IMPACT OF LOAD AND GENERATION FLEXIBILITY ON THE LONG TERM PLANNING OF YLPIC DISTRIBUTION NETWORK

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ABSTRACT

Long-term investments planning of distribution networks are no longer limited to investments in electrical equipment, but can also include investments in information and communication technology (ICT) required to enable both load and generation flexibility. New factors such as flexible loads, distributed generation etc. should be taken into account in modern long-term planning. The advantages of load and generation flexibility can then be fully exploited to reduce the total investment cost. This paper studies the impact of load and generation flexibility on the long term planning of the YLPIC distribution network (a typical MV network that can be encountered in Wallonia, Belgium) using the Smart Sizing tool, currently developed by Tractebel.

INTRODUCTION

Long-term planning of distribution networks is a complex process [1] that has only become more difficult in the context of smart distribution systems. Network planning investigates the required network investments which in turn includes infrastructure costs and operation costs. Traditionally the infrastructure costs included the cost of transformer, cables etc. and the operation costs included the cost incurred due to losses in the network. However, in the smart distribution network, the key additional factor that can influence the planning is the flexibility in the network. Load shifting and generation curtailment are a couple of examples of flexibility. Thus, investments in infrastructure are no longer limited to investments in electrical equipment, but also include information and communication technology (ICT) investments. More importantly, the challenge and the value of network planning lies in the trade-off between the two types of infrastructure investment. Similarly, in smart distribution systems, the operation costs is not limited to the losses alone but also includes the cost incurred due to load and generation flexibility [2]. Here again, the trade-off between the two, that is the operation cost incurred due to losses and the one incurred due to flexibility, is interesting.

Recent literature on planning attempts to adapt the traditional planning methodologies to fit in the smart grid context [3] – [7]. In addition, software tools are developed to aid the planner in the planning process. In this paper, the impact of load and generation flexibility on the long term planning of the YLPIC distribution network, a typical MV network that can be encountered in Wallonia (Belgium), is envisaged with the help of the Smart Sizing tool. Smart Sizing is a new network planning tool that fully takes into account the smart grids context. The Smart Sizing tool was first presented in [9]. The tool takes into account smart technologies such as distributed generation, load flexibility, and ICT. The role of the Smart Sizing tool in the long-term planning process is to find an ideal target network in terms of size of equipment, system architecture etc. A green field approach is envisaged in the tool. The target network is in that sense ideal, as it does not take into account the existing network. The results obtained from Smart Sizing can be used as guideline for the distribution system expansion planning [10].

The paper will first state the problem under consideration followed by the description of the methodology adopted to solve the problem. This is followed by the description of the YLPIC network and two case studies. The results of the two case studies are presented from which the conclusions derived.

PROBLEM STATEMENT

In this paper, long term planning of the HV/MV (70/10.5 kV) substation and of the MV network of YLPIC is envisaged. The objective involves, assessing the impact of load & generation flexibility in the planning of the distribution network. YLPIC includes the following:

1. The HV/MV substation (s) (70 kV/10.5 kV),
2. The MV (10.5 kV) network,
3. The MV/LV substations (10.5 kV/ 0.4kV) (mainly transformers)
4. The LV (0.4 kV) network

However, out of the three voltage levels 70 kV, 10.5 kV & 0.4 kV, the optimal investment planning for two voltage levels (70 kV and 10.5 kV) are envisaged in this study as shown in Figure **1**. The Wind generation is directly connected at the 10.5kV side of the 70/10.5 kV substation. All the other generation and load are connected along the feeders. Hence the wind generation affects only the HV/MV transformers and the HV cable sizing.

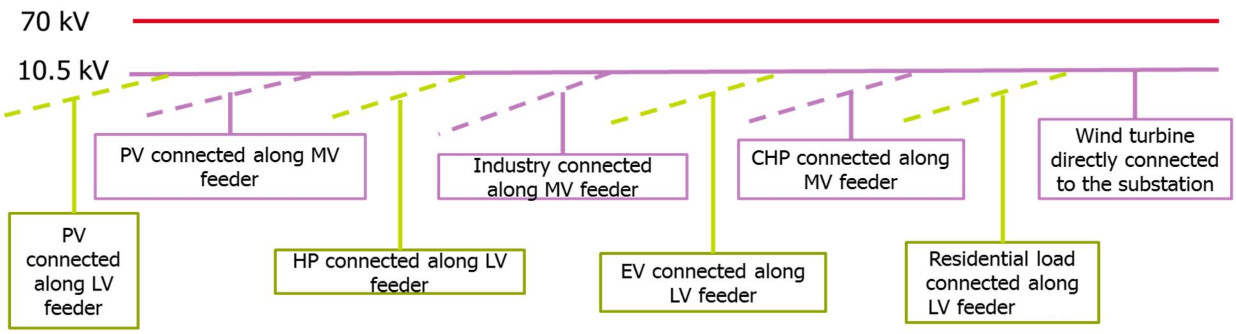

Figure 1: The YLPIC network

METHODOLOGY

The Smart Sizing tool [9] is used in the planning of the YLPIC network. At the heart of Smart Sizing lies an optimization routine that minimizes the total cost of the network, i.e. the sum of CAPEX and OPEX over the study horizon. CAPEX mainly includes the infrastructure cost including ICT cost where as OPEX includes the cost of losses & operational flexibility. The decision variables of the optimization problem are variables related to the investment in electrical equipment & the required flexibility in the network. Examples of constraints include restrictions on voltage drop and overvoltage, and loading of equipment.

The mathematical formulation of the problem is as follows:

$$\text{Minimize } \left(\sum_i IC_i + CACT \sum_{i,p} w_p * OC_{i,p}\right)$$

Where *IC* is the infrastructure cost representing the CAPEX, *OC* is the Operation cost representing the OPEX, *i* is the total number of voltage levels, *p* is the number of time periods under consideration, w_p is the weight of period *p* and *CACT* is the capitalised unit cost.

At the end of the optimization, an ideal network is proposed. The output of the tool is not only the number of substations and transformers, the total length and size of the cables, but also the required amount of flexibility to be contracted [9]-[10]. The flexibility options include load flexibility and generation curtailment.

THE YLPIC NETWORK NET LOAD PROFILE

The net load peaks and the energy decide the size of the equipment and the flexibility required in the network. 12 representative days, shown in Figure **2**, which when combined will capture the network peaks & energy, were used in the simulation to plan the network. These days and their associated probabilities of occurrence were computed using customised techniques on the yearly data provided by ORES, a major Distribution System Operator in Wallonia. The following network characteristics were captured by the twelve representative days along with their corresponding weight:

- Net energy = 109 GWh per year
- Positive peak = 46.56 MW
- Negative peak = -14.9 MW

CASE STUDY

Two different case studies as described in Table 1 were carried out.

Table 1: Case studies

Case study	Description
Case 1	No flexibility option activated
Case 2	All flexibility option activated

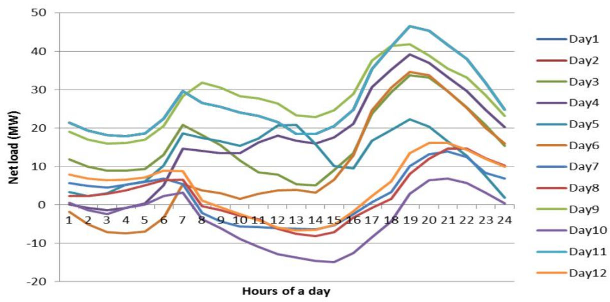

Figure 2: Net load profile of the 12 representative days

Both the test cases were studied to analyse the impact of load and generation flexibility in the planning of the YLPIC network. For this purpose, Case1 included no flexibility option in the network whereas Case 2 included the following flexibility options:

1. Load shifting
2. Curtailment of generation connected along feeders (PV_LV, PV_MV, CHP)
3. Curtailment of generation directly connected to the 10.5 kV substation (Wind)

The following were the costs assigned to each flexibility under Case2:

1. Load shifting (OPEX) = 0 Euro/MWh
2. Curtailment of generation connected along feeders (OPEX)= 0 Euro/MWh
3. Curtailment of generation directly connected to the 10.5 kV substation (OPEX) = 0 Euro/MWh
4. ICT cost for load shifting and generation curtailment (CAPEX) = 0 Euro/MW
5. Cost of losses (OPEX) = 50 Euro/MWh

As can be noticed from the list above, the flexibility costs are assigned a zero value in order to assess the maximum benefit that can be reaped from the use of flexibility in the YLPIC network.

RESULTS

Figure **3** shows the net load profile seen by the transformer in Case 1 & Case 2. It is to be noted that though the net load profiles over the 12 representative days is shown as continuous in the figure, the days are non-consecutive. The net load profile, represented as L-G-W (where L stands for the total load in MV and LV, G is the generation connected along MV & LV feeder and W is the wind connected directly to the HV/MV substation) is seen by the HV/MV transformer(s). There is a reduction in net peak by around 35% due to activation of flexibility in Case2 compared to Case1 as shown in Figure. This leads to a 20.6% reduction in the transformer cost in Case2 when compared to Case1.

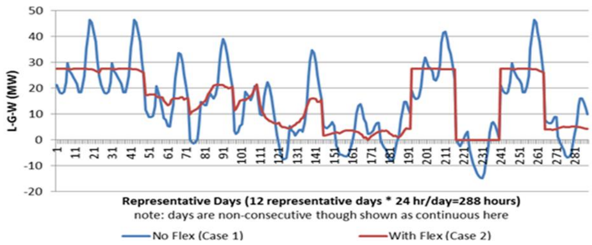

Figure 3: Net load seen by the transformer in Case 1 & Case2

Though there is approximately 21% reduction in transformer cost, the reduction of total cost is only 1.4%. This is because the cable cost takes a major part of the total cost in both the cases as shown in Figure **4**.

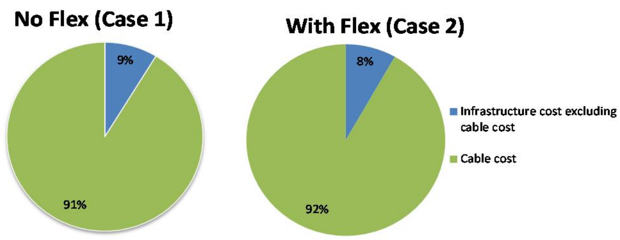

Figure 4: Infrastructure cost

The MV cable sizing is determined based on L-G as shown in Figure **5**. The cable cost reduction is negligible primarily because the cost contributed by the cable length outweighs any reduction in cost that may be achieved by reduction on peak load which will positively affect the cable rating. In addition, though a reduction in peak results in lower size of the cable it may result in increased losses, thus the cost reduction due to cable size reduction is also negligible.

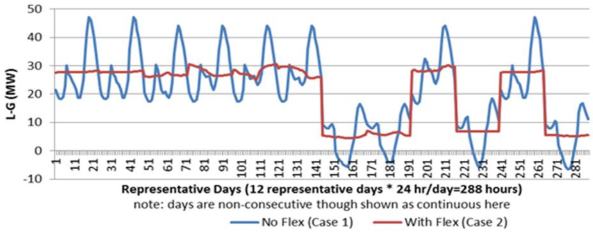

Figure 5: Net load seen by the MV feeders in Case 1 & Case 2

Also, the operation cost contributes only to a relatively small percentage (8%) of the total cost as shown in Figure **6**.

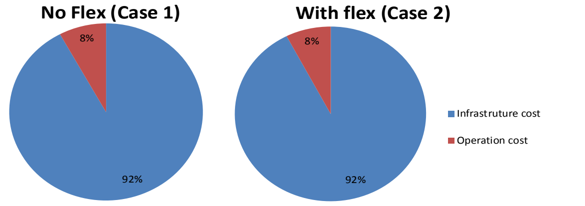

Figure 6: Comparison of infrastructure cost versus operation cost in Case 1 & case 2

Figure **7** gives the effect of peak reduction on the sizing of the equipment. The net load peak has been reduced by around 35% due to activation of flexibility, resulting in a major reduction in power rating of the transformer (approx. 42%). However, reduction in HV and MV cable power rating & sizing remains limited because a large part of the cable cost is independent from its rating and a reduced cable sizing leads to higher losses.

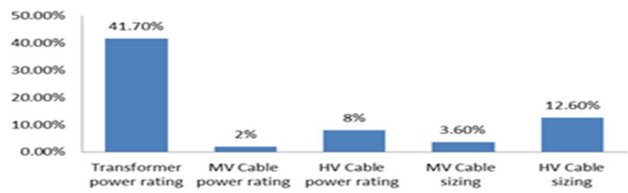

Figure 7: Effect of peak reduction in the equipment sizing

A sensitivity analysis has been carried out in order to measure the sensitivity of load and generation flexibilities towards the various costs (i.e. ICT cost, activation cost etc.). Table 2 gives the result of the sensitivity analysis.The critical cost is defined as the cost below which at least one type of flexibility (out of the available types) will be activated for the purpose of total cost reduction.

Table 2: Critical costs of flexibility

Available flexibility in the network	Critical ICT costs (k€/MW)	Critical Activation costs (€/MWh)
Wind curtailment	Equal to 0	Less than 1
Wind, PV, CHP curtailment	Equal to 0	Equal to 1
Load Shifting	Equal to approx. 75	Equal to 10

From the table we see that the generation (Wind, PV, CHP) curtailment critical costs as very low implying that it is economically not beneficial to curtail generation in the YLPIC network. This result can be justified since the peak consumption is higher than the peak generation in the network and the option of generation curtailment will bring in no economic benefit. Therefore, out of the available flexibility options, the one that makes more economic sense is load shifting for the YLPIC network.

CONCLUSIONS

The net load peak of the YLPIC network can be reduced by around 35% due to activation of load shifting & generation curtailment (both assumed to have zero cost), resulting in a major reduction in power rating of the transformer (42%). This in turn leads to a 20% reduction in transformer cost & 4% reduction in operation cost when using load shifting & generation curtailment (at zero cost).

However, reduction in HV & MV cable power rating & sizing remains limited when using flexibility because a large part of the cable cost is independent from its rating but is heavily dependent on its length. In addition, a reduced cable sizing leads to higher losses.

A considerable impact on the total cost of the network by using load & generation flexibility will be realized when the key factors influencing the total cost are the peak and the total demand rather than the length of the cable which is influenced more by the geography than the load and generation.

Infrastructure and operation cost vary differently depending on the type of grid. Load and generation flexibility will find increased value in reducing the total cost when the infrastructure is mainly dimensioned by the peak (in load or in generation), when the level of DG penetration in the system is high and there is non-simultaneity between the load and generation.

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