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Added value of integrated substations in improving social acceptance of power system infrastructure

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The Netherlands

SUMMARY

The Netherlands is a densely populated country. To meet the growing demand for electric energy there is a need to expand the transmission grid capacity in various locations, in particular in urban areas. Social acceptance is an increasingly important factor: most people accept the need for an electricity system, but most don't want to have it built in their backyard (NIMBY).

One of the lessons learnt from major projects in recent years is that the idea of building an "invisible" grid is wishful thinking. For overhead lines a new regulation has been laid down in the Netherlands. It states that the Transmission System Operator (TenneT TSO B.V.) can build new 380-kV overhead lines on the condition that the total length of the overhead high-voltage lines shall not be increased. This regulation results in the upgrading of existing lines, increased use of cables and replacement of lines with cables in the 110-kV and 150-kV grids.
For substations, no regulation exists as yet. TenneT wants to be prepared for the discussion about this subject, however, and started a survey on how to deal with stakeholder needs in relation to substations.

The most important stakeholders in this discussion are the asset owner and the local authorities that represent the community. In general, the acceptance of substations in terms of landscape integration will increase if alternatives are available, especially if some of these alternatives offer added value (through public functions) or are better suited to the surrounding area. If TenneT can show the various stakeholders that several alternatives have been investigated and can convince them that TenneT really wants to act as a "good neighbour", it will be able to reduce the initial resistance. It is therefore important to

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anticipate these discussions and to introduce feasible solutions and alternatives for various landscape types (including urban areas).

The aim of the study was to offer more options and possibilities for substations in order to increase acceptance by local authorities without the main company values of the TSO being affected. Various issues were taken into account, like environmental considerations (e.g. SF_6), land use, electrical safety, reliability, constraints during operation, possibilities for future expansions, etc. Employees from various departments were involved: besides planners, architects and engineers, almost all other disciplines of TenneT and Movares contributed by participating in the discussions as well.

The study also addressed the future renovation/expansion of existing high-voltage substations in the Netherlands, combined with their integration into complex public infrastructures.

The result is a catalogue or sketchbook describing concepts and practical examples of how to integrate the electrical installation into its environment. Various types of landscape and their limiting conditions are described and alternatives are compared. The catalogue will be used as a guide when TenneT will be proactively looking for new substation locations and is moreover intended to make people realise that there are more options than just the "standard substation". This catalogue is also to be used for future projects to determine the best possible design in cooperation with local authorities. It is intended to be a source of inspiration for the careful integration of vital infrastructure. By taking the surrounding area into account, TenneT is showing how highly it values corporate social responsibility (CSR).

This document gives an overview of the Dutch conditions and considerations which apply to the integration of substations into the surrounding area. All aspects related to the design of a substation have been considered and are illustrated by a number of examples.

KEYWORDS

Substations, Underground, Urban Environment, Social Acceptance, Aesthetics, Compactness, Stakeholders, Types of Landscapes, Environmental Integration and Public Acceptance.

I. INTRODUCTION

The population density of the Netherlands ranks among the highest in the world. At the same time, the annual electricity consumption per resident is still growing. The outstanding reliability of the electricity supply in the Netherlands shows that technical solutions have been found to manage this apparent problem. However, due to the growing demand for energy, the increased number of distributed power generators and the greater awareness of environmental and sustainability issues, the required extensions and modifications to the electrical infrastructure are becoming a real challenge for TenneT, the Dutch Transmission System Operator (TSO), and the possibilities are limited.

The substations are crucial elements of the power grid and act as linking pins in the system. They fulfil important roles, such as voltage transformer and switchyard for network configuration, and are used for monitoring, control and protection of the local systems. For decades, TenneT was pursuing a basic design to meet the requirements of maximum reliability, solidity and safety. Currently, the key issues for the planning and realisation of substations are public acceptance, reducing EM fields, security against external threats and local integration, in addition to issues like technical and financial feasibility. Factors that can enhance public acceptance are transparency and involvement of local authorities and the public, and TenneT tries to create a win-win situation within the limits of technically and financially feasible solutions.

To be proactive and to overcome the new challenges, TenneT and Movares conducted a study entitled “Jointly switching”. This study of the integration of substations into (rural as well as urban) landscapes has resulted in a catalogue describing several concepts and practical examples for various types of solutions for (urban) landscape-friendly integration. The aims of the study were:

- to increase acceptance of the planning of substations (both internally and externally);
- to proactively line up all (im)possibilities from a broad perspective of various disciplines (technology, security, permits, land use, urban development, financial feasibility, etc.);
- to create a source of inspiration and a concept for a vision of new generations of substations based upon a balance between security of supply and public acceptance, smoothing the way for TenneT to deploy new sites;
- to reduce the risk of long lead times and additional costs due to the allocation of rights and permits;
- to find a balance between creative solutions and requirements of the high-voltage grid on the one hand and the requirements of local authorities on the other.

Examples of derived objectives:

- to draw up TenneT policy to give substance to the corporate social responsibility (CSR) goals;
- to create a source of inspiration for future users (TenneT’s staff and external parties).

The title of the study, “Jointly switching”, refers to four dimensions:

- the connecting link in the process of identifying the needs and requirements of the public (authorities) on the one hand and the possibilities from an asset management, operations and maintenance perspective on the other (Figure 1), to explore win-win solutions;
- the creative and interactive workshop model for this study, in which many different factors for TenneT (HV substations, environment, costs, security, innovation, maintenance, legal affairs, land use, building, grid strategy, public affairs, regulations) as well disciplines of Movares (electrical and civil engineering and (landscape) architecture) played a role;
- the connecting link between internal (staff of TenneT) and external stakeholders (the public, represented by local authorities);
- the end result aimed for: a substation that offers social benefits.

The results of the study are set out in this document, which is subdivided into five chapters:

I. Introduction with an explanation of backgrounds, aim of the study and an overview of the process of creation
II. A short explanation of the most important starting points, the reference models and an overview of the developed models
III. A systematic description of landscape and architectural considerations which played an important role in this study, supported by descriptions of some typical examples
IV. A systematic description of the technical considerations, including an overview of the most important issues to consider for the various types of solution
V. Concluding remarks, including the lessons learnt

II. REFERENCES AND STARTING POINTS

We have tried to enhance the practical usability and accessibility of this document by making use of models and including photographs of typical examples.

To develop various models for the substations, we used the most typical reference models in the Netherlands as our starting points, i.e.:
- 150-kV air-insulated substation;
- 150-kV gas-insulated substation.

The expectation is that over the coming years substations will be built particularly in the 110-kV and 150-kV grids. The substation version with hybrid insulation was not included in this study.

All technical assumptions were based on the standard list of requirements [1] used by TenneT for the planning and realisation of substations.

From a landscape point of view we distinguished nine different characteristics of the various landscapes that were relevant for this study [2].

III. LANDSCAPE AND ARCHITECTURAL CONSIDERATIONS

TenneT's substations are classified according to various models based on architectural perspectives(figure 1).

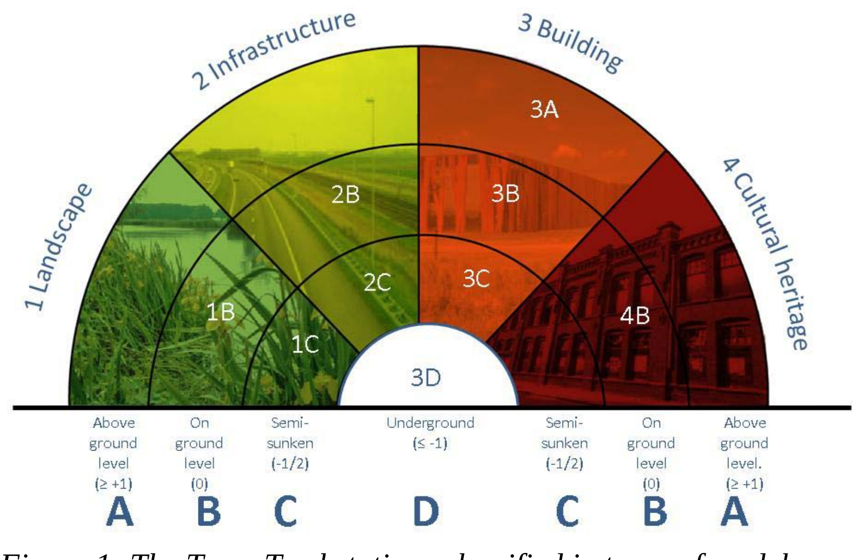

Figure 1: The TenneT substations classified in types of models. The numbers refer to typical examples which are detailed in the catalogue.

Position in metres compared to ground level:

A. Substations above ground level (level +1);
B. Substations on ground level (level 0);
C. Semi-sunken substations (level -0.5);
D. Substations below ground (level -1 or lower).

Way of integrating them into the surrounding area:

1. Landscape: These solutions make use of the typical characteristics of the various landscapes in the Netherlands;
2. Infrastructure: These solutions make use of infrastructural aspects, their functions and appearance to integrate the substations;
3. Building: These solutions add value by putting the substation and/or the operations in the building to good use, for example through heat delivery to a public swimming pool;
4. Cultural heritage: These solutions preserve an historic building for our nation's heritage by transforming its original function.

Landscape

Figure 2: For many substations the integration with landscape structures in Netherlands is very common.

For many substations the integration into common landscape structures in Netherlands is very straightforward. In some cases (for example, to reduce visual effects) it may be helpful to realise a semi-sunken high-voltage station. By using the characteristics of the various landscape types, sustainable integration with added value for the surrounding area may be achieved. Each landscape type has different characteristics and these need to be taken into account. The high-voltage substation can also be used in an urban area. Other elements than scenic ones can add value to the urban area as well. Substations can, for instance, be used as a landmark or sound barrier, or combined with green areas or bicycle routes. In areas where landscape elements such as allotment gardens, wooded areas and other planting elements are common, these elements can be used as a means of integration. An example of a specific solution is a high-voltage substation that is surrounded by trees planted in a way that suits the surrounding area. The addition of dykes may gain acceptance for the construction of a ground-level or semi-sunken substation (level-0.5).

Infrastructure

The Netherlands has a dense network of various types of infrastructure. For the integration of high-voltage substations a combination with rail, water or road infrastructure is preferred. These types of infrastructure can be easily combined with 150-kV high-voltage stations, particularly on ground level, both visually and in terms of ownership and the planning process. By combining the characteristics of the infrastructure with the scenic possibilities and characteristics of the substation, sustainable integration can be achieved with added value for the surrounding area. This model can also be applied in a more urban area. The scenic elements will have added value for the urban area through their use in combination with functions like sound barrier, green area or walking route. Along road and rail routes, high-voltage substations can be accommodated in sound walls, for example.

Figure 3: For the integration of high voltage stations a combination is preferred with rail, water or road infrastructure.

Building

Figure 4: High voltage substation above ground(Rotterdam)

High-voltage substations impose specific requirements on the buildings that accommodate them. In addition, the surrounding area affects the design of these buildings. This applies to visual elements, of course, such as colour, texture and material, but also to the desired location, the shape (elongated, block, etc), and so on. The most popular solutions will be located on ground level. Many examples of this type are already in use. Newly constructed high-voltage substations can also be designed above ground level, so that space will be available for other functions on ground level (below the substation), allowing for multifunctional use of the building. The semi-sunken form (level -0.5) offers good opportunities as well. Because of its limited height, such high-voltage substations can be integrated into the surrounding area more easily. Semi-sunken locations require less space and are less visually intrusive. A substation build under ground, gives more opportunities for using the space above. But of course there is mutual influence, like possibilities for ventilation, requirements for safety and health and escape-routes.

Cultural heritage

In many places in the Netherlands there are unique buildings which are highly valued as parts of the national heritage. Yet maintenance of these buildings (and their history) is apparently difficult. By accommodating high-voltage substations in such buildings, their preservation can be assured by giving them a new function. Technically this is a challenge, however.

Combining the limited space and structural possibilities available in an existing historic building with the requirements imposed on the construction and operation of a high-voltage substation is a complex puzzle. However, it is of great importance to find solutions of this kind. It can be one of the best approaches to realising high-voltage substations with added value in urban locations. If it is possible to revitalise a monumental historic building and realise a substation in it subject to the limiting conditions for a high-voltage substation in the location concerned, this solution will be greatly appreciated.

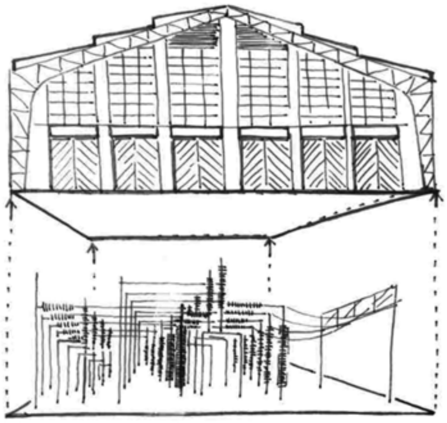

Figure 5: A high voltage substation in a former railway maintenance yard can provide the heritage with a new feature yet preserved.

IV. TECHNICAL DESIGN CONSIDERATIONS

Whenever an extensive integration of a substation in an urban area or a natural landscape is considered, it is important to properly match the functional requirements with the architectural design to avoid ending up with solutions which are technically not desirable. No concessions can be made to the functional requirements of the substation. Constraints for construction, operation and maintenance must be taken into account proactively when new substations are built or existing ones are renovated [3], [4]. During the study we drew up a list of issues that may affect integration. A summary can be found below. For each item, an explanation is given in the Appendix of the catalogue, as well as references, answers from departments involved, propositions and unsolved questions. TenneT's company policies sometimes conflict with a desired solution, such as the use of SF6 for compact substations. In each project where integration of a substation is desired, the aspects listed will need to be addressed during the detailed design phase for the substation.

Reliability	Reliability is generally expressed as the likeliness of a failure occurring and the time that will be needed to resolve it. Indoor and even underground substations are less prone to faults caused by external factors. However, TenneT's data show that the resolution time in such substations will be longer. Accessibility is the main determining factor that needs to be considered in the engineering of the substation. Maintenance access is important for the scheduled lead time as well. For example, a suitable location for a crane must be taken into account.
EM fields	Combining the substation with other (social) functions is desirable due to space limitations. There are several examples where a high-voltage substation is located in a building [7]. In the Netherlands, however, this is not common for these high voltage levels. Calculations indicate that incoming overhead lines significantly increase the total strength of the electromagnetic (EM) field. This needs to be taken into account to avoid adverse effects of EM fields on the surrounding area [6]: - *Human health and safety including non-ionising radiation:* TenneT limits the EM fields for new overhead lines to 0.4 microTesla. This value also serves as a reference value for the vicinity of the substation.

	- *EMC:* Analysis of effects on third-party systems is common for overhead lines. This aspect should also be considered when a substation is integrated in order to avoid disturbances. Not only technical arguments are important here. Potential reputation damage also plays a role. To avoid any kind of discussion, some combinations of functions, such as integration with a data centre or hospital, are therefore excluded in advance.
Noise	In general, noise, if it is properly taken into account during the design phase, is not a problematic issue for the design of *new* substations. However, many expansions are related to *existing* installations where some noise is already being generated. There are a number of potential sources. The noise of transformers and reactors which are already present is particularly important as it limits the room for additional sources. The statutory limits may have already been reached. Reactors can sometimes be placed elsewhere in the grid, however.
Primary installation	In general, TenneT makes use of standard components specified in framework contracts. The use of GIS transformers [5] instead of oil-filled ones saves space, but would mean that special components will be used in the grid.
SF_6	The general, TenneT's policy is not to use SF_6. If no other options are feasible, GIS installations may be opted for, e.g. due to space limitations. Various configurations are currently in use; they are either fully or partially gas-insulated. Benefits include a shorter implementation process. Space limitations are more likely when considering the integration of a substation with other functions and may necessitate the use of SF_6 equipment. This may conflict with company policies, however.
Safety	When integrating a substation into a rural landscape or urban area, all safety requirements regarding fires, hazardous substances / gases and the leakage thereof, explosions or flooding must still be met. The use of independent compartments and fire-resistant paint [8] can limit the impact of incidents. As stated before, accessibility is an important aspect and special attention must be paid to emergency planning in cooperation with the responsible authorities.
Connections	The connections to the substation can be either underground cables or overhead lines. For overhead lines a new regulation has been laid down in the Netherlands. It states that TenneT can build new 380-kV overhead lines on the condition that the total length of the overhead high-voltage lines shall not increase. This results in the upgrading of existing lines or increased use of cables (mostly in the 150 kV grid). The total cable length of 380-kV cables is restricted in the TenneT grid. Other reasons for the reduced use of 380 kV cables are other technical constraints and, moreover, failures in cables have a greater impact. Therefore, the realisation of connections via 380-kV cables is unlikely in the short term. The necessity of the location being entered via overhead lines may limit the possibilities for integration. 150-kV substations are usually located in urban areas and are often connected via cables, which offers more options for integration.

Security — Securing the system against third-party threats is becoming increasingly important. A significant part of the lifecycle costs of the substation are determined by security systems like CCTV.

A separate appendix to the catalogue describes the technical backgrounds in more detail. In this appendix, typical characteristics of landscape types are compared for their technical impact.

V. CONCLUDING REMARKS

To meet the growing demand for electric energy, there is a need to extend the transmission grid capacity in various locations, both in remote and in urban areas. Public acceptance is increasingly important in this regard.

TenneT and Movares initiated a project in which almost all disciplines participated. The result of this combined effort is a catalogue which is intended to reduce opposition and which presents feasible solutions and alternatives for various landscape types and urban areas. The technical appendix gives an overview of the various options and the constraints which were taken in account during the study.

This catalogue is also to be used for future projects to determine the best possible design in cooperation with local authorities. By taking the social and the natural environment into account, TenneT gives shape to its policy in the area of corporate social responsibility (CSR). The catalogue is intended as a source of inspiration for integration of key infrastructure into the surrounding area respecting the interests of all stakeholders. Our aim is to finally achieve a “joint switch”.

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