Long-term investments in electricity distribution networks: a real options approach

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Overview

Due to the rise of Smart Grids, new players and services are emerging and can have an impact on decision-making process in distribution networks. More particularly, new technologies like Demand Response (DR), curtailment of generation, Distributed Energy Resources (DER's) and other renewable energy technologies are bringing a significant challenge for the future of our electricity grids, which in past for many decades, were driven by centralized generation and a linear demand growth. Nowadays, many uncertainties exist: when, where and in what quantity will these new services or players appear in the network? For example, the case of load shedding could make it possible to size network equipment below the theoretical maximum power of customers (consumers or producers). In this context, the evolution of distribution networks and investment decisions (conductors and transformers) can no longer be based solely on deterministic assumptions of load evolution.

Classically, the DSO might consider a deterministic rate of peak load variation in the coming years and base their investment strategy on it. However, this method does not take into consideration the possibility of faster/slower growth rate, induced by socio-economic events, such as a recession or an economic boom in an area, or by trend change, such as an increase in the number of electrical vehicles. Consequently, improvements of the method are necessary to mitigate the effect of these uncertainties on the decision-making process.

In this paper we focus on the uncertainty of maximal power and the flexibility to choose between different topologies of electric network. If the maximal power is sufficiently important, a DSO may decide to reconfigure the network and change the initial structure with an alternative one. Because the DSO is interested in optimizing its power losses costs at specific times, the level of maximal power determines his willingness to undertake the reinforcement cost associated to the increase of lines. Therefore, the major purpose of this paper is to derive a rule for switching between different electrical grid configurations and thus, to answer the question: Given the uncertain evolution of maximal power, how long should a DSO wait before introducing a new branch to the already existing network and reconfiguring the load connections?

To solve this problem, we apply a real option approach, which offers a different perspective of the decision under uncertainty and flexibility of choice. When it comes to real options in conjunction to investments in electricity distribution networks, there is very little reporting in scientific publications. For example, during our survey we identified the papers of Schachter and Mancarella (2016) and Schachter et.al. (2016). The former presents a literature review and methodological insights from real options theory and their potential use in electricity distribution networks, while the latter consider an uncertain evolution of the peak demand through Monte Carlo simulations in order to highlight a particular investment strategy for the DSO. Our article aims to contribute to this literature by considering a stochastic maximal power variation in a continuous-time framework, and provide an analytical model with closed-form solutions which allows a full treatment of the dynamic aspects of the decision to reconsider the configuration of the network.

Keywords: smart grids, distribution grid, quadratic power losses, switching real options

JEL Classification:. Q40, C61, D81

Methods

We model the maximal power as a continuous stochastic process such as a Geometric Brownian Motion (GBM). This uncertain evolution may be related to short term conditions like weather or more longer term effects such as increase in the economic activity, changes in the consumer behaviour or arrival of new technologies. We use dynamic programming techniques and theoretical tools from Dixit and Pindyck (1994) and Guerra et.al. (2016) to derive the threshold of maximal power for which a DSO should be inclined to choose an alternative network configuration. Similarly, we use a Jump Diffusion (JD) model for the maximal power evolution and compare results obtained from both uncertainty models. Finally, we add a case study in which we explore the effect of flexibility through peak load differal introduced by EVs on the investment decision.

Results

We find an analytical expression for the optimal level of the maximal power. The threshold of the peak power for which it is interesting to reinforce the network is higher than the one in conventional case. The result illustrates that, if the peak power of electricity is uncertain, the DSO should wait longer before adding a new line. When new information arrives over time, the DSO has the flexibility to use it and thus to choose the optimal timing. If there is significant uncertainty about future power, the real options embedded in incremental investment programs (such as small grid upgrades) or other approaches that defer grid investment (such as the use of grid alternatives) can be very valuable, potentially outweighing the economies of scale advantage of large upgrades. Moreover, through a comparative statics analysis, we infer the sensitivity of the option value to reconfigure the network with respect to the volatility of the peak power, the associated investment cost or other types of costs of power losses, the growth rate or the discount rate. The comparison between results obtained for GBM and JD modelling shows non-negligible differences. We notice a stark increase in the expected investment timing, optimal investment trigger and NPV when switching from JD to GBM representation. When positive jumps are expected to occur, the DSO might find it more compelling to invest earlier due to the potential increase in savings made from the reinforcement of the grid. Furthermore, the introduction of load differal, coupled with load uncertainty, might render an investment on the distribution grid unnecessary. In this sense, we find a maximum EV integration value for which the investment is still valid economically. Our findings indicate that the introduction of uncertainty increases the maximum flexibility for which the DSO whould be inclined to invest. In addition, this maximum level is the highest for JD processes which is due to the expected jumps that artificially increase the real drift rate of the load.

Conclusions

The goal of this paper is to show how the economic theory can incorporate the uncertainty and the managerial flexibility which may be available in investment decisions related to electricity distribution networks. We have also found that the type of uncertainty greatly affects the managerial decision pertaining to distribution grid investments. Our closed-form solutions may offer recommendations for decision makers who need to modify their strategies continuously under a highly uncertain context.

References

Dixit, A. K., & Pindyck, R. S. (1994). *Investment Under Uncertainty*. New Jersey: Princeton University Press.

Guerra, M., Nunes, C., & Oliveria, C. (2016). Exit options for a class of profit functions. *International Journal of Computer Mathematics*, 20177-2193.

Schachter, J. A., & Mancarella, P. (2016). A critical review of Real Options thinking for valuing investment flexibility in Smart Grids and low carbon energy systems. *Renewable and Sustainable Energy Reviews*, *56*, 261–271. https://doi.org/10.1016/j.rser.2015.11.071

Schachter, Jonathan A., Mancarella, P., Moriarty, J., & Shaw, R. (2016). Flexible investment under uncertainty in smart distribution networks with demand side response: Assessment framework and practical implementation. *Energy Policy*, *97*, 439–449. https://doi.org/10.1016/j.enpol.2016.07.038