TRANSITION TO ‘SMART’ DISTRIBUTION GRID STRATEGIC PLANNING USING A SCENARIO APPROACH

Weiyu DU
TU Delft, the Netherlands
w.du@tudelft.nl

Johannes G. (Han) SLOOTWEG
Enexis B.V., the Netherlands
han.slootweg@enexis.nl

Wil A.H.THISSEN
TU Delft, the Netherlands
w.a.h.thissen@tbm.tudelft.nl

Erik PRUYT
TU Delft, the Netherlands
E.Pruyt@tudelft.nl

Warren E. Walker
TU Delft, the Netherlands
w.e.walker@tudelft.nl

ABSTRACT

In this paper, transition policy alternatives for moving an electricity distribution grid towards being ‘smart’ are developed and evaluated using a scenario approach. Making the distribution grid smart involves system development under deep uncertainty and complexity. In this paper, several transition policy options from a distribution network operator’s perspective were evaluated and adjusted for various scenarios. As a result, insights were gained for identifying a robust transition policy towards ‘Smart Grid’ in the face of a deeply uncertain future.

INTRODUCTION

‘Smart Grid’ is a broad concept referring to equipping the current MV and LV electricity grids with information and communication technologies, aiming at providing real-time supervision and control of the condition of components, network configuration and power flows. Hence, Smart Grid can improve grid reliability, flexibility, intelligent control, quality control, and efficiency [1, 2].

Full-blown Smart Grids require a long time to implement, large financial investments, and huge labour resources. Therefore, a plan for this should root in a clear and well thought-through vision in which developments such as electrical vehicles, decentralized generation, heat pumps, etc., are incorporated.

The principles of the future electricity supply are highly uncertain. Will Smart Grid be an appropriate development? Is there a risk that fundamental changes in the environment might occur half-way through its implementation? And what are the influencing factors on its development? In other words, what would be appropriate Smart Grid transition policies (decisions or plans) for the distribution network operators (DNOs), and how should they deal with the high degree of uncertainty? Answers to these questions would be of high interest for the DNOs, such as Enexis B.V., the Netherlands.

Answering these questions not only requires looking forward to understand the possible futures, but also testing the potential opportunities and threats for Smart Grid transition strategies. Therefore, a well proved uncertainty analysis approach, scenario analysis, is applied in this research [3]. It looks forward into the possible futures, and evaluates the transition strategies on their advantages and disadvantages in these possible futures. In this way, insight will be gained for designing robust transition policies towards Smart Grid.

METHODOLOGY

The approach that is used in this research to develop Smart Grid transition policies is illustrated in figure 1.

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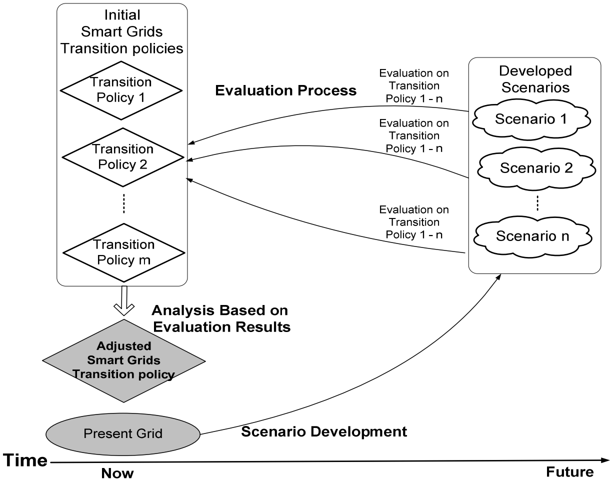

Figure 1. Scenario Analysis Approach to Smart Grid transition policies

In this paper, the initial transition policies of DNOs toward Smart Grid are designed in terms of time, scale, and technical automation level, taking Enexis B.V. as a case study. First, a number of plausible future scenarios (context and environment) for the electricity distribution network are developed with a time phrase of 30 years based on Schwartz’s scenario development method [3]. Then, criteria are identified for evaluating the outcomes of the policy options for each scenario from the perspective of DNOs. Based on the results, requirements for more attractive systems are formulated, through which an adjusted policy is determined.

‘SMART’ CONCEPT: FULL DISTANCE MONITORING AND CONTROL FOR MV NETWORKS

In this paper, the ‘Smart Grid’ concept that is investigated is remote monitoring and control, which is one of the main future concepts that Enexis B.V. the Netherlands envisions. Full remote monitoring and control allows remote observation and data acquisition as well as remote switching for network restoration after an outage. It can bring benefits to the DNOs especially on:

- Quick and accurate fault localization
- Reduced outage time
- Increased work force productivity
- Load curve recording for capacity management

As a first step, Enexis had decided to equip selected MV switchgear installations and ring main units with remote monitoring and control devices. As illustrated in figure 2, the grid can be ‘smarted’ with remote monitoring and control at the circuit breakers at the origins of the distribution ring, and at the disconnect switches at substations and splitting point. In principle, however, all switchgears can be equipped with remote monitoring and control.

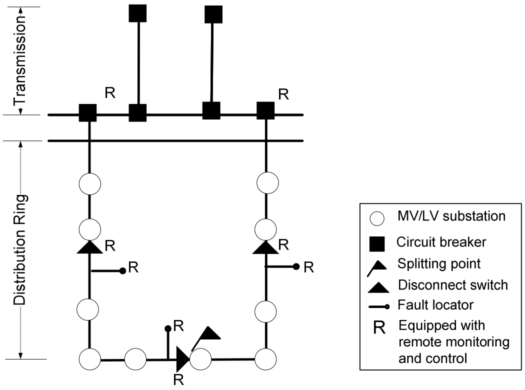

Figure 2. Smart Concept: Full distance monitoring and control, based on [4]

TRANSITION POLICIES

Policy elements

A transition policy toward a Smart Grid is a combination of three elements: time, implementation scale, and automation level. The options for each element are shown in Table 1.

Table 1: Transition Policy Elements

Time (Element A)	Implementation scale (Element B)	Automation level (Element C)
A1.immediate A2.gradual	B1. complete B2. partial: - aging items - specific types - specific regions of various scale (such as demand)	C1. none C2. high C3. medium

The automation level of ‘smart’ refers to the degree of remote switching and monitoring in the distribution grid. It can be measured roughly by number of switchgears being installed in each local distribution cable loop, including circuit breakers and disconnect switches.

Initial transition policies

Transition policies can be made by various combinations of the three elements. Due to the high implementation costs and complexities, immediate implementation of the entire grid with high automation level is probably not feasible. Four transition policies can thus be initially specified for DNOs:

1. No further ‘smarting’: Stay with the current network automation level, only replacing aging assets like for like;
2. ‘Smarting’ of new elements: when aging or failing assets must be replaced, they are replaced by smarter items so that the grid becomes smart with the speed at which replacements are carried out.
3. Gradual ‘smarting’: gradually smarting the entire grid with high automation level without external triggers such as aging or network extension. Various ways to determine the smarting stages can be used, such as region, age, and/or installation type. After completing a stage, continuation of the smarting program can be reviewed.
4. Complete ‘smarting’: immediate smarting of the whole grid with medium automation level. Note that due to the amount of work involved, ‘immediate’ smarting is impossible and a full blown smarting program would still take a few years and would therefore be divided into a number of short phases. The main differences with option 3 are, however, that in principle the complete implementation time should be shorter, and no reconsideration of the program is foreseen after completion of a phase.

SCENARIO ANALYSIS

Scenario development

Many studies have developed scenarios for the future energy supply. Here, we focus on four scenarios using demand and decentralization level as the primary scenario variables, based on Schwartz’s scenario development method [5], and integrating the electricity network infrastructure scenarios of ‘super grid’ and ‘local grid’ [6].

1. A scenario based on a continuing electrification of the Dutch energy supply (particularly transportation and heating) with the electricity generated from centralized technologies, such as nuclear fission, coal and off-shore wind power.
2. A scenario based on an extrapolation of the current situation. For heating and transportation fossil and biofuels (both liquids and gas) will increasingly be used, leading to a modest growth of electricity consumption. The largest part of electricity continues to be generated in centralized power plants.

3. A scenario based on a continuing electrification of the Dutch energy supply (particularly transportation and heating) with the electricity generated from decentralized technologies, such as micro CHP and solar panels. The combination of an increase in electricity consumption combined with the large growth of decentralized generation leads to a huge demand for MV and LV network capacity. Further, demand side management options open because some of the new load may be flexible.
4. A scenario based on an extrapolation of the current situation for the use of electricity. For heating and transportation, fossil and biofuels (both liquids and gas) will increasingly be used, leading to a modest growth of electricity consumption. However, generation gradually shifts from centralized to decentralized technologies, leading to an increase in the demand for MV and LV grid capacity.

The scenarios are depicted schematically in Figure 3.

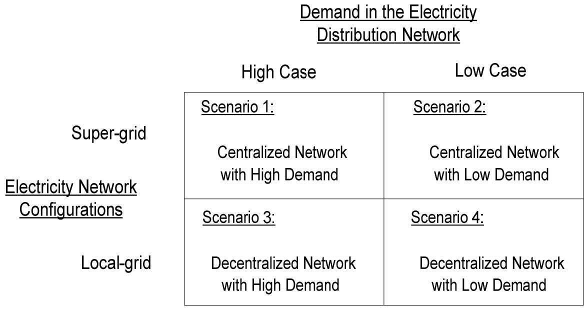

Figure 3. Schematic representation of the scenarios

Outcome criteria

In order to identify a robust transition policy, criteria are identified for evaluating the outcomes of the policy options. Figure 4 shows the policy analysis framework used to assess the performance of alternative policies [7].

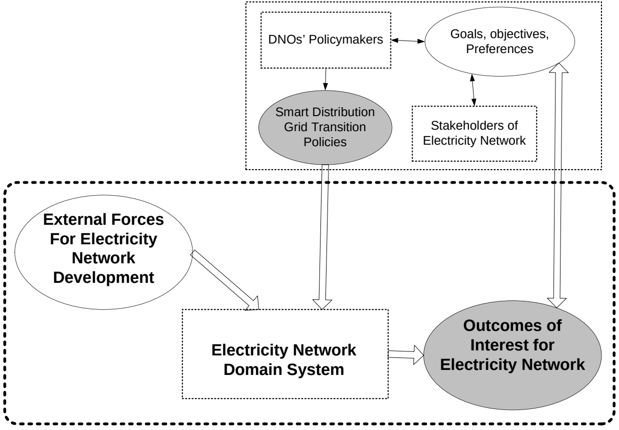

Figure 4. Policy analysis framework for assessment of alternative policies, based on [7]

The four outcome criteria we used for DNOs in our analysis are:

- Reliability of supply
- Cost, both for the information and communication technology as well as for primary equipment (cables, switchgear)
- Accessibility of real-time load data
- Efficiency of maintenance

Scenario evaluation

Evaluating the four transition polices against the criteria for each of the scenarios yields the results presented in Tables 2-5.

Table 2. Evaluation of transition policies for super grid with high demand (Scenario 1)

	No smarting	Replace-ment	Gradual	Complete
Reliability	-	0	+	+
Cost	0	0	-	-
Accessibility	0	-	0	+
Efficiency	-	0	+	+

Evaluation degrees: '+' means performance is positive, '-' means negative and '0' means not obvious effects, which are applied to all the tables.

Table 3. Evaluation of transition policies for super grid with low demand (Scenario 2)

	No smarting	Replace-ment	Gradual	Complete
Reliability	0	-	+	+
Cost	+	+	-	-
Accessibility	0	-	0	+
Efficiency	+	-	+	+

Table 4. Evaluation of transition policies for local grid with high demand (Scenario 3)

	No smarting	Replace-ment	Gradual	Complete
Reliability	-	0	+	+
Cost	-	-	0	-
Accessibility	0	0	0	+
Efficiency	-	0	0	+

Table 5. Evaluation of transition policies for local grid with low demand (Scenario 4)

	No smarting	Replace-ment	Gradual	Complete
Reliability	-	0	+	+
Cost	+	0	0	-
Accessibility	0	-	0	+
Efficiency	0	0	+	+

Note that when demand differs between high and low for the super grid (scenarios 1 and 2), the main differences that occur are in "replacements". If demand is high, more replacements will be carried out, as equipment ages quicker due to high current loadings and due to more replacements induced by capacity constraints.

For the "no smarting" transition policy, the demand growth is largely indifferent because like for like replacements are carried out. However, some differences occur due to the fact that when demand is high, the traditional approach of network extension will require huge investments.

In case of the “gradual” and “complete” smarting policies, no differences occur due to the fact that with these transition policies smarting is quicker than demand growth anyway, so demand growth does not affect the evaluation of the transition path.

It is clear that the local grid scenarios have more impact on the distribution grids than the super grid scenarios, because in these scenarios developments concentrate on the distribution grids. This can be seen in Tables 4 and 5, where only the “complete smarting” transition policy is not affected by the demand growth while it is assumed that it is quite quick. The “no smarting” transition policy performs quite well with low demand, because when demand is low, the current grids will in general have enough capacity. However, when demand is high, “no smarting” performs badly, since the traditional approach of extending the network will require huge investments.

The replacement and gradual smarting policies perform about equally well, with the first performing better with low demand and the latter with high demand. This is of course caused by the fact that with high demand the cost of gradually smarting the grid will be outweighed by a reduction of investment in network capacity, whereas with low demand the replacement smarting policy performs better, because it requires less investment in “smarting” and investments in traditional solutions (i.e. network extensions, are lower so that a reduction in those with low demand can not compensate the cost of smarting).

Analysis: adjustment of transition policy

As can be concluded from Tables 2-5, no unique optimal transition policy exists. This leaves room for an adjustment step, as depicted in Figure 1. From the scenarios, it is clear that the goals are partly contradictory. On the one hand, the increase in reliability that can be gained by smartening the grid is desirable. On the other hand, quickly smartening the grid to this end would cost much effort and money and reduces flexibility to cope with changing circumstances, resulting from e.g. the electrification of transportation or a rapid increase in decentralized generation.

Therefore, as a next step an adjusted transition policy is designed. This policy comes down to selecting MV switchgear installations on topological grounds. In this way, maximum gains in reliability of supply are achieved while optimizing flexibility and cost. The preferred transition policy is described in more technical details in [4] and is a combination of the initial policies “replacement” and “gradual”, with the grades determined on topological grounds.

CONCLUSIONS

In this paper, a scenario analysis approach is applied to deal with uncertainties surrounding the important topic of the transition of electricity distribution grids towards a Smart Grid. Transition alternatives are initially identified. These transition alternatives are evaluated in the developed scenarios and adjusted. Thus, a robust transition policy can be found through the assessment analysis process.

It is suggested that it is wise for the DNOs not to opt for an immediate transition, because gradual transitions give more flexibility in the highly uncertain energy market development. A robust transition policy would be a gradual transition in the regions with average integrated value of aging assets, decentralized coverage, and high density of local distribution cables.

FUTURE RESEARCH

One of the smart-grid concepts -- full distance monitoring and control for MV -- networks is considered in the paper. However, the concept of Smart Grid is much broader, and other aspects, such as decentralized generation and electricity storage, should also be taken into account. Further research will be done to consider more Smart Grid concepts for long-term strategic planning.

Also, other uncertainty analysis approaches can be applied for the domain system. In this research, relatively simplified transition options were chosen, which yielded a simplified setting for the application of the approach. More sophisticated options will be considered in future research by taking account of more complex uncertainties originating from technical, environmental, economical and social developments.

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