SOCIALLY OPTIMAL SCHEDULING OF BATTERY STORAGE IN POWER SYSTEMS WITH HIGH PENETRATION OF SOLAR ENERGY

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Overview

The need for more flexible electricity generation sources and the fall of battery storage system (BSS) costs have increased interest in batteries over recent years. Many studies have assessed the benefits of BSS based on existing market arrangements (Moreno et al, 2015). However, due to the many market failures present in electricity markets not all societal benefits are captured in these studies. In particular, there are no granular economic assessments of the BSS value to avoid CO_2 emissions. This societal benefit arises from the damage cost of climate change, known as the 'social cost of carbon' (SCC). Its value is much higher than typically seen carbon taxes and prices. In this work, we estimate the societal value of BSS, in the short term, considering reserve service, energy and emission benefits, in the context of power systems with high penetration of solar energy. We use real hourly data of the societal marginal costs of reserve service, energy generation and CO_2 emissions, in the Chilean electricity market. We find significant BSS reserve service benefits in the north of Chile as here, often, low-cost generators provide reserve services. In addition to that, the high solar generation of the north causes transmission congestions which create an important opportunity for BSS energy and emission cost arbitrage in this market with nodal energy prices.

Methods

We estimate the marginal societal benefits of a 10MWh/6MW BSS which we assume installed in the Zone Substation (ZS) named 'D. de Almagro', in the sunny north of Chile. The estimation is undertaken for a complete week of January 2018. We use real-life hourly data of the system marginal cost of energy generation, marginal cost of reserve service and marginal cost of CO_2 emissions, all of them seen at the 'D. de Almagro' ZS (CEN, 2018). This approach captures, empirically, the variability and correlations present in the societal costs (Oliva H et al, 2014). We optimise the operation of the BSS in order to maximise the total avoided societal cost. Detail about the societal benefits included in this study is provided as follows.

Reserve service benefit

The societal BSS reserve service is estimated hourly as the multiplication of the BSS reserve volume in MW times the reserve price. The BSS reserve volume or provision refers to the ability of the BSS to rapidly respond, changing its output to counterbalance an imbalance between supply and demand due to a sudden loss of supply (e.g. generation outage). For doing so, the BSS needs to plan sufficient power capacity margins and levels of stored energy in order to be able to increase its output above the levels scheduled in the pre-contingency state. The reserve price is estimated as the subtraction between the system marginal cost of energy in the targeted ZS (nodal energy price) and the variable cost of the generator with the lowest marginal cost providing reserve. This difference represents a societal opportunity cost.

Energy arbitrage benefit

Energy arbitrage takes advantage of low marginal costs of energy to buy low-cost energy, which is stored and then delivered at times of high marginal cost. We modelled this by multiplying, hourly, the BSS power (negative for charge and positive for discharge) times the marginal cost of energy in the targeted ZS area.

CO_2 emission arbitrage benefit

Likewise for the case of energy, emission arbitrage consists in charging the BSS whenever the system marginal generator has a low CO_2 emission rate (in tCO_2/MWh), to then deliver the stored energy at times of high emission rates. This approach is conducted using hourly real-life CO_2 emissions rates for generators in the margin with capacity above 50MW. For the case below 50MW, we use standard emission rates associated to the specific generation technology in the margin.

As such, the socially optimal BSS scheduling is obtained by maximising the following objective function:

$$Max \sum_t \{ (MCe_t + ER_t \; x \; SCC) \; x \; BSSp_t + MCr_t \; x \; BSSr_t \}$$

Where at hour *t*, optimization variables are: $BSSp_t$ as the BSS power and $BSSr_t$ as the committed BSS reserve service power. Inputs at the 'D. de Almagro' ZS are: the system marginal cost of energy generation (MCe_t), the emission rate of the system marginal generator in tCO_2/MWh (ER_t), the social cost of carbon in $/$tCO_2$ *(SCC)*, and the reserve price or marginal cost of reserve (MCr_t). More detail about the constraints of the optimization model can be found in (Moreno et al, 2015).

The case study

We study the ZS area of 'D. de Almagro', in Chile, during summer, as here there is a disproportionally high solar power generation which drives marginal energy costs down to zero every day during daylight hours. This is so since the power line connecting this ZS area with the main electricity network is congested due to the delay in new transmission expansion. The situation may present an important opportunity for BSS societal cost arbitrage.

Results

In this section we show the resulting societal costs and the BSS optimal scheduling (Fig. 1), for the week and ZS area of our case study. Note that we have used a SCC value of US$50/$tCO_2$ in line with a common middle range estimate seen in the literature.

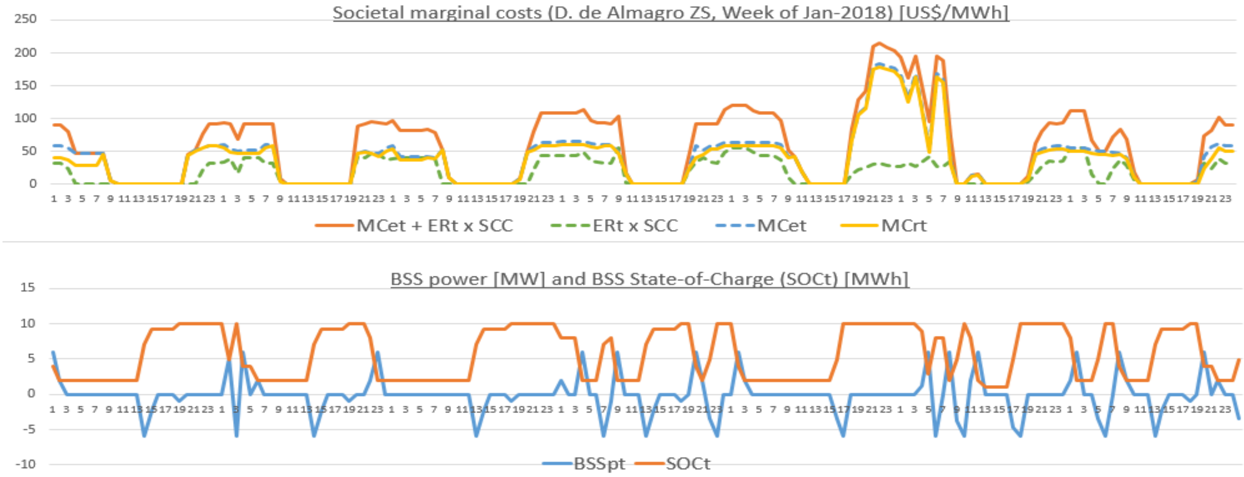

Fig. 1. Societal marginal costs and socially optimal BSS power and SOC at the D. de Almagro ZS, for a week of January 2018.

Fig. 1 shows that, in this ZS area, solar generators are in the margin in daylight hours. This is caused by the congestion of the power line that connects the ZS with the upstream main electricity network. Under nodal energy prices the 'D. de Almagro' subsystem is decoupled from the main electricity network, which brings the marginal cost of energy and emission rates down to zero. This creates great potential for both BSS energy and emission arbitrage. At the same time, the congestion reduces the BSS reserve service benefit as during congestion it is not possible to transfer reserve services into the main electricity network.

For this week, we estimated BSS societal benefits of about US$33,000 for reserve service and US$5,800 for arbitrage. A total just below US$40,000/week. The BSS reserve service benefit is quite high because in the north of Chile low-cost generators are often seen providing reserve services (which may be inefficient). This happens as generators providing reserve are not chosen from an economic optimization criterion. This would not be the case in other electricity markets where reserve services are co-optimized with the dispatch of energy generation.

Conclusions

- Significant change in the societal costs of energy generation, reserve service and CO_2 emissions in areas where high solar penetration causes transmission congestions.
- High BSS reserve service value in the north of Chile where low-cost generators are found providing reserve services.
- This, together with the inclusion of avoided CO_2 emission benefits, makes BSS economically attractive from a societal perspective in the north of Chile.

References

Moreno, R., Moreira, R., Strbac, G., 2015. A MILP model for optimising multi-service portfolios of distributed energy storage. Applied Energy 137, 554-566.

CEN, 2018. Sistemas de Información Pública. Coordinador Electrico Nacional. https://www.coordinador.cl/sistema-informacion-publica/.

Oliva H, S., MacGill, I., Passey, R., 2014. Estimating the net societal value of distributed household PV systems. Solar Energy 100, 9-22.