

Minimising visual impact of 400 kV support structures

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SUMMARY

In line with global experiences, obtaining planning permissions/permits for new overhead transmission lines (OHLs) is a task that is becoming increasingly difficult in European countries. The awareness amongst both the planning profession and the general public of environmental issues and the real and perceived impacts of new OHLs has led to an ever increasing difficulty in gaining public acceptance and planning approval. As recent public discussions have heard on major European transmission projects, the selection of an overhead line or underground cable solution for any circuit or part of a circuit is influenced by a number of factors including technical acceptability, reliability, flexibility, local issues, environmental impact including visual impact and cost. The developer of new circuits needs to weigh up all these factors on a case-by-case basis in selecting the optimum technology to be deployed on a particular circuit. Nevertheless it is fair to say the objections to transmission line projects are broad and varied; ranging from perceived negative health impacts, devaluation of property and intrusion to the visual amenity of the areas through which they pass to name but a few. The visual impact of overhead transmission lines or “pylons” is an interesting subject matter and is generally regarded as the main residual impact once a line is completed.

In response to Irish Government policy document titled “The Strategic Importance of Transmission and Other Energy Infrastructure” [1], EirGrid commissioned a design study which sought to expand the number of structures under consideration and provide real alternatives to the standard lattice steel tower/pylon design. This paper describes how a suite of new lattice tower and monopole designs were developed as part of this study in addition to a new “aesthetic” single circuit support structure. The aim of this paper is to outline the design process followed by ESBI, Knight Architects and SAE which led to the development of this new aesthetic “Wine Glass” structure.

KEYWORDS

Tower design, reduced visual impact, overhead line design, environmental impact

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INTRODUCTION

Irish novelist Margaret Wolfe Hungerford is widely credited with first coining the phrase “*beauty is in the eye of the beholder*” in her 1878 novel “Molly Bawn”. Given the ever increasing difficulty all European utilities face in extending their high voltage grids, the subjective nature of “pylon” beauty has never been more topical. The increasing knowledge amongst the planning profession and the general public of environmental issues and impacts of new overhead lines (OHLs) has led to an ever increasing difficulty in gaining public acceptance and planning approval [2]. When seeking to expand their HV grids, utilities need to fully consider many factors including:

- Technical acceptability,
- Environmental impacts,
- Visual impacts,
- Reliability,
- Cost and
- Construction impacts



The developer of new circuits need to weigh up all these factors on a case by case basis in selecting the optimum technology to be deployed on a particular circuit. Whilst the design and overall appearance of an OHL and its support structures is a critical issue with respect to visual impact, the principal mitigation lies in the routing or alignment on the landscape. Consequentially it is imperative that a rigorous assessment is carried out at the line route selection stage in order to show that the least impact route has been chosen. The potential visual intrusion of a line can be mitigated by routing the line away from settlements and using, insofar as possible, the topography so that adverse visual impacts are reduced. In addition, a well routed line should avoid other environmental sensitivities. Once an optimal route has been defined, further mitigation can be found by refining the aesthetics of the tower or pylon design.

BACKGROUND TO REDUCED VISUAL IMPACT DESIGN

Traditionally OHLs have been designed and constructed using lattice steel towers or pylons. The benefits of lattice steel towers lie in their excellent structural efficiency, durability, ease of construction and their comparatively low cost. Their beauty or otherwise is a subjective matter, but in my own opinion the beauty of the steel tower lies in their invisibility. Whilst up close they are functional and “industrial” looking structures, within a short distance their lattice design means they become transparent on the landscape. Anecdotal evidence suggest that members of the public don’t notice or perceive the transmission already constructed in Ireland and only become aware when their interest is awoken by a new project in their area. Consequentially the design of any new or aesthetic OHL structure needs to be mindful of this transparency and avoid developing a



structure which “stands out” or has too much character. Whilst bold new designs may be nice as a once off structure, they would lose their appeal rapidly when repeated three to every kilometre! The Finnish appreciate this point very well and have for decades used once off aesthetic structures on the transmission system at locations of high visibility close to major urban centres. A once off or low use structure can have greater character or prominent architectural features as they are considered works of art. A very good example is the double circuit 132 kV line which is constructed on a series of small islands in Helsinki’s harbour area. Due to the high profile and city centre location it was decided to make an architectural feature of the line with very interesting results. The towers are quite tall and painted a bright blue in addition to being flood lit at night [3]. A range of structure types is very useful, but utilities must also consider the significant time and effort required to develop new structure types and ideally need to be developed as separate projects and not tied into planned/normal grid extensions

IRISH CONTEXT

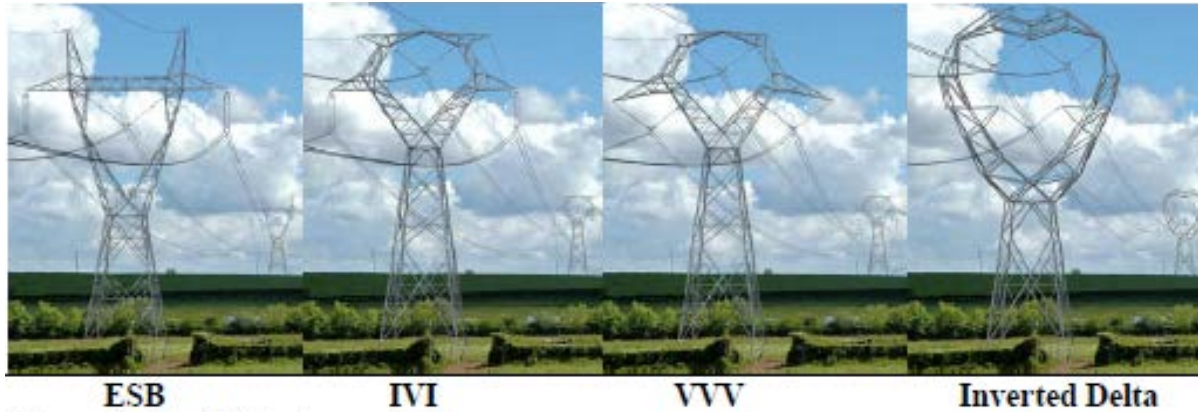
On the Irish transmission system both ESB and EirGrid have and are examining how the design of OHL’s might be improved upon from a visual prospective. The first of these studies was carried out for the development of two new 220 kV OHL’s in the West of Ireland in the late 1990’s. This study looked at the various options for a reduced visual impact including supporting structures, phase conductors, shieldwires and insulators. A suite of candidate designs were developed including a cold formed steel compact design, a braced woodpole, a H-frame design and a compact cold formed delta configuration design. The candidate designs were presented in photomontages and given to a panel of recognised landscape architects for assessment. The candidate designs were assessed with regard to shape, profile complexity, visual density and landscape integration. Overall there was general agreement that the cold formed steel compact design, illustrated on the far right, was the best option and provided a significant improvement over the standard designs.



Photomontage of main 220 kV designs developed during 1999 study.

Likewise EirGrid have continued research and developed a suite of potential 400 kV single circuit tower designs at the outset of recent 400 kV projects with ESBI and SAE PL [4]. Given the large loadings involved at 400 kV level a woodpole option was not viable, hence all candidate designs were lattice steel towers with varying geometrical dimensions, see photomontages below. The ESB tower was simply a redesign to modern standards of the existing 400kV design used on the existing Irish 400 kV grid. The IVI and VVV designs

looked to minimise the size of the tower head through use of a compacted delta phase arrangement. The previous ESB design had a horizontal conductor configuration and a phase to phase spacing of 10.5m. In both the IVI and VVV designs the elimination of the prominent shieldwire peaks was possible by raising the centre phase leading to a phase spacing of 9.5m. As with the 220 kV study, a landscape architect reviewed all designs and concluded that of the four tower types the IVI design had the least visual impact on the landscape.



Photomontage of main 400 kV designs

APPROACH TO WINE GLASS DESIGN

As stated earlier the overhead line transmission system is largely constructed over rural landscapes where their material “transparency” can be successful in minimising the visual impact, industrial appearance and scale. Indeed, they are such a commonplace item that most people do not ‘see’ them. It is also worth recognising that visual impact analysis of transmission lines along with factors such as public opinion relies less upon measurement and more upon experience and professional judgement. Unlike engineering disciplines or other impact assessment types, visual impact assessment require a larger degree of subjective opinion in determining their potential visual impact and is usually carried out during the planning process with input from the public and other stakeholders.

In the present paper the authors relate the design aims of a new suspension tower for supporting the conductors of a three-phase 400 kV overhead transmission line (single circuit line) and the comparison with the state of art. In transmission line systems, a series of towers are used to support the phase conductors. The connection between the phase conductors and the supports is arranged with the purpose to satisfy the design requirements in order to guarantee a right and safe working of the line. The proposed design of compact EHV transmission line is focused at reducing the main dimensions through the application of a new aesthetic tower with compact delta configuration of conductors. This tower design allows a sensible reduction of the Right of Way and the visual impact of support without reducing the towers ratings.

DESIGN CRITERIA

In a general sense the ESB/EirGrid line design standards are derived from studies performed for the original 400 kV network development in the late 1970’s. Over this time, both of the lines have been operating continuously and successfully with very high reliability levels. The existing design are single circuits IVI flat configuration lattice steel towers (short double circuit sections are included at the run ins to the terminal substations). In addition to the above

the development of a new suite of support structures, as described in this report, drew on the following documents:

- Both current and superseded versions of CENELEC Standard EN 50341-1 and EN50341-3-11 National Normative Aspects (NNA) for Ireland (IS_EN50341, 2012).[5]
- IEC 60826 (IEC60826, 2003) [6]

Reliability Level 2 (150 year return period) as defined by IEC60826 and EN50341 was used in the loading calculations for all structures in this study. The primary driver of this decision was to match the new structures with the IVI towers already designed as part of recent EirGrid projects.

WINE GLASS MONOPOLE DESIGN

Generally, the phase conductors are connected to the towers so that the distance between two adjacent conductors is adequate for protection from phase-to-phase voltage breakdown; in addition, the clearance between each conductor and steel parts of the tower must be sufficient to avoid the arcing between live metal and steel tower elements; furthermore, also the distance between each conductor and the ground has to be sufficient in order to meet safety requirements.

In the most common solution for the single circuit EHV transmission line, in order to allow a right and safe lines operation, the phase-to-phase horizontal distances must be kept very high because one phase passes through a latticed window and the two adjacent phases pass outside the steel structure, with consequently increase of the frontal width of the tower and of the right of way required by the line, and therefore negatively affecting its visual impact. For this solution, where the conductors configuration is flat, the main drawback resides in the fact that some latticed elements of the tower are interposed between two adjacent phases and the front width of tower increases significantly.

Another solution for the single circuit line involves the use of self-supporting towers (latticed and tubular type), pyramid type, with quinconce conductors configuration in which the height of the tower is greater than the one above described. For this solution the main drawback resides in the fact that the overall height of tower increases significantly and is normally applicable up to 132 kV voltage level.

Alternative solution adopts a phases arrangement where the conductors are connected by special insulator strings as a “bunch” in a dependent-phase manner thus introducing their reciprocal electro-magnetic influence and potential danger due to a big displacements (this dependent-phase configurations is generally named “cross-rope” solution and provides use of guyed structures, not self-supporting). For this solution the main drawback resides in the fact that the footprint of tower increases significantly due to the encumbrance of the guy-wires at ground level. Obviously, the higher is the voltage of the line, the larger must be the distance between adjacent conductors, between each conductor and the structure of the tower, and between each conductor and the ground, also when the conductors swing under the wind actions. These requirements impact on the overall dimensions of tower, on the right of the way required by the line and consequently its land occupation, thus affecting the visual effect and the cost of the line itself.

Several constructive solutions have been studied and developed in order to meet these requirements; although these solutions allow a satisfactory, right and safe functioning of the line, at the present state of the art they still present some drawbacks especially in term of visual impact.

A good compromise is to arrange the phase conductors in an “hybrid” solution with delta configuration, reducing as much possible the horizontal and vertical distance between phase conductors (compact design), and combining this phases arrangement with an innovative structural design which minimize the overall dimensions and number of the steel elements of support. The developed structural solution is a new aesthetic tower named “Wine Glass”.

WINE GLASS CONFIGURATION

The peculiarity of “Wine Glass” solution is to provide a suspension tower for 400 kV transmission line reducing the visual impact adopting innovative solutions in term of concept of tower and relevant design methods.

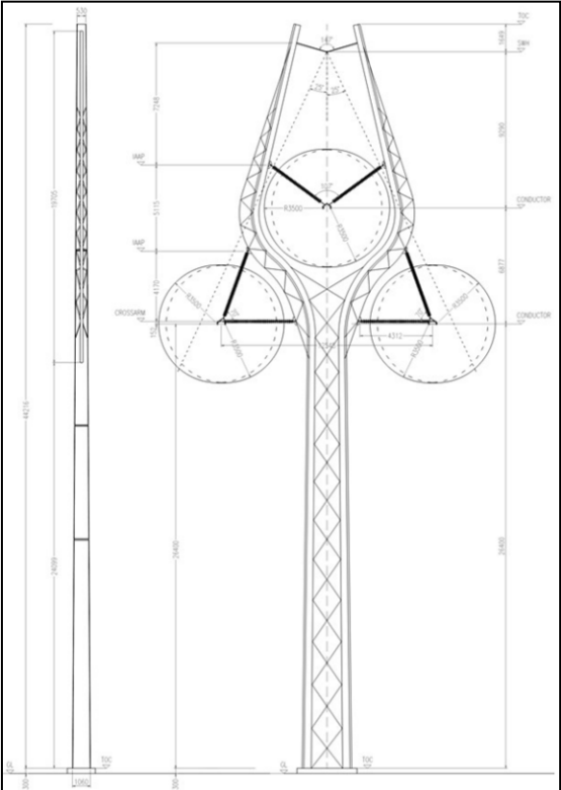


Figure 2 Wine Glass structural



The support has been developed in order to suspend the central phase in an open window (without top beam) utilizing a traditional “V” string and the outer phases attached directly on tower head adopting an innovative insulated cross-arms; furthermore the shield-wire is suspended on the top of tower by cables.

In addition the loads exerted by the outer phase conductors are not transferred to the top part of the tower but is applied to a lower portion of tower head; accordingly, the bending moment applied to the base of the tower is reduced and therefore it is possible to lighten the structure of the tower itself.

This solution minimizing as much possible the number and size of steel elements modelled in tower design reduces significantly the visual impact of tower with consequent benefit in term of structure transparency, see picture 1 above.

The tower has been modelled adopting the following structural solutions:

- “Wine Glass” symmetric Single-Monopole structure;
- “Wine Glass” symmetric Twin-Monopole structure;
- “Wine Glass” asymmetric Twin-Monopole structure;
- “Wine Glass” latticed and tubular structure, which can be constituted by a mix of plurality of cold formed elements (tubular, box or open flange elements) and conventional hot rolled members (see figure 1).

These innovative solutions with delta configuration of phase conductors allow to reduce the visual impact of the tower by reducing:

- Phase to phase distance (compact design);
- Steel elements between the inner and outer phases;
- Transversal and longitudinal overall width of the tower by adopting adequate structural members.

This particular design, by providing independent support for each phase, allows avoid the transversal swing and displacement of the conductors, hence leads to minimize also the size of window, as shown on figures 2 to 4.

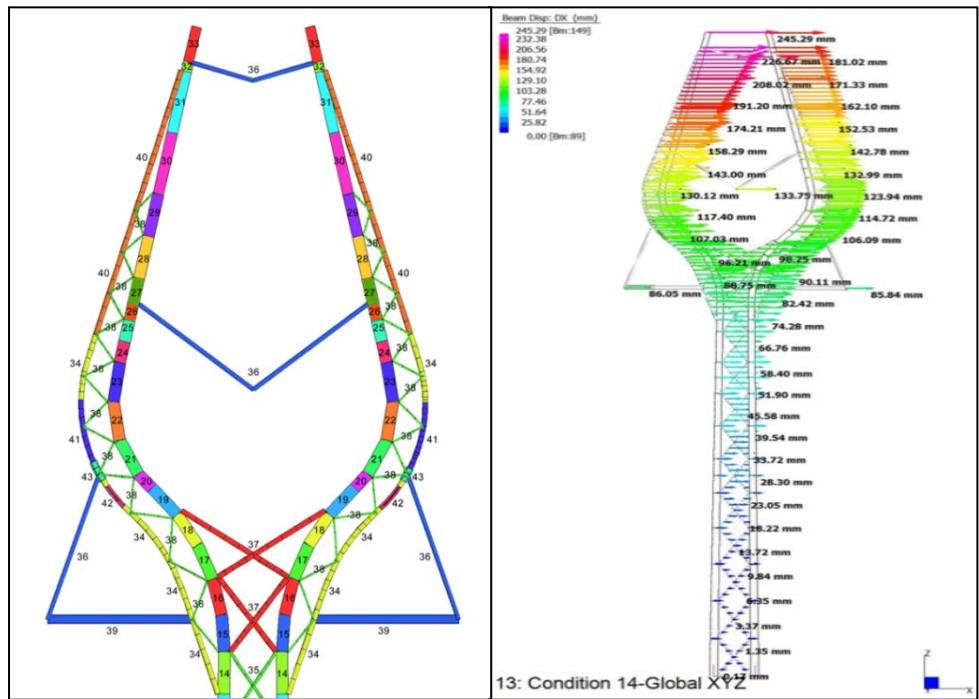


Figure 3 – Tower head modelling

Figure 4 – Typical model analysis

The following table reports the comparison of main tower dimensions for evaluation of visual impact.

Tower characteristics	400 kV flat configuration tower	400 kV Wine Glass tower
Phase to Phase horizontal distance (m)	12.0 + 12.0	12.5
Tower width – maximum frontal view (m)	32.0	10.5
Tower width – lateral view at top (m)	2.0	0.6
Overall tower height (Hu = 26.4 m) – (m)	36.4	44.4
Footprint at ground level – transversal (m)	10.0	2.8
Footprint at ground level – longitudinal (m)	10.0	1.1
R.O.W (m)	80.0	68.5

Table 5 – Wine Glass comparison with standard tower

Criteria	Value
Phase conductors	Twin AAAC Rubus ~ 587 mm ²
Earthwire/OPGW	AA/ACS 177/51;
Wind span	320m
Weight span	380m
Tower head clearance	3.5m
Standard height	26.4m
Shielding angle	25 degrees

Table 6 – Wine Glass design details

DISCUSSION

The main aim of “Wine Glass” solution is to design a tower for supporting the conductors of a three-phase line, which allows for improving the distribution of electrical stress in the phases and the optimization of the mechanical stress in the tower itself, thus allowing the structural lightening of the tower and reduction of its visual impact. It is also worth recognising that visual impact analysis of transmission lines along with factors such as public opinion relies less upon measurement and more upon experience and professional judgement. Unlike engineering disciplines or other types of impact assessment, visual impact assessment requires a larger degree of subjective opinion in determining their potential visual impact and is usually carried out during the planning process with input from the public and other stakeholders.

Other significant advantages of the “Wine Glass” tower are due to the fact that, thanks to the described configuration, each phase conductor are almost arranged in a delta configuration (the three phase conductors are positioned at the vertices of an imaginary triangle, almost equilateral). As a consequence, the mutual electro-magnetic influence exerted by each phase onto each other is quite equal among them, thus allowing to mitigate the need of

transposition tower which are instead necessary in the conventional lines, moreover for long transmission lines.

Further, with this configuration, compared with the flat one, the impedance of the line is reduced, and the power transmitted is increased with respect to other configurations (such as the flat configuration). The radio interference, usually generated by power lines, is reduced too.

An additional object of the “Wine Glass” solution is to provide a tower for supporting the conductors of a three-phase line, which facilitates the stringing of the lines, due to the easy accessibility of all phases because the upper part of window is open. This allows to adopt also the helicopter for stringing operations.

The use of new materials and design software can facilitate the development of more complex support structures than was possible in the past and these can offer potential for reducing the visual impact on the landscape. Like the T-Pylon currently under development by National Grid UK, new structure types benefit from full scale type testing and trialling prior to becoming an approved structure for use on the transmission grid.

CONCLUSIONS

Traditionally OHLs have been designed and constructed using lattice steel towers or pylons. The benefits of lattice steel towers lie in their excellent structural efficiency, durability, ease of construction and their comparatively low cost. Their beauty or otherwise is a subjective matter. Whilst up close they are functional and “industrial” looking structures, within a short distance their lattice design means they become transparent on the landscape. Consequently the design of any new or aesthetic OHL structure needs to be mindful of this beneficial transparency. The development of the Wine Glass aesthetic design will allow EirGrid offer a greater range of potential support structures in future projects and assist is gaining a greater level of public support.

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