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COMMENTS

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Low-carbon technology calls for comprehensive electricity-market redesign

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Abstract The energy transition also calls for electricity-market redesign. Low-carbon technologies will fundamentally reshape the electricity sector. The electricity generation and demand will be significantly unpredictable and uncontrollable thus require for a more sophisticated system operation to guarantee the grid stability and reliability. The higher difficulty induced by the green-technology penetration expose the electricity-market to a higher market-failure risk. Thus, the future low-carbon electricity-market and associated regulation scheme require a comprehensive new design.

Keywords low-carbon technology, electricity-system operation, market design

Low-carbon technologies increase the complexity of the electricity-system operation thus the failure risk of the electricity-market. Electricity sector is one of the largest green-house gas (GHG) discharging department. Thus, the clean-electricity policy stands at the center of the GHG-mitigation stage. During the last two decades, a great number of policies are designed for encouraging the green-electricity technology innovation and penetration. Those clean-electricity technologies' integrations into the electricity grid fundamentally change the electricity-supply technologies and electricity-demand patterns. Those changes challenge the current system operation and market design. In general, the future low-carbon electricity sector must complement with a much more complex system operation as well as market design than the current electricity sector.

In general, the low-carbon technologies sophisticate the grid-system operation and market design by rising three challenges. The mostly-addressed challenge is that the low-carbon technologies bring a significantly more uncontrollable uncertainty into the electricity grid. The intermittent renewable energy (RE) and the electrical vehicle (EV) remarkably exacerbate the uncontrollable variability in a grid system thus make the real-time balancing on the grid even harder than on the traditional grid (Fernandez et al., 2011; Yi et al., 2018).

Another challenge sophisticating the grid operation is that the penetration of the low-carbon technologies is changing the distributed grid from the current one-directional power flow toward the future bi-directional power flow. Traditionally, the power flow on a distributed network is oriented from the substation toward the consumers. Thus, the current distributed-grid systems do not have operators and only yield to very limited controls. Now, the spread of the household solar photovoltaic panel and storage facilities allow the consumers to inject power flow back to grid. Those inversed power flows on the grid exacerbate the grid instability thus call for more resources and new infrastructures to guarantee the system reliability (Carrasco et al., 2006; Chen et al., 2010). Consequently, a future distributed-grid system must have its own system operator.

In addition, once the distributed-grid operators are widely established, the whole power-grid operation will become much more complex than the current one. The transmission-grid operator and the distribution-grid operators must timely communicate with each other and synchronize their operation strategies. Thus, the current one-center system operation structure will be replaced by a hierarchy-and-multi-center-jointed operation structure (Chen and Mei, 2015).

The above three challenges threat the electricity-market's efficiency and low-carbon policies' effectiveness. Operation complexity is the key reason of the electricity-market's failure risks. In the current conventional electricity-system, the operation's complexity is mainly

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designed to deal with the market-failure potential due to the Kirchhoff Laws. The operation complexity causes the impossibility of establishing a fully competitive market if an elegant market design is absent. Even in a well-designed market, the potential of economic inefficiency inevitably exists due to the non-convexity of optimal-power-flow (OPF) problem. Those inefficiencies are originated from the insolvability of the optimal market-equilibrium searching problem and the market-manipulation loopholes caused by OPF's non-convexity.

An extra operation complexity induced by green technologies will endanger the current electricity-market. The significant intermittency caused by the green-technology penetration enlarges the difference between the solvable approximated market equilibrium and the optimal operation strategy supporting the first-best equilibrium. The interactive operation between the transmission system-operator and multiple distribution-system operators can generate additional loopholes allowing strategic players to manipulate the market. In addition, the green-technology stakeholders have unique strategies to obtain and exercise their market power while those strategies are unable to be adopted by conventional market players (Yu et al., 2014).

A sequence of studies has addressed the importance of redesigning the electricity-market to adapt the operation complexity due to the green technologies' penetration. The current literature mainly proposed two types of market-redesign suggestions including:

• Adjusting the current wholesale market's designs on the transmission-grid level toward a dynamic design for the green technologies;

• Introducing additional economic institutes to organize new distribution-grid markets for marketizing the green technologies.

Redefining the auction and pricing mechanisms is the core issue for green technology's grid integration in the wholesale market. Researchers have proposed a blanket of suggestions that have portraited a roadmap for future wholesale market redesigns. The current studies suggested a dynamic pricing scheme for intermittent renewable resources to complement the sequential auction structure of the wholesale market. The proposed dynamic pricing scheme aims at limiting the risks due to the green-technological uncertainties in addition to traditional system-operation targets, such as cost minimization and system-robustness improvement (Bitar et al., 2012).

The market designs for commercializing the green technologies on the distribution-grid level are still preliminary. Some studies proposed an adjustment on the current retail price to adapt a high-green-technology-penetration system. The adjustment is based on the current two-tiered price including a fixed access fee and a payment varying according to users' consumption. In particular, the proposed adjustments argue that the green-technology owners ought to pay for the infrastructure even when they supply electricity (Munoz-Alvarez and Tong, 2016). Further, the per-unit electricity rate must vary across consumers to improve the economic and environmental efficiency of green technologies (Yu et al., 2017). Some other studies proposed the plans fundamental reshuffling the distribution-grid. Most of those designs have the vision that aims at allowing decentralization and free trade in a distributed-grid market (Qin et al., 2018). Sharing economy as a candidate for the economic institute coordinating the distribution-grid market has attracted a great number of attentions. Pioneering studies claim that a sharing market supported by an information-collection and calculation service can achieve the economic efficiency while consumers still face to a simple rule to pursue for their private welfare optimization (Kalathil et al., 2017).

In all, the low-carbon energy transition requires not only the green hardware technologies but also the complementary smart-market redesign. The market redesign will inevitably reshuffle the market structure of the wholesale and retail electricity-market. Correspondingly, the regulatory scheme on the electricity sector must also transient. All the current laws, regulations, and policies must be reexamined for confirming their adaptability to the uncertain and multi-layer-operated low-carbon electricity-system.

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