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OPERATION OF DISTRIBUTED GENERATION UNDER STOCHASTIC PRICES

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Overview

The ongoing deregulation of electricity industries worldwide is providing incentives for microgrids, entities that use small-scale distributed generation (DG) and combined heat and power (CHP) applications to meet local energy loads, to evolve independently of the traditional centralised grid. Under this new paradigm, the traditional centralised grid still delivers large quantities of energy to end users, but electricity supply is augmented via DG. The advantages of micrgrids are fourfold: 1. the possibility of self-generating electricity at a cost below the delivered cost from the macrogrid; 2. the application of CHP technology, which can significantly improve the economics of self generation; 3. the opportunity to tailor the quality of power delivered to suit the requirements of end uses, here called heterogeneous power quality and reliability (PQR); and 4. the more favourable environment potentially created for energy efficiency and small-scale renewable generation investments.

In this paper, we conservatively address only the first benefit by comparing the wholesale price of electricity with the cost of self generation and ignoring transmission and distribution (T&D) costs. Specifically, we examine the operation of a microgrid that has installed DG to meet some of its electric load and also purchases electricity from a wholesale market as needed. We gain insight into the optimal DG operational policy by taking a real options approach (see Deng and Oren (2003) and Näsäkkälä and Fleten (2005)). Specifically, we recognise that owning a flexible DG unit entitles the microgrid to a strip of embedded options to vary its output according to the relative price of wholesale electricity and natural gas, the fuel on which DG run. Therefore, at each time period, the microgrid faces stochastic electricity and natural gas prices and must decide how to operate its installed DG units in order to minimise the cost of its electricity consumption. We factor in operating and maintenance (O&M) costs for DG as start-up costs that account for the additional wear imposed by frequent changes in operating status. In solving the microgrid's cost-minimisation problem, we obtain not only an optimal operating policy for DG, but also its implied option value, i.e., the maximum amount the microgrid would be willing to pay to rent DG. Since we do not account for T&D costs or for CHP-related benefits of DG, the implied DG option value is a lower bound (see Siddiqui *et al.* (2005) for a more comprehensive analysis in a deterministic setting).

Methods

We formulate the microgrid's cost-minimisation problem as a stochastic dynamic programme (SDP) over a finite time horizon in which the natural logarithms of both electricity and natural gas prices evolve according to correlated mean-reverting Ornstein-Uhlenbeck (OU) processes. The periodic energy cost of the microgrid includes not only purchases of wholesale electricity and natural gas, but also start-up costs if any DG unit is switched on from an idle state. If we ignore such start-up costs, then the microgrid's SDP may be solved using a simple myopic policy: in each period, use the cheaper source of energy without taking into account the current DG operating state. The presence of start-up costs implies that the current operating state of DG, e.g., active or idle, must be considered since the structure of future cash flows depends on current operating decisions. Typically, a backward-induction procedure, based on a lattice is used to price such real options (see Boyle, Evnine, and Gibbs (1989)). However, if either the number of underlying prices is large or the stochastic processes are too complex to be discretised, then lattice-based methods are computationally intractable. Instead, least-squares Monte Carlo (LSMC) simulation may be used, which first generates a large number of sample paths for the underlying assets' prices and then provides an estimate of future expected values in each state by performing a cross-sectional, least-squares regression of the future values in each state on a function of current prices (see Longstaff and Schwartz (2001)). Using this approach, the implied option value of DG may be obtained as the difference between the average minimised expected costs without and with DG installed.

Results

We run three cases to examine the effect of start-up costs: 1. no start-up costs (NS), 2. include start-up costs and optimal decision-making by the microgrid using LSMC simulation (SU), and 3. include start-up costs, but the microgrid uses a myopic policy from case NS to make operating decisions (SM). Relative to case NS, we find that although the option value of DG is not significantly reduced, the presence of start-up costs introduces a zone of inaction in the operating policy (see Fig. 1, where the blue (red) markers indicate instances of turning on (off) an idle (active) unit). Specifically, the microgrid waits until the electricity price more than exceeds the cost of self generation before turning on an idle DG unit because it trades off current cost savings with future expected start-up costs. If it ignores this tradeoff and proceeds myopically, then the value of DG decreases significantly because it turns off active DG units too soon, i.e., without considering future expected start-up costs. Conversely, the myopic policy makes idle DG units appear less attractive as current start-up costs are not traded off against future expected cost savings.

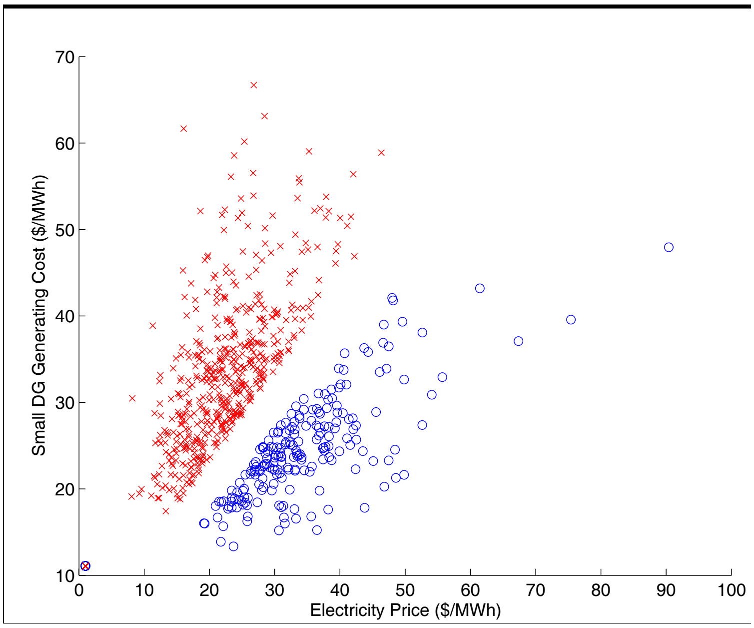

Fig. 1: Operational Thresholds for a 200 kW DG Unit with Start-up Costs

Conclusions

We find that although the implied option value of DG is not statistically significantly affected by start-up costs, these do have a large impact on DG operating policy. Intuitively, start-up costs make the microgrid more hesitant in making decisions..