Poster: Flattening the Duck Curve Using Grid-friendly Solar Panel Orientation

M. Doroshenko
School of Computer Science,
University of Waterloo
Waterloo, Ontario, Canada
mdoro@uwaterloo.ca

S. Keshav
School of Computer Science,
University of Waterloo
Waterloo, Ontario, Canada
keshav@uwaterloo.ca

C. Rosenberg
Dept. of Electrical and Computer
Engineering, University of Waterloo
Waterloo, Ontario, Canada
cath@uwaterloo.ca

ABSTRACT

By adopting grid-scale solar power, a utility can reduce both its carbon footprint and its fuel bills for legacy thermal generation plants. However, as solar penetration increases, generation can exceed load during the middle of the day, and diurnal variations in solar generation cause rapid ramps every morning and evening.This so-called 'duck-curve' causes increased wear and tear of thermal plants and wasteful curtailment. We study how flexibility in solar panel orientation at the time of installation can be used to flatten the duck curve mitigating these ramping problems. We find that grid-friendly panel orientation can indeed reduce ramping by 25-30%, also reducing overgeneration during mid-day periods, without significantly increasing net load. Thus, it is an attractive approach for future solar deployments.

CCS CONCEPTS

•Hardware → Renewable energy;

KEYWORDS

Solar generation; Ramp reduction; Panel orientation

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1 INTRODUCTION

Solar power is growing at an unprecedented rate around the world. However, increased solar penetration comes at a cost. With increased generation, the net load (i.e., load - solar generation) takes on a shape that is commonly referred to as the 'duck curve' [4, 6]. The curve has two distinct characteristics: a fast ramp down every morning and a fast ramp up every evening, as the sun rises and sets (the 'tail' and 'neck' of the duck) (see the red curve in Figure 1). Additionally there is the potential for overgeneration during the mid-day if solar generation exceeds load and the 'belly' is below zero.

These characteristics can negatively impact utilities [2, 6]. Fast daily ramping of thermal plants causes wear and tear which leads to increased maintenance costs [6, 11].

Several mitigation actions to reduce ramping and overgeneration have been proposed in the literature [1, 6, 9, 10, 12]. An interesting alternative that has been proposed recently is the East-West orientation of fixed solar panels at the time of installation [3, 13]. Note that this orientation of solar panels effectively results in curtailment in that it generates less energy than a conventional equator-facing orientation. However, with this approach, there is additional generation during the morning and evening hours, reducing ramping. Thus, it has been suggested that this choice of solar orientation can not only reduce ramping but also reduce overgeneration.

We investigate the degree to which choice of solar panel orientation reduces ramping and overgeneration without significantly increasing net load.

2 RAMP REDUCTION USING FLEXIBLE PANEL ORIENTATION

We use a Linear Integer problem formulated in A Mathematical Programming Language (AMPL)[8]. The model is subsequently solved with IBM ILOG CPLEX Optimization Studio (CPLEX)[5] under the default configuration.

We consider optimization over a calendar year time frame. Thus, the number of hourly readings for electricity generation and electrical grid load is always $365 \times 24 = 8760$. We also limit the number of tilt/orientation combinations to 29[1]. The chosen tilts are: 15°, 30°, 45°, and 60°. The chosen orientations are: 120°(east), 150°, 180°(south), 210°, 240°, 270°(west). In addition, the combination of 0° tilt and 0° orientation represents a panel that is lying flat on the ground, facing the sky.

We assume that we are given the following parameters:

- I – the number of hourly electricity generation and electrical grid load readings for one year
- J – the number of tilt/orientation combinations. Note that we study *all* combinations of tilt and orientation, not just East-West or North-South orientation
- H_i – aggregate electrical grid load at time i
- $\gamma_{i,j}$ – solar electricity generation level for time i and tilt/orientation combination j
- Q – aggregate number of panels mandated for installation
- one panel's capacity is assumed to be 200 Wp

[1]While we assume that all these combinations are feasible, this might not be the case in a real-life setting, e.g., if the panels are being installed on rooftops.

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The optimization variables are:

- q_j – quantity of panels with tilt/orientation combination j

Our optimization returns the following variables:

- G_i – aggregate fossil-fueled electricity generation needed at time i
- S_i – aggregate solar electricity generation at time i
- C_i – aggregate solar curtailment at time i

Note that the only vector variable the solver uses to optimize an objective function is the vector q, whose elements are the number of panels with a certain tilt/orientation combination. **Constraints:** By changing the value of Q, we study the effect of the number of panels deployed on our results:

$$\sum_{j=1}^{J} q_j = Q \tag{1}$$

Note this is an equality constraint, rather than an inequality, so that it is possible to control the level of solar penetration in the region.

Aggregate solar electricity generation is:

$$\forall i : S_i = \sum_{j=1}^{J} \gamma_{i,j} q_j \tag{2}$$

The curtailment C_i is defined by:

$$\forall i : C_i = G_i + S_i - H_i \tag{3}$$

and the constraint is that $C_i \geq 0$. Thermal generation needs to be restricted to levels greater or equal to zero:

$$\forall i : G_i = \max(0, H_i - S_i) \tag{4}$$

If net load is positive, it is effectively equivalent to thermal power production level (G_i). If net load is negative, no electricity needs to be produced with fossil fuels, but there is solar power curtailment present in the system (C_i). Note that we decided against putting a constraint on the maximum net load increase (with respect to the base case scenario). Instead, we will investigate how much net load increase is brought by the solution to our problem.

Objective function: Reducing the magnitude of ramping can be formulated as:

$$\underset{q_j}{\text{minimize}} \sum_{i=1}^{I} \left| G_i - G_{i-1} \right| \tag{5}$$

3 EVALUATION

We consider a range of relative installed PV capacity levels between 60% to 180%. Figure 1 illustrates how orientation control decreases ramping on a typical day. The black curve is the aggregate grid load in the region. The blue curve, which corresponds to the net load curve of the flexible orientation scenario, exhibits no aggressive ramps, such as those observed in the red curve, which represents the base case scenario.

The optimal panel layout for each value of relative installed PV capacity is shown in Figure 2. We find that it is optimal to place most panels facing east and west with the highest tilt available (60°) so that solar generation is minimized during the afternoon hours. This helps avoid high levels of thermal generation variation caused by the afternoon sun. Simultaneously, solar generation is maximized in the morning and in the evening.

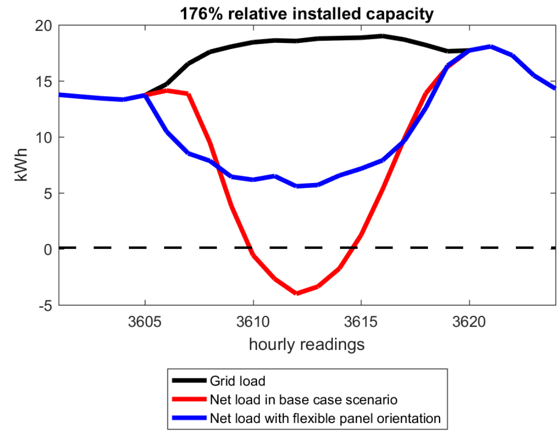

Figure 1: Flattening the duck curve: the original curve is in red. With optimal choice of orientation, the blue curve shows a substantial reduction in ramping.

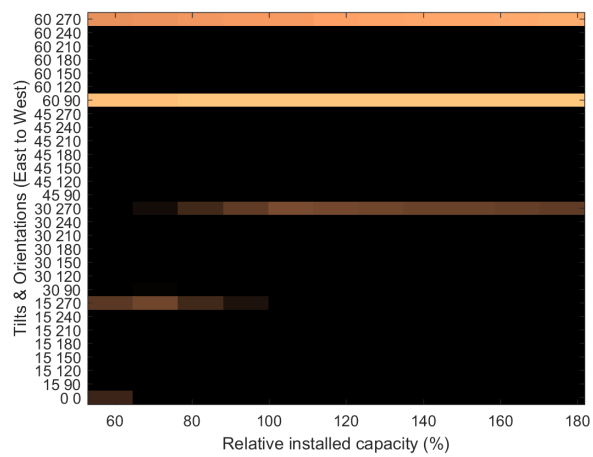

Figure 2: Optimal orientation. The X axis shows relative installed PV capacity and 0 degree orientation corresponds to North.

Overall, we found that flexible panel orientation reduces ramps by 25–30%, when relative installed PV capacity levels go beyond 100%,i.e., when solar power curtailment appears in the base case scenario. We saw that the solution produced by the flexible orientation scenario yields much less curtailment than the base case scenario. At the same time, the increase in relative thermal energy penetration stays below 10%, which corresponds to a relative decrease in solar penetration of 25–29%. Thus, this model may be helpful in some jurisdictions where the electrical grid has a high cost of ramping due to a high proportion of legacy thermal generators and curtailment proves to be expensive, for example if generators are paid for curtailed production.

More details regarding this work can be found in Reference [7].

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