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Nempy: A Python package for modelling the Australian National Electricity Market dispatch procedure

Nicholas Gorman[1, 3], **Anna Bruce**[1, 3], **and Iain MacGill**[2, 3]

1 School of Photovoltaics and Renewable Energy Engineering, University of New South Wales, Australia **2** School of Electrical Engineering and Telecommunications, University of New South Wales, Australia **3** Collaboration on Energy and Environmental Markets (CEEM), University of New South Wales, Australia

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Summary

Nempy is a python package for modelling the dispatch procedure of the Australian National Electricity Market (NEM). Electricity markets are a way of co-ordinating the supply of electricity by private firms. The NEM is a gross pool spot market that operates on 5 min dispatch basis (Australian Energy Market Operator, 2020). Described simply, this means all generators wishing to sell electricity must bid into the market every 5 minutes, market clearing proceeds by calculating the cheapest combination of generator operating levels to meet forecast demand at the end of 5 the minute dispatch interval. The price of electricity is set as the marginal cost of generation, which, under a simple market formulation, would be the cost of the next generation bid to be dispatched if demand for electricity were to increase. Real-world formulations require significant additional adjustment in order to manage the technical complexity of securely and reliably operating an electricity grid. For example, in the case of the NEM additional markets for ancillary services have been introduced. One set of ancillary markets that have been integrated into the market dispatch procedure are the Frequency Control Ancillary Services (FCAS) markets. In these markets generators compete to provide the ability to rapidly change generation levels in order to control the grid frequency. Nempy is flexible in that it allows for formulation of very simple market models, for the formulation of market models of near real-world complexity, and at the various levels of intermediate complexity. Simple models can be constructed using just generator bids and electricity demand, so called bid stack models. More complete models can be constructed by using the inbuilt features to create multiple market regions, ramp rate limits, loss factors, FCAS markets, FCAS trapezium constraints, dynamic interconnector loss models, generic constraints and fast start dispatch inflexibility profiles. Outputs include market clearing prices, generator and scheduled load dispatch targets, FCAS enablement levels, unit FCAS availability levels, interconnector flows, interconnector losses and region net inflows. Nempy is written in Python 3, and uses a relatively small number of first-order dependencies; pandas (McKinney, 2010; The pandas development team, 2020), Numpy (Harris et al., 2020), MIP-Python (Santos & Toffolo, 2021), xmltodict (Blech, 2021), and Requests (Python Software Foundation, 2021).

Statement of need

In modern industrialised economies, the electricity sector plays a key role in societal welfare and progress, yet commonly is also associated with major environmental harms, particularly where primary energy is sourced mainly through the burning of fossil fuels. As such, all of us are stakeholders in the continued successful operation of the electricity industry, while it transitions to cleaner energy sources, and beyond. Computer models are often used to study the operation, interactions and potential future direction of the electricity sector, review papers highlight the large body of work in this space (Chang et al., 2021; Fattahi et al., 2020; Ringkjøb et al., 2018). Such tools are, invariably, simplifications of the underlying processes of electricity industry operation and investment for reasons including the underlying complexity of the processes and the difficulty of gathering representative data. Commonly they tackle only a subset of the decision making that must operate from milliseconds (for example, under frequency relay trips) through to decades (investment in large generation units with long lead times). A particularly challenging and key task is that of operational dispatch – setting generator outputs and controllable network elements to meet expected demand over the next five to thirty minutes, and minimising costs while ensuring secure and reliable operation. To the best of the author's knowledge `Nempy` is the only open-source software that provides a detailed model of the NEM's dispatch procedure. Other more generalised models of the NEM (Grozev et al., 2005; McConnell et al., 2013; Mountain & Percy, 2019; Wild et al., 2016; Wood & Ha, 2021) or commercial tools such as PLEXOS (Energy Exemplar, 2021) and Prophet (Intelligent Energy Systems, 2021) are used to model NEM dispatch, at various levels of complexity, but are not open-source. More recent work by Xenophon and Hill provides open-source code and data for modelling the NEM, but the dispatch functionality does not include many of the NEM wholesale market features (Xenophon & Hill, 2018).

Nempy has been designed as a flexible model of the NEM's dispatch procedure and to be re-usable in a number of contexts. The software is aimed at analysts and modellers studying the NEM either in industry or academic. It can be used either as is, or as building block in a large modelling tool. Some potential use cases are outlined below:

1. As a tool for studying the dispatch process itself. Models of any energy system or electricity market are necessarily simplifications, however, to improve model performance it is often desirable to add additional detail. Nempy can be used to study the impact of different simplifications on modelling outcomes, and thus provide guidance on how model performance could be improved by adding additional detail. Figure 1 shows a simple example of such an analysis. The price results from the New South Wales region for 1000 randomly selected intervals in the 2019 calendar year are shown. When Nempy is configured with a full set of market features price results closely match actual prices. When the FCAS markets and generic constraints (network and security) are removed from the model, results differ significantly. Resorting the results of the simpler market model, we can see that both models produce a similar number of medianly priced intervals. However, the highest and lowest priced intervals of the simpler model are significantly lower. The average historical price is 81.4 \$/MWh, the average price of the full featured model is 81.3 \$/MWh, and the average price of the simpler model is 75.0 \$/MWh. The close match between the results of the full featured model and actual prices allows for the attribution of the deviation of the simpler model explicitly to the simplification that have been made.

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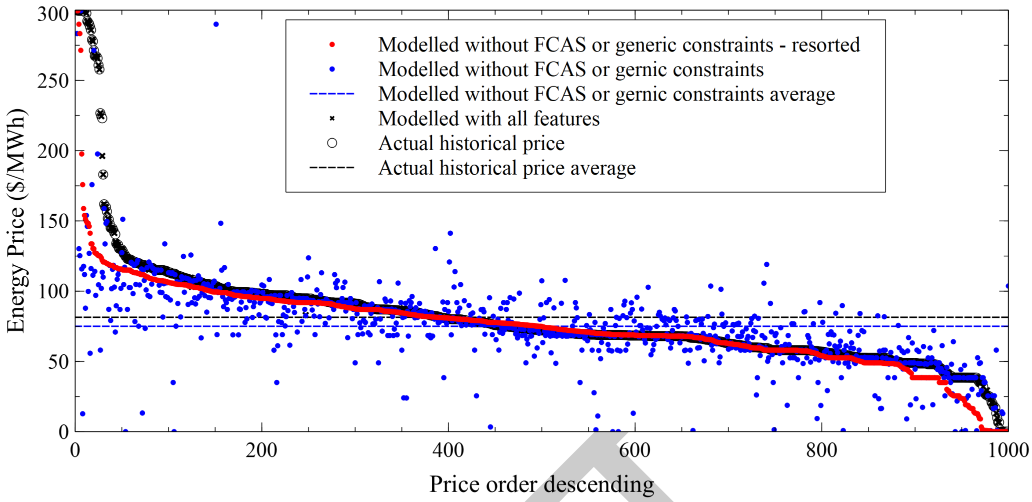

Figure 1: Dispatch price results from the New South Wales region for 1000 randomly selected intervals in the 2019 calendar year. The actual prices, prior to scaling or capping, are also shown for comparison. Results from two Nempy models are shown, one with a full set of dispatch features, and one without FCAS markets or generic constraints (network and security constraints). Actual prices, results from the full featured model, and the simpler model are shown in descending order for actual prices, results from the simpler model are also shown resorted.

2. As a building block in agent based market models. Agent based models can be used to study electricity market operation, and are particularly useful in modelling both the competitive nature of electricity markets and their complex operational constraints (Ventosa et al., 2005). In such models, agents must interact with a modelled environment, and a key part of that environment is the market dispatch process. Thus, Nempy could be useful as a building block to create agent based models of the NEM, and play a role in answering various questions about market operational outcomes. Such questions could include:

   - How does changing the demand for electricity effect market outcomes?
   - How does the entry of new generating technologies effect market outcomes?
   - How do patterns of generator ownership effect market outcomes?

   Of course, another necessary component of agent based models are the behavioural models of the agents, a prototype behavioural model of NEM participants is being developed as part of the NEMPRO project (Gorman, 2021).

3. To answer counter factual questions about historical dispatch outcomes. For example:

   - What would have been the impact on market dispatch if a particular network constraint had not been present?
   - How would have dispatch outcomes differed if a unit had offered a different bid into the market?

   The answers to such questions have direct, and potentially large, financial implications for market participants. AEMO offers access to a production version of the market dispatch engine to allow participants to answer such questions (Australian Energy Market Operator, 2021a). However, access is restricted to registered participants and is provided at a cost of $15,000 per year. Additionally, users of this service are not provided with a copy of the dispatch engine, but access it by submitting input files to AEMO. This prevents the use of this service to answer questions about how changes to the dispatch process, rather than the inputs, would effect dispatch outcomes. In contrast, access to Nempy is not restricted, it is free to use, and is open to modification.

4. As a reference implementation of the NEM's dispatch procedure. While the Australian Energy Market Operator (AEMO) has published several documents that describe aspects of the dispatch process (Australian Energy Market Operator, 2012, 2014, 2017a, 2017b, 2021b), our experience developing Nempy has indicated that key implementation details are often missing from the publicly available documentation. Through a process of testing various implementation options, where the documentation was not explicit, Nempy has been refined in an attempt to better reflect the actual dispatch procedure. As a result Nempy is a useful additional reference for analysts and modelers looking to understand the NEM's dispatch procedure.

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