,7 – 5,6 m and subsea from 1,7 to 14 m.
Figure 5.1 illustrates the impedance and resistance for the case of two parallel 10” Duplex steel risers as a function of the spacing. Both heating of one of the risers and simultaneous heating is shown in the figure. The impedance is calculated for an equivalent distance of approx. 6m for this case.

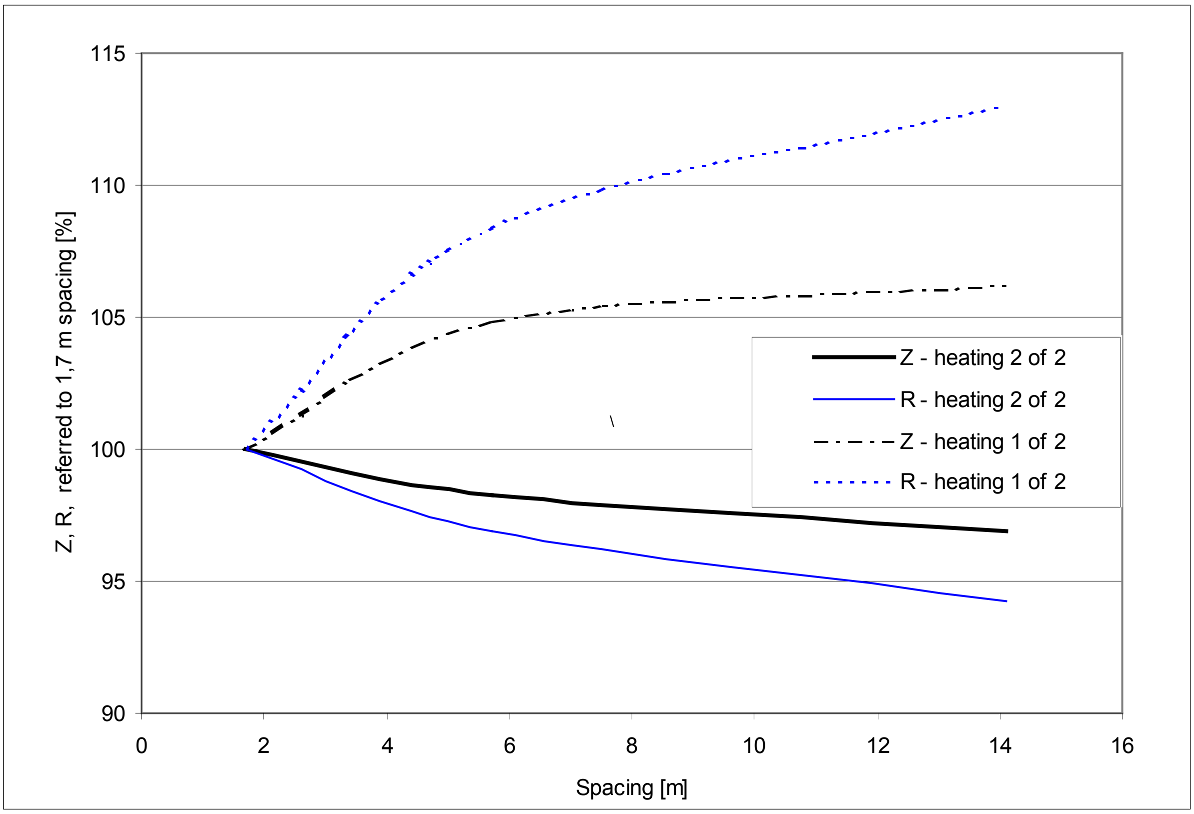

Figure 5.1: The impedance and resistance for the case of two parallel 10” Duplex steel risers as a function of the individual distance. Both heating of one of the risers and simultaneous heating are shown.

The electrical parameters are calculated by finite element simulations. For neighbouring risers the model is the cut with individual separation of risers corresponding to the mean value of the impedances. The **Figure 5.2** illustrates the model for two Duplex risers. The model must include all conductors including sufficient area of seawater. The area of seawater should be at least two times the penetration depth from the risers, i.e. an area of 200 m x 200 m with the risers located in the middle. One of the lines surrounding the model (far from the active conductors) is used as the boundary conditions with constant vector potential and the magnetic field equal to zero. In general the first element from the surface should be chosen less than the depth of penetration and the next elements with increasing length.

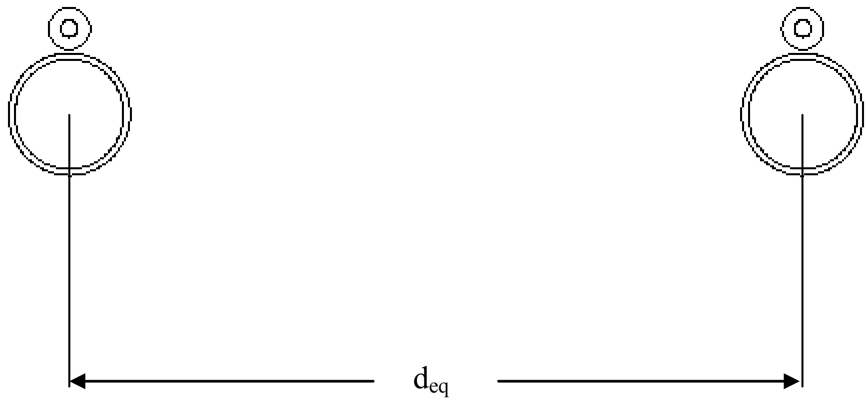

Figure 5.2: Electromagnetic model of two point grounding both for the cases with and without intermediate anodes of two Duplex risers.

In order to determine the required current to heat the riser combined electromagnetic (**Figure 5.2**) and thermal calculations (**Figure 3.1**) can be performed. **Table 5.1** shows parameters that can be obtained from the simulations.

Table 5.1: Calculated parameters for DEH of two point grounding system derived from finite element simulations. Results are obtained for each riser.

Parameter	Symbol	Comments
System current piggyback cable	I	Input
Current in riser	I_r	Calculated
Current in seawater	I_s	Calculated
Generated heat in riser	P_r	Calculated
Generated heat in piggyback cable	P_c	Calculated
Generated heat in seawater	P_s	Calculated
Voltage drop of piggyback cable	U_c	Calculated
Voltage drop of riser	U_r	Calculated
Induced voltage in neighbouring cable	U_{ind}	Calculated
Single phase terminal voltage	U	Calculated voltage between riser and cable
Active power	P	Calculated
Reactive power	Q	Calculated
Temperature conditions	-	Calculated field plot. The temperature conditions must comply with the target riser temperature

The system impedance, Z_r (complex), is calculated by the ratio between single phase terminal voltage and system current:

$Z_r = U/I$ (Equation 5.1)

Power system requirements

The requirements for the topside power supply can be obtained directly form the finite element simulations:

- U – single phase terminal voltage
- I – system current
- P – active power
- Q – reactive power

A single phase system is used for heating. Each riser can have separate transformer. Capacitor bank for reactive compensation and single to three phase symmetric conversion may be required, [4].

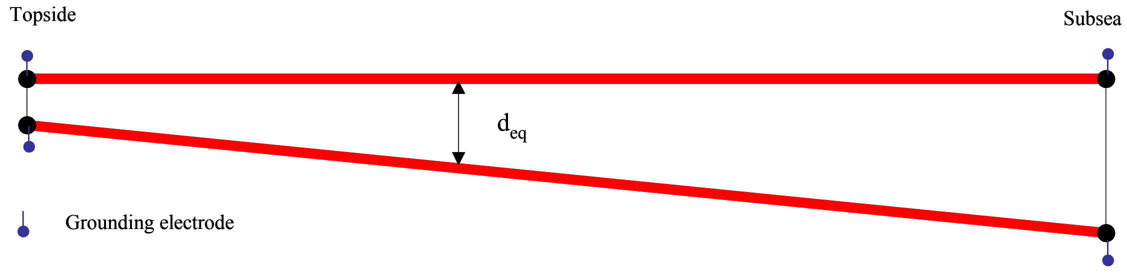

Figure 5.3: Two point grounding without intermediate anodes. d_{eq} is the equivalent distance for two dimensional modelling.

6 RATING OF RISERS WITH TWO POINT GROUNDED SYSTEM WITH INTERMEDIATE ELECTRODES (ANODES) ALONG THE RISERS.

When only one of the risers is heated for system with two point grounding and intermediate anodes the minimum current appears at min. spacing (topside) and is calculated as the equivalent current (rated) for parallel risers at this spacing.
For simultaneous heating and two point grounding with intermediate anodes the minimum current appears at max spacing (subsea) between risers. It is calculated as the equivalent current (rated) for parallel risers at this spacing, see **Figure 6.1**.

The electrical parameters are calculated by finite element simulations with the same principle as for the case with two point grounding without intermediate anodes. For neighbouring risers the geometric model is shown in **Figure 5.2**. The geometry model must comply with individual distances for single and simultaneous heating of riser as presented.

In order to determine the required current to heat the riser combined electromagnetic (**Figure 5.2**) and thermal calculations (**Figure 3.1**) can be performed. As for two point grounding without intermediate anodes **Table 5.1** shows obtained parameters from the simulations.

Power system requirements
The requirements for the topside power supply can be obtained directly form the finite element simulations similar to the case in **Section 5** without intermediate anodes.

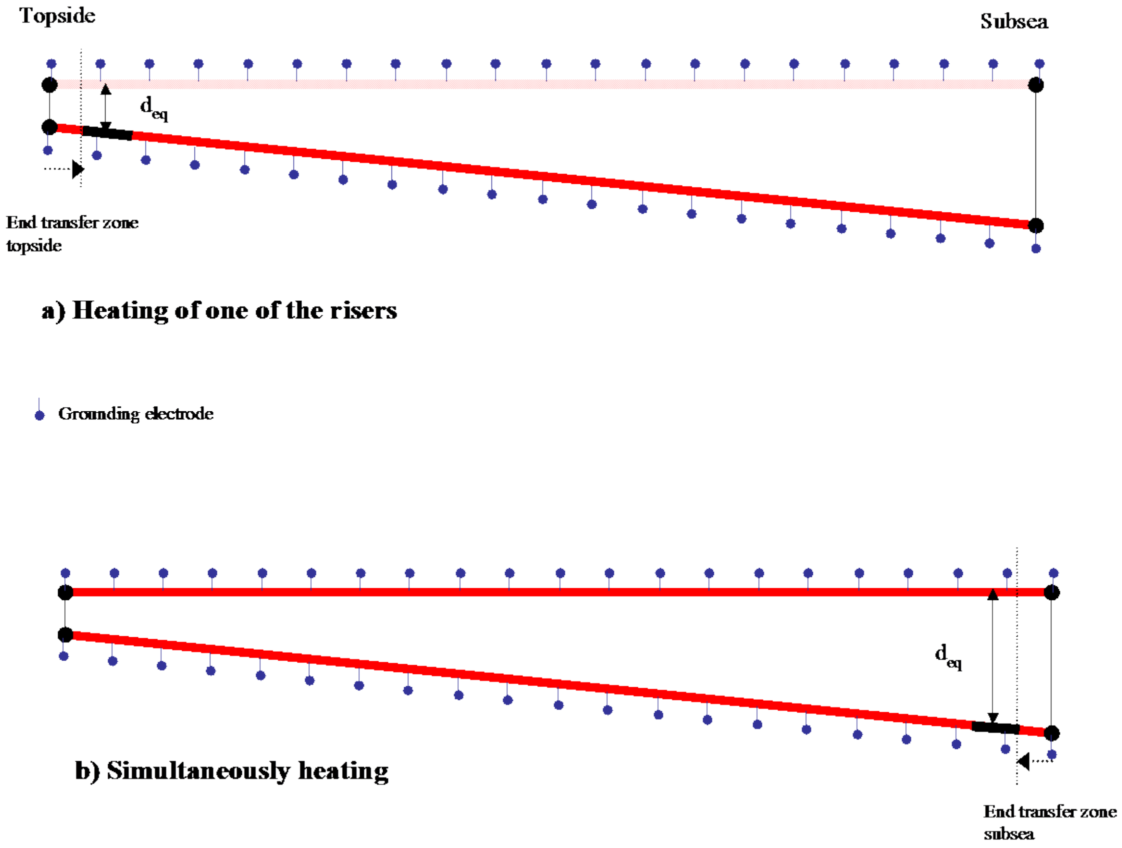

Figure 6.1: Two point grounding with intermediate anodes. d_{eq} is the **equivalent distance** for two dimensional modelling.When only one of the risers is heated d_{eq} is at min. spacing (topside) close to the end of the transfer zone. For two point grounding with intermediate anodes d_{eq} is at max.spacing (subsea) close to the end of the transfer zone for simultaneous heating.

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