MINISTERIE VAN ECONOMISCHE ZAKEN

GENERAL COST COMPARISON BETWEEN UNDERGROUND CABLES AND O.H. LINE SYSTEMS FOR H.V. TRANSMISSION

REPORT ON NETWORK RELIABILITY ASPECTS OF THE CHOICE LINE VERSUS CABLE FOR THE RANDSTAD380 PROJECT

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1. INTRODUCTION

The present document summarizes the complementary analysis made by TE (Tractebel Engineering) on the “System” aspects of the choice line versus cable for the Randstad380 kV project. This complementary analysis was requested by MINEZ after a concern formulated (rather late) by TenneT that cables would endanger network stability and so the reliability of the whole 380 kV system of TenneT.

A first investigation of several documents (also of international origin) submitted by TenneT in support of the stability risk statement did not reveal evidence reported by others on the subject of stability.

In order to clarify the matters a meeting was held in MINEZ offices on April 11, in the presence of TenneT, MINEZ, VROM and TE.

The present report condenses the opinions of TE after the discussions and clarifications as obtained at said meeting.

(The final version of this report will also comment on the ppt presentation shown by TenneT at the meeting, but this document has not been distributed yet to us).

In this report we also refer occasionally to the document Visie2030 published by TenneT in February 2008.

2. DISCUSSION OF PREPARATORY QUESTIONS RAISED BY TE

2.1. STABILITY RELATED QUESTIONS

Quote of questionnaire

- What kind of phenomena are feared by TenneT in relation with electrical stability of the network ?
- Which physical background underlies these phenomena ?
- To what extent is this background specifically linked to cable transmission ?
- Which examples of said phenomena have been recorded elsewhere before and are documented in technical literature (CIGRE, JI-CABLE, IEEE, …) ?

Unquote.

Opinion of TE at the issue of the discussion:

There is no specific stability risk related to cables, provided that the Mvar (reactive power) produced by the cables are suitably compensated (by shunt reactors). This statement is not conditioned by the cable length.

In none of the reports supplied by Tennet stability aspects are dealt with. The absence of reported experience with cables in similar situations does not mean that such experience would necessary imply instability.

The stability aspects of cables are twofold:

- **Transient and dynamic stability: here the determining factor to be compared is the series reactance of the circuit. As the equivalent cable circuits have far lower reactance compared to the comparable line circuit, cables are more favourable than lines in this respect.**

- **Voltage stability: if cable capacitance is uncompensated, the large capacitance Mvar injected in the network moves the generators to lower excitation levels and moves the "voltage versus load" curve upward. Transmittable power increases but the voltage collapse point (nose of the "voltage versus load" curve) rises also to values closer to rated voltage, which may be a hidden danger of voltage instability. The voltage stability impact of cables may be completely neutralized by shunt compensation using reactors. Suitable compensation means compensation which neutralizes the cable Mvar (or at least those cable Mvar which are not useful as compensation of Mvar transmission losses elsewhere in the network).**

2.2. OTHER SYSTEM RELIABILITY RELATED PROBLEMS

Quote of questionnaire

- What other problems (electrical stability left aside) are feared by TenneT as a consequence of implementation of 400 kV cable links ?

Unquote.

Several points were raised by TenneT as there are:

- Added complexity due to additional components (essentially shunt reactors, possibly series reactors);
- Distorted load flows in mixed (lines, cables) meshed grids, with a tendency to overload the cables;
- Ferranti effect rises cable midpoint voltage, beyond control of the system operator;
- Cables introduce weak spots as regards system operating voltage;
- Cables may produce resonance effects.

2.2.1. Added complexity due to additional components

Cables 380 kV in the arrangement proposed produce some 22 Mvar / km and per circuit.

Depending on the strength of the network, these shunt Mvar need compensation by shunt reactors. This will probably be necessary from ~10 km, i.e. a shunt reactor of 110 Mvar at each end for 10 km. Shunt reactors cause also no-load losses.

TenneT mentions that voltage control by switching operations (on shunt reactors) is a complex operation, particularly at high voltages in meshed networks.

TenneT mentions also series reactors to counter the problem in the next item 2.2.2. Series reactors are bulky, noisy and cause on-load losses.

Opinion of TE at the issue of the discussion:

Shunt reactors are needed for substantial cable lengths. These components exist in suitable sizes for links of 20 km and more, from different manufacturers and are not specially fragile from an operation point of view. They may be permanently fixed on the cable ends and switched together with the cable circuit. For links of 40 km, also a midpoint compensation may be considered.

The Mvar effectively produced by cables vary with the square of the operating voltage applied, the same applies to the Mvar absorbed by shunt reactors. This is just a matter of definition of rated voltage.

Switching the shunt reactors together with the cable circuit ensures an automatic balancing of excess Mvar and is thus favorable for the voltage stability of the system, see comment under 2.1 above. Switching the reactors together with the cable circuit facilitates therefore the complex voltage control operation mentioned by TenneT.

Series reactors are only intended to mimic an overhead line behaviour with the cable. The need for these depends on the existence of real distortions as per point 2.2.2.

2.2.2. Distorted load flows in mixed (lines, cables) meshed grids

The series impedance of cable circuits (pro km) only 25 to 33 % of the series impedance of the equivalent line circuit (pro km). In meshed grids, with mixed cables and lines, the lower cable impedance will favour transport through the cables.

As a result cables will reach their limit first, whereas lines remain partly loaded. The overall network might be inefficiently used. The situation depends on the actual production and load configuration to be served, and by the topology of the network and is by no means systematic. If the problem should become systematic, then several measures are possible:

- Mimic line by added series reactor to cable (probably cheapest solution);
- Flow control by phase shift transformers at well chosen points;
- Series capacitor compensation of well chosen overhead lines.

Opinion of TE at the issue of the discussion:

The problem of load flow distortion may effectively occur in mixed meshed networks, depending on the actual generation and load pattern to be served. The problem does however not disqualify the cable as such, because corrective measures are available (most indicated : series reactor), however with some added complexity.

This added complexity of a series reactor is only at the level of space occupied and lay-out of substations. In operation, the series reactors are purely passive static devices and their influence on system behavior is of constant and predictable nature. In fact the cable plus series reactor mimics an overhead line, which is the most common network element of TenneT.

2.2.3. Ferranti effect rises cable midpoint voltage, beyond control of the system operator

Capacitive Mvars are produced all along the cable, whereas compensation by shunt reactors is installed (or switched) at the ends. The transport of Mvar from the middle to the ends does rise the cable midpoint voltage, out of reach and view of the system operator.

Opinion of TE at the issue of the discussion:

A quick check of the no load situation (worst case) for a 20 km cable (or a 40 km cable with also midpoint compensation) shows midpoint voltage rise in the order of 0.1 to 0.2%, which is negligible compared to voltage ranges found in operation at the cable ends (5 to 10%).

2.2.4. Cables introduce weak spots as regards system operating voltage

TenneT fears that cables will introduce additional operating voltage constraints, which will make the task for system operators more difficult. (A similar problem occurred before with some particular GIS substation of TenneT.)

Opinion of TE at the issue of the discussion:

The present day cable technology and manufacturer practice of XLPE cable provide sufficient safety margins on operating voltage. If one does not give confidence to this cable technology, then even the shortest cable sections (river crossings) would have to be excluded. Nonetheless TenneT has already a cable river crossing intended for future operation on 380 kV.

2.2.5. Cables may produce resonance effects

TenneT fears resonance effects due to cable capacitance during transient conditions. Similar cases seem to have occurred in 150 kV networks with ungrounded neutral point.

TenneT also refers to the possibility of harmonic resonance due to cable capacitance in otherwise mainly inductive networks.

Opinion of TE at the issue of the discussion:

Systems with ungrounded neutral may give rise to resonance conditions during earth faults. This is not specific to cables in the network, and may as well occur in completely OH line networks. Determining factors are the total inductive impedance (positive + negative sequence) of the source and the total capacitance to ground in the zero sequence equivalent network. Rigidly earthed networks such as the 380 kV effectively short-circuit the zero sequence capacitance and eliminate this phenomenon.

As regards harmonic resonance, one should consider that any line or cable brings into the network equivalent diagram series reactance and resistance as well as shunt capacitance. The resulting equivalent diagram of the network shows at each of its nodes a frequency response diagram (Impedance Zh) which is generally rising with frequency, but with peaks and valleys which correspond respectively to (partial) shunt resonances and series resonances as seen from the node in question. The deviation of peaks and valleys (with respect to the general rising trend) depends also largely on the natural damping in the system (resistive losses, loads, generator damping coils). Cables instead of lines bring greater capacitance for less series reactance. Cables will influence the frequency response curve differently, in that they will move the first resonance responses to lower frequencies than in pure overhead line systems. Localized resonances on 400kV are not very likely, as overall system damping is high and disturbing loads are generally connected at a far lower voltage level. The only exceptions may be large arc furnaces, HVDC converter stations or Static Var Compensators. However such devices are always equipped with filter circuits, which have to be dimensioned taking into account the frequency response curve (including the cables effects, if any) of the system seen at their connection point.

2.3. EXPERIENCE RELATED QUESTIONS

Quote of questionnaire

- What is the operating experience of TenneT on cable links presently in operation ?
- How is this experience related to the present position of TenneT regarding 400 kV cable transmission ?

Unquote.

Tennet mentions one river crossing, with unforced water cooling, designed for 380 kV but presently operated on 150 kV. No specific operational problems.

Opinion of TE at the issue of the discussion:

TenneT has no (negative) experience of 380 kV operated cable which might explain their present reluctance regarding cables. On former occasions TenneT has shown sufficient confidence to introduce cables 380 kV in the network for river crossings.

2.4. PLANNING CRITERIA RELATED QUESTION

Quote of questionnaire

- How where the network planification criteria and their application-interpretation adapted to the specific properties of cable links ?

Unquote.

This question was not explicitly discussed during the meeting. From the TenneT presentation, and also from Visie2030 (4.1, pg 25), it appears that the basic planning module is an overhead line, 2 circuits, each circuit rated 2750 MVA.

For the cable solution, a similar rating per circuit was selected, with two cables in parallel per phase in each circuit.

Opinion of TE at the issue of the discussion:

This is an obvious choice for mixed connection with sections of line and cable in series. However for entirely cable links it would be more economical to consider planning unit blocks of 3 circuits, each with one cable per phase. This gives the same or better transmission capacity in N-1 and N-2 conditions and some 20 to 25% reduction on capex.

Assuming a link of 20 km, in cable, 2 circuits as per TenneT design, compared to 3 circuits of one cable per circuit, which needs two additional 400 kV bays (one at both ends of the extra circuit) and using reference costs as per the companion report one comes to the following conclusion:

20 km x 11.1 M€ x 0.20 – 2 bays x 3 M€/bay = 38.4 M€ CAPEX reduction. This is still considerable money not to be lifted out of the pocket of the end consumer which in fine bears all the costs.

In a similar way one may consider to replace (starting from one end) part of the 2 circuit OH line by 3 circuits of cable (one cable per circuit). Here additionally 6 bays 400 kV are needed. The extra substation expense is compensated as soon as 8.11 km of line is converted to cable.

(6 bays x 3 M€/bay) / (11.1 M€ x 0.20) = 8.11 km

3. OVERALL DIAGNOSTIC OF THE SITUATION

This chapter reflects the view of TE as outsider on the situation. It is not meant to interfere whatsoever in the procedure or the prerogatives or competences of the parties involved.

3.1. APPROACH AND EXPECTATIONS OF TENNET AT PLANNING STAGE

- TenneT conceived quite some time ago the Randstad380 connection as a logical sequence in its planning process, using its standard planning unit block of double circuit OH line, 2750 MVA per circuit;
- Among the various possible alternatives, the almost straight (and thus short) connection Wateringen-Zoetermeer and then Zoetermeer-Beverwijk was best ranked and therefore proposed as necessary and optimal investment;
- TenneT engaged in the permit procedure, expecting an approval of this connection as OH-line, maybe with minor cable sections on specific technical spots.

3.2. OUTCOME OF THE PERMIT PROCEDURE

- TenneT receives an approval of the proposed route, but with the constraint that part may have to be executed as cable;
- The environmental and public pressure is such that “part” tends to become “total”, despite the substantial higher cost of cable;
- TenneT realizes that the link for which they will receive permit is not the link they planned for (which was based on OH line, the full cable alternative was never considered at planning stage).
- Furthermore, the link will cost 5 to 6 times the original line budget. This upsets completely the ranking of possible solutions as considered at the planning stage.

3.3. EVOLUTION OF SYSTEM VIEW SINCE THE PLANNING DECISION FOR RANDSTAD380

- The Visie2030 document looks for various scenarios of development of production and loads from now to 2030.
- Essential is the concentration of production infeed at coast locations Borssele, Maasvlakte, IJmuiden en Eemshaven;
- In the same document (pg 28, item 4.3, second paragraph), it is stated that direct links between the coastal production sites are not favourable;
- The present Randstad380 is just the beginning of such a coastal interconnection. The future usefulness of this link is thus indirectly questioned by the Visie2030 report

3.4. SUMMARY FOR TENNET

- TenneT receives permit for a link which has not been thoroughly planned and which is not optimized for the technology imposed;
- TenneT has additional effort to make the link fit with the rest of the 380 kV network;

- The investment budget is multiplied by 5 to 6;
- New insights question the usefulness of the link in the future;

3.5. TOO LATE FOR ALTERNATIVE SOLUTION ???

Again, this is not meant to interfere whatsoever in the procedure or the prerogatives or competences of the parties involved.

TenneT might as well consider;

- An additional double circuit line, each circuit rated 2750 MVA, as follows: Maasvlakte – Crayestein – Krimpen – Diemen – Oostzaan – Beverwijk , with in addition a double circuit antenna (uitloper) from Krimpen to Bleiswijk;
- This solution would have been poorly ranked in the initial planning (roughly double length), but ;
- The solution uses existing corridors, without any further footprint on virgin ground;
- The solution becomes economically attractive compared to the imposed cable solution on Wateringen- Zoetermeer-Beverwijk;
- The solution fits better with the views of Visie 2030, which favours direct links from the coastal production sites to the "Great Ring"

4. CONCLUSIONS

The above considerations may be summarized as follows:

- Is there a major objection from network reliability against the implementation of 380 kV cables of ~20 km ?

  NO
- Is the full cable solution Wateringen- Zoetermeer-Beverwijk as proposed anywhere near the optimum Technically-Economically-Environmentally ?

  VERY QUESTIONABLE