Demand-Side Management and Economic Dispatch for Energy Transition in Karnataka, India

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Overview

India has set 2070 as the target year to achieve carbon neutrality, while fossil fuels are dominating its energy system and the country's GDP per capita still significantly trails developed countries. The economically optimized energy transition towards renewables is crucial for India to reduce CO_2 emissions in an affordable manner. India has installed a large fleet of solar PV and thus, maximizing their capacity factors play an influential role in such energy transition.

Curtailment can be implemented due to technical and policy issues (Boddapati et al., 2021)). The technical reasons for renewable energy curtailment are constraints in transmission capacity, system balancing, excessive supply coupled with low demand, grid congestion, etc. (Bird et al., 2016; O'Shaughnessy et al., 2020). The lack of available transmission infrastructure is also a reason for curtailment. The policy-related issues for curtailment are tariff issues, changes in power purchase agreements, electricity dispatch rules, etc. Considering dispatch rules, if the utilities did not follow the least cost dispatch or renewable energy priority dispatch, curtailment is possible. Curtailment of net zero-emission solar PV and wind power is adverse to achieving carbon emission targets as it increases operational hours of conventional carbon emitter thermal power plants (Golden and Paulos, 2015).

This study examines how the state of Karnataka managed to substantially enhance the solar PV capacity factor from 2017 to 2019 by two-thirds. We built a mixed-integer linear programming (MILP) model with detailed hourly data to quantify the impacts of two major policy changes, shifting electricity supply to irrigation from nighttime to daytime (load shift) and dispatching electricity generation units by their merit order (economic dispatch). Our results indicate that these two measures could explain about one-fifth and three-quarters of the capacity factor increase, respectively, over the three years, which is equivalent to reducing the cost of solar electricity by about 40%. India and other countries may further expand these policies for accelerating and optimizing energy transition.

Methods

We present a mathematical model-based approach to reproduce the real-life scenario. The proposed mathematical model is a mixed-integer linear programming (MILP) model. The objective of the mathematical model is to meet the electricity supply and demand with two types of dispatch strategies, namely random dispatch, and economic dispatch. The random dispatch, and economic dispatch strategies mimic the real-life day ahead self-schedule market design and market-based economic dispatch strategies, respectively. Further, the model is used to study the combined impacts of the introduced demand-side management strategy (load shift) with the dispatch strategies. The economic dispatch (dispatch based on marginal cost) strategy aims to meet the electricity supply and demand by minimizing the cost of electricity supply. Load shift denotes the demand-side management strategy introduced in the electricity system. It signifies the shift of irrigation electricity demand to the daytime from night hours.

Regarding the constraints used in the mathematical model, no generation or operation limits are imposed on large hydro, mini hydro, solar, wind, biomass, and cogeneration power plants. Nuclear power plants are assumed to be base load power plants and will supply electricity throughout the day and all through the year. For thermal plants, ramp and generation limit constraints are imposed on their operation. The ramp-up and ramp-down limits are considered as 35% of the power plant's installed capacity. Further, the generation of thermal power plants should not exceed the maximum available potential. On the lower side, when the power plant is in operation, the generation from the plant should be at least 40% of its installed capacity. For thermal power plants, the model considers shut down costs and two types of startup costs (hot start and cold start). If the thermal power plant startup within five hours of its shut down, it is considered a hot start, and everything else is regarded as a cold start. For the ease of solving and for better convergence, the model is solved as a linear model. So, the startup and shut down costs are calculated outside the model. Electricity transmission and distribution costs are not considered in the model.

Results

The validity of the impact of the policy change and load shift on solar PV capacity factors is evaluated. In January 2017, the installed capacity of solar PV was just 0.3 GW, and it increased to 1.6 GW by December 2017.

Correspondingly in January 2019, the installed capacity was 5.5 GW, and it rose to 6.6 GW by December 2019. Our research shows the two-week moving average of the solar PV capacity factors of economic and random dispatch with 2019 demand (with load shift) and without load shift. We can observe that with change in dispatch policy and without agricultural load shift, the consumption of solar PV was low, which can be understood from the low-capacity factors. Except during the second half of July and the beginning of August, the load shift has helped to elevate the capacity factors of solar PV in all the other periods. The likely reason for load shift not helping the increase in capacity factor during those days is that July and August are the peak monsoon months in Karnataka. During peak monsoon, the irrigation water demand is low, and there is a very high generation of wind power in the electricity system. From the two-week moving average of the solar PV capacity factors of economic and random dispatch with 2017 demand (without load shift) and with load shift, it can be observed that with the implementation of the policy change and load shift, the impact varies differently across the year, while with a random dispatch policy, the utilization of solar PV is low.

We present the impacts of load shift, economic dispatch, and greater installed capacity for the above discussed two sets of simulations. With random dispatch and without load shift in 2017, the total annual energy generated from solar PV is 1,053 GWh, which correlates to an annual capacity factor of just 12.1%. Further, with the increase in installed capacity and without load shift in 2019, the capacity factor of solar PV for random dispatch has increased by just 0.4% when compared to the similar scenario in 2017. This proves our assertion that with random dispatch the utilization of solar PV is low. In 2019 the total energy generated from solar PV with load shift and random dispatch is 7,551 GWh. Whereas without load shift and with random dispatch the total energy generated from solar PV in 2019 is 6,628 GWh. This shows that with random dispatch scenario the load shift was helpful in additional generation of 923 GWh in 2019 i.e., an increase of 1.9% more in capacity factor. This proves our second assertion that load shift is helpful to elevate the solar PV capacity factors. With random dispatch, the total electricity generated from solar PV in 2019 (actual demand, i.e., with load shift) is 7,551 GWh, whereas with economic dispatch, the total electricity generated is 10,852 GWh. With both load shift and economic dispatch in 2019, 3,301 GWh of more energy is generated from solar PV which is an increase of 6.1% in solar PV capacity factors. The electricity generated without load shift and with economic dispatch from solar PV in 2019 is 9,843 GWh and without load shift and with random dispatch is 6,628 GWh. Compared to with load shift and with economic dispatch policy for 2019, the electricity generated without agricultural load shift and with economic dispatch policy is 10% less which validates our hypothesis that the change in dispatch policy and agricultural load shift has helped in increasing the consumption of solar PV.

Conclusions

This paper systematically establishes the causal relationship between dispatch policy and demand-side management (load shifts) on the capacity factor of solar PV power plants. With the random dispatch policy, the solar power in the system is underutilized. To mitigate this issue, a change to economic dispatch policy was introduced in the system. The capacity factor of solar PV technology has significantly increased with a corresponding reduction in the usage of thermal power. Further, implementing a demand-side management program, i.e., shifting the electricity supply to irrigation from night-time to daytime, has a significant impact on improving the utilization of solar power. The current research validates the hypothesis that solar PV curtailment has been reduced with the introduction of the new economic dispatch policy and irrigation load shift.

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