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Behaviour of small scale dispersed PV generation

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Abstract. The spread over of the small scale PhotoVoltaic plants requires a central production forecast. The regional meteorological information is not suitable for individual production calculation. We investigated the behaviour of the PV plants in different regions. We have also been looking for the relation between daily irradiation and energy production.
We start from a basic assumption then we visualize the appropriate series of data and we calculate the correlation or other factors. Finally we confirm or neglect the initial idea.
The geographical extent has significant effect on the daily cumulated production curve.
The co-running of the daily power peak in a region is really strict but it has no correlation with the daily irradiation. The daily irradiation is proportional with the daily electricity production. The individual production forecast is not really viable that is why aggregation is necessary. The area of the whole country must be handled by regions.

Key words

Forecast of PhotoVoltaic production, Geographic dispersion, Correlation of the daily irradiation and daily production, Co-running of different plants

1. Introduction

The PhotoVoltaic electricity production is called 'weather dependent' because the meteorological and astrological conditions strongly define the actual production curve. The knowledge about the behaviour of the PV plants is important for the power system dispatcher to schedule the electricity production, and is also important for the investors who are looking for the Return on Investment. Simulation is required also for feasibility calculation of the solar tracker systems [1].
The continuously developing PV technology results in different plant characteristics, different efficiencies [2].
Nowadays a huge amount of remotely measured data is available for further analysis [3].

In this paper we investigate the
- Effect of geographical dispersion
- Co-running of PV plants on different geographical areas
- Correlation of the daily irradiation and daily production
- Co-running of the daily peak production and global irradiation
- Co-running of the daily irradiation in different regions

Having these results we can build better forecast for the small scale, large number but non measured PV plants. In the analysis we used the measurements of the Transmission System Operator, of ELMU utility, some household and data series of Óbuda University (Fig.1. and Fig.2.).

Figure 1. 15 kW_p reference system of ELMÜ utility – Fót

Figure 2. PV systems at Óbuda University, Budapest

2. Effect of geographical dispersion

A. Supposition

Although Hungary is a relatively small country, a measurable delay occurs between the eastern and western sunrise and sunset.

B. Basics

The longitude difference of Hungary is approx. 6° (Fehérgyarmat 22,3° – Sopron 16,3°):

- 1 full revolt of the Earth is 360 ° –> it takes 24 hours,
- 15° turning –> takes 1 hour,
- 6° turning –> takes 24 minutes –> delay between the two remote corners of the country.

C. Methodology

We identify similar events in distinct point of the country:

- sunrise
- sunset
- solar eclipse

The output of the different size systems are normalized (100%) for better comparability.

The data of the partial eclipse:[1]

city	*eastern longitude*	*northern latitude*	*1st contact (UT) hh:mm:ss*	*maximum (UT) hh:mm:ss*	*4th contact (UT) hh:mm:ss*
Nyíregyháza	21° 43’	47° 57’	8:43:45	9:52:46	11:03:29
Szombathely	16° 38’	47° 13’	8:35:39	9:44:35	10:56:11

D. Data sources

Measurements are taken from the Transmission System Operator (MAVIR) with quarter hour density.

E. Visualisation

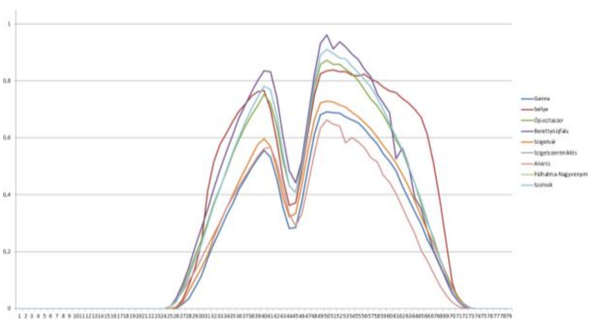

Figure 3. The effect of the solar eclipse on the production curves on 20/03/2014

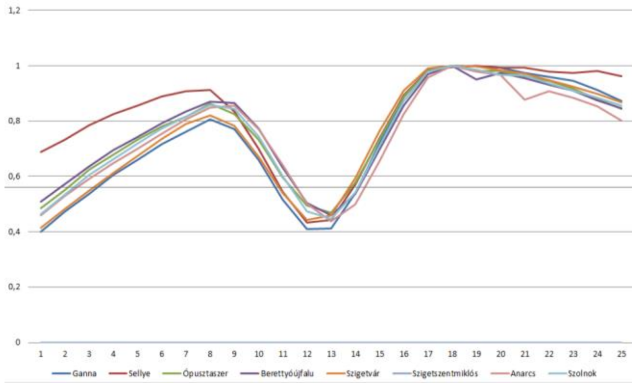

Figure 4. The delayed valley effect of the wandering solar shadow on the day of the eclipse

On the quarter-hour-step curve one can see that the production valley had a 10 min delay between the Western and Eastern Hungary deployed PV plants (Fig. 3. and Fig. 4.). This delay was caused by the “movement of the solar shadow” at the eclipse day on 20th of March 2015. This effect is independent from the orientation of the panels.

On Fig. 5. the effect of the solar trackers can be seen. Most plants have quasi sinusoidal production curves but one is close to a “rectangular” shape. It produces definitely more in the morning/afternoon period and has a larger production change gradient (Fig.5.).

The daily natural delay effect comes from the rotation of the earth. In Hungary it means almost a ½ hour delay between the east side and west side locations. The indirect diffuse radiation depends only on the geographical location but the daily peak depends on the azimuth orientation of the panel (Fig.6.; 7. and 8.).

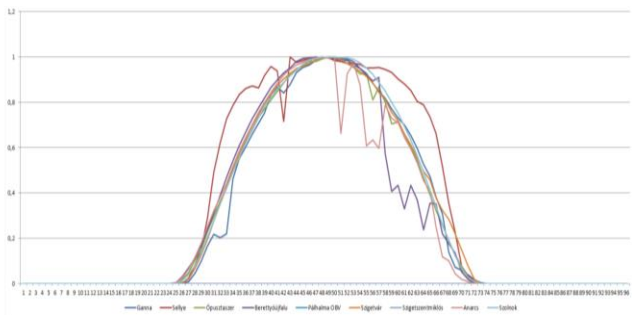

Figure 5. Daily production curves

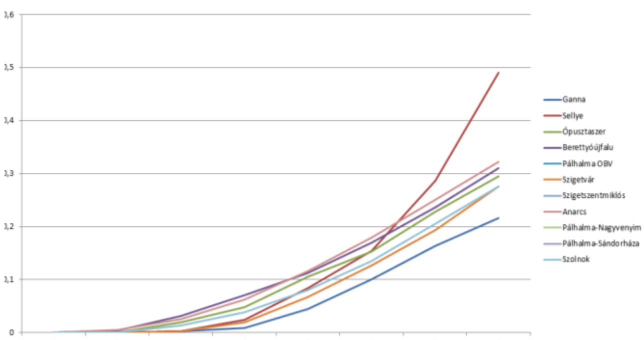

Figure 6. Delay of the diffuse irradiation in different geographic location (Sunrise)

[1] Kaposvári Zoltán csillagászati honlapja; http://saros139.hu/index.html

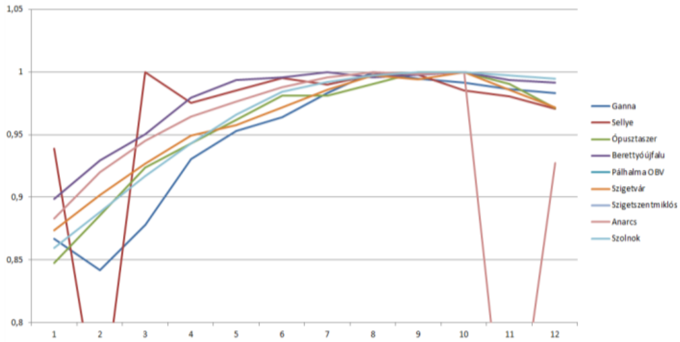

Figure 7. Production peaks on 18/03/2015

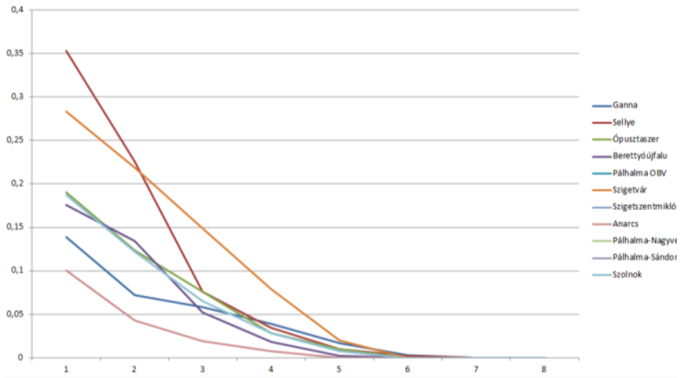

Figure 8. Production stops on 18/03/2015

F. Statement

– Even in a small size country like Hungary the East-West production delay can be measured, one should consider this effect in the forecast.

3. Co-running of PV plants in different geographical areas

A. Supposition

The fixed PV units in case of ideal deployment produce synchronously. The settings are not identical (different azimuths, different tilts – the panels look in different directions), phase shifts can be measured in the same locations.

B. Methodology

Data coming from different sources are normalized and visualized in one diagram.

C. Data source

PV plants close to Budapest in 13 km distance.

D. Visualisation

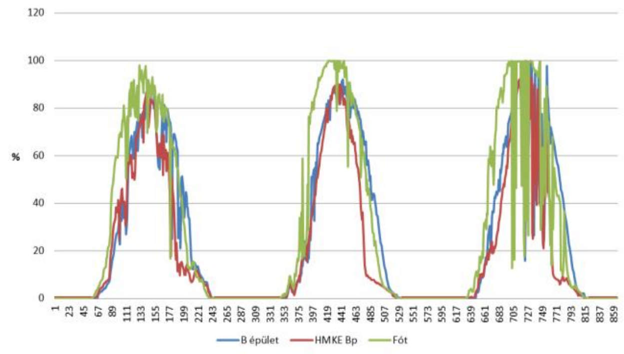

Figure 9. Parallel running of distinct plants in the same region 12-14/06/2014

In the curves of three days (Fig. 9.) the following observations can be made:

Similarities:

– start, stop (sunrise, sunset)
– average coverage of the sky (clouds)

Differences:

– peak production on different days (because of different tilt)
– the peak reached at different time in the day (because of different azimuth)
– some production is limited (by the inverter – see Fót)
– different bell forms (because of local shadowing only the diffuse belighting is longer)
– different cloud courses

Because of cloudy weather 80% power drops happened during 15 mins at an individual producer (13/06/2014; Fót). The unified production of different plants in the same region (20-20 km) has far less deviations – about 40%.(Fig. 10.)

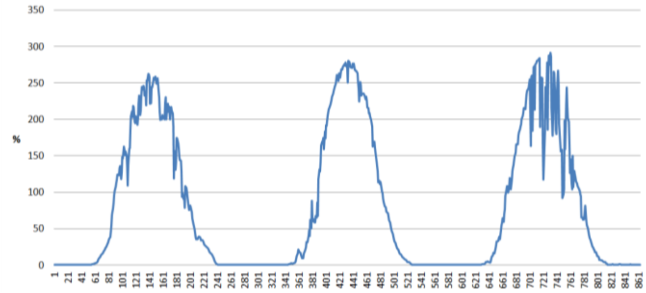
Figure 10. Common normalized production of three plants (12-14/06/2014)

The different orientations of the panels urge or delay the time of the daily production peak (the Sun arrives at the culmination position (Fig. 11.).

Figure 11. PV plants (buildings) with different orientations

E. *Statement*

- The PV plants in the same region can have different deployments (orientation), so its' production curves differ.
- The daily production curve of a large number of PV plants is statistically balanced.

4. Correlation of the daily irradiation and daily production

A. *Supposition*

The daily global irradiation has a close correlation to the daily energy production. On long summer days in case of fix setting panels the diffuse radiation has a role early in the morning and around sunset.

B. *Basics*

The global irradiation is an integrated value that tells how much energy arrives (Wh) on a definite area (m^2). This energy is transformed by the PV cells to electricity with the appropriate efficiency (5-18%). During daytime the total global radiation arrives at the panel but before/after only the diffuse part because of the geometry (the panel is illuminated from the backside or is in shadow).

C. *Methodology*

From the nominal power and from a simulated expected production (from simulation) we formed a specific measurement number:

Daily produced energy / daily expectable maximum in case of maximal irradiation (no clouds) [%]

Now we visualize the correlation between the daily production ratio and irradiation values.

D. *Visualisation*

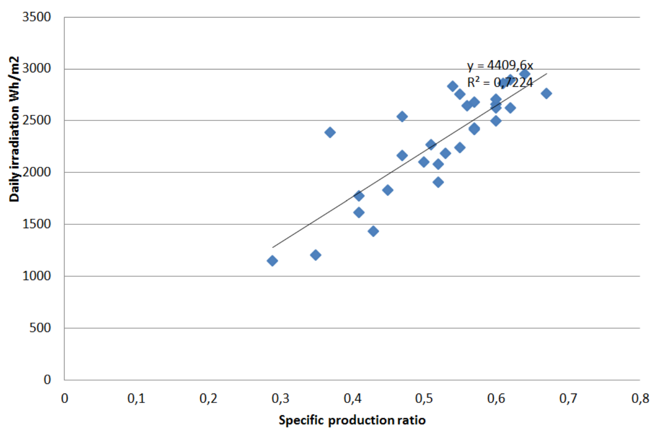

Figure 12. Correlation of daily irradiation and produced energy, 2,2 kW_p plant, June, 2014

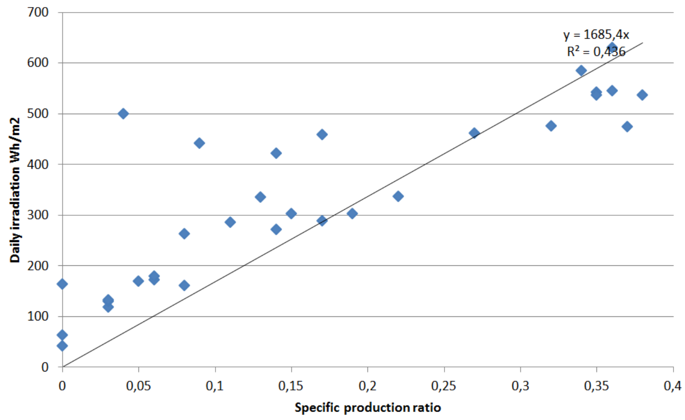

Figure 13. Correlation of daily irradiation and produced energy, 2,2 kW_p plant, December, 2014

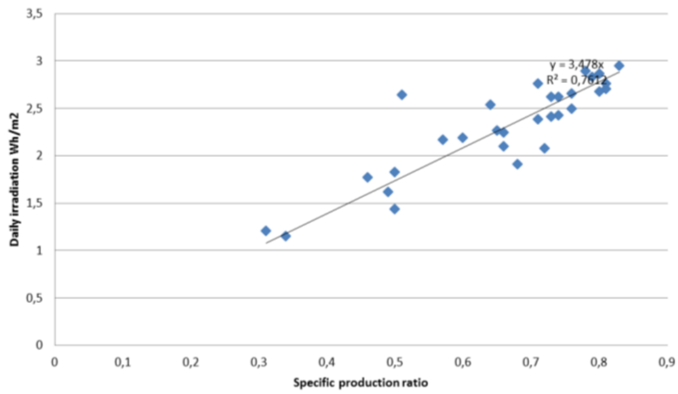

Figure 14. Correlation of daily irradiation and produced energy, 3,5 kW_p plant, June, 2014

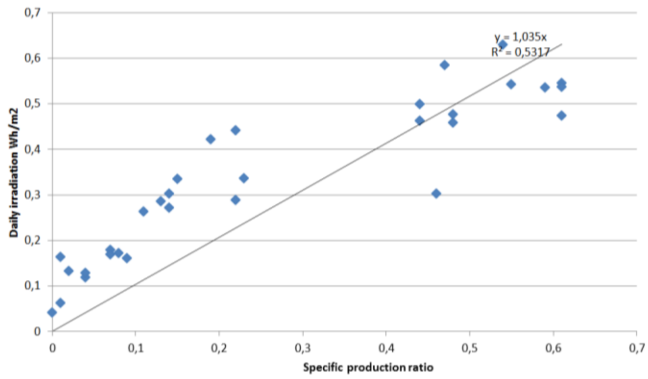

Figure 15. Correlation of daily irradiation and produced energy, 3,5 kW_p plant, December, 2014

E. *Statement*

As the figures show there is a close correlation between the daily global irradiation and the daily energy production (Fig.11-15.), so on the basis of the daily irradiation forecast the PV production can be well predicted, too. In summertime the correlation is better because of the larger load factor of the panel (the daily production time is longer so the „forecast" is more punctual.)

5. Co-running of the daily peak production and global irradiation

A. Supposition

The global radiation is proportional to the daily peak production (power).
The daily peaks run together in a region.

B. Basics

For the power system controller/dispatcher (System Operator) it is crucial to know the shape of the daily power curves (peaks and gradients).

C. Methodology

From the nominal power and from a simulated expected power peak (from simulation) we formed a specific measurement number:

Daily power peak / daily expectable power peak in case of maximal irradiation (no clouds) [%]

Now we visualize the correlation between the daily peak ratio and irradiation values.

D. Data source

- irradiation data of the National Meteorological Service (Fig. 16.)
- 2,2 and 3,5 kW_p household systems in Budapest

Figure 16. Irradiation meters at a meteorological station (NMS)

E. Visualisation

a., Daily production peak and daily irradiation

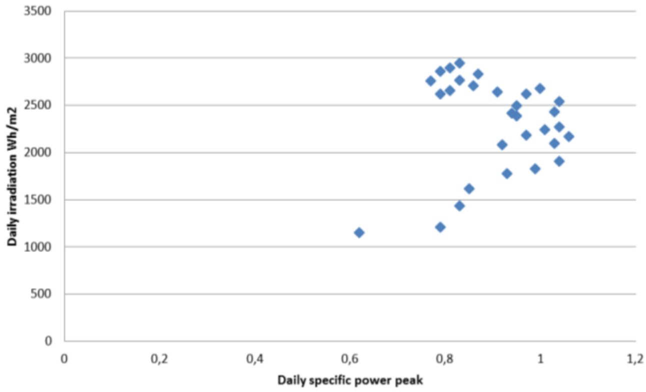

Figure 17. Correlation of daily irradiation and power production peak, 2,2 kW_p plant, June, 2014

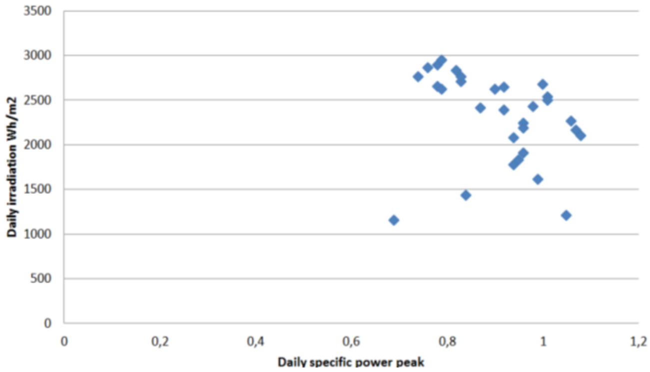

Figure 18. Correlation of daily irradiation and power production peak, 3,5 kW_p plant, June, 2014

b., Daily power peak co-running

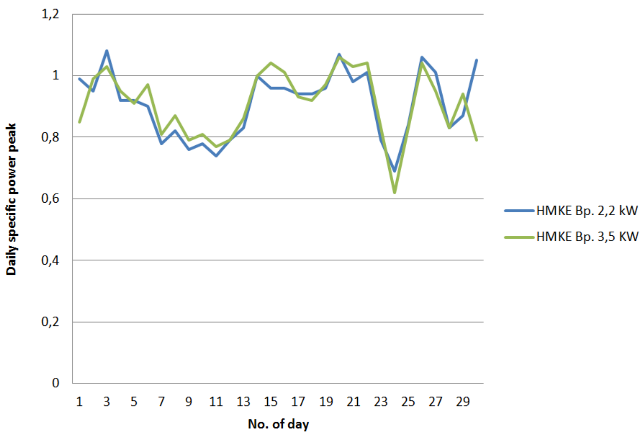

Figure 19. Daily power peak co-running, June, 2014

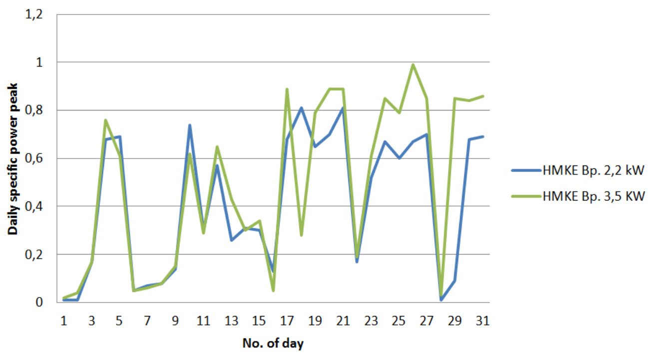

Figure 20. Daily power peak co-running, December, 2014

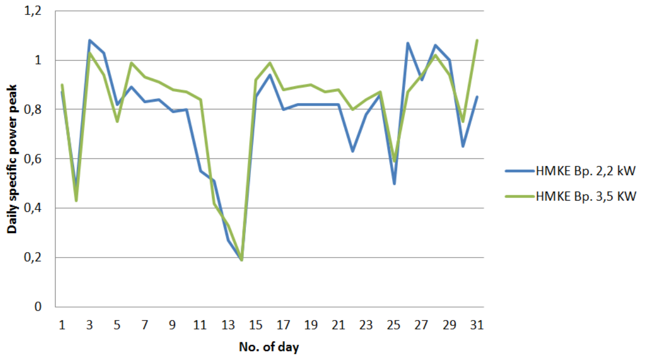

Figure 21. Daily power peak co-running, March, 2014

F. Findings

Figures show that
- the daily production peaks haven't a close correlation with the irradiation integral, so it is an INDEPENDENT effect (Fig. 17-18.).
- BUT the daily peaks are really close to the simulated values also in case of low daily irradiation! (from Fig. 19. to Fig.21.)
- On the other hand in the same region the daily peaks show quite strong correlation.

6. Co-running of the daily irradiation in different regions

A. Supposition

The daily global irradiation is similar in the different points of the country. The local forecast is not necessary.

B. Methodology

We cumulate the productions of six different utilities. We check the co-running of the curves. (Of course the co-running/correlation can be measured but some trends can be seen at first sight.)

C. Data source

Daily energy irradiation measurements from six regions of the country.

D. Visualisation

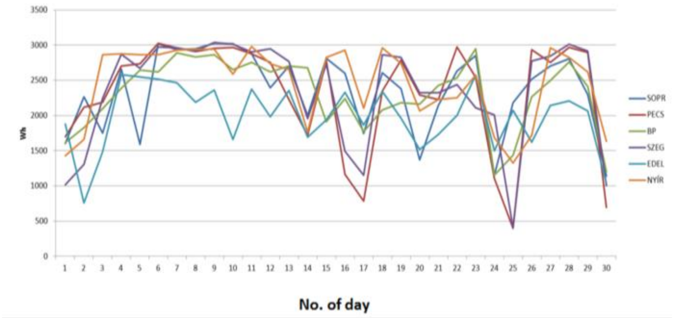

Figure 22. Daily regional irradiation values (June, 2015)

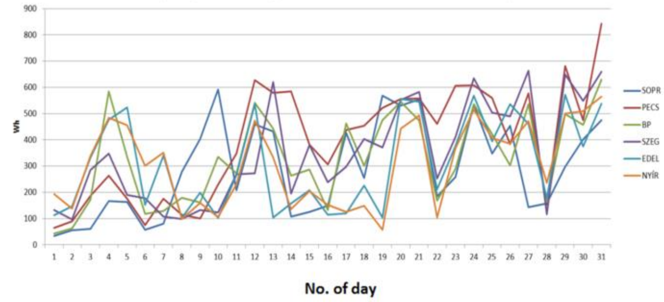

Figure 23. Daily regional irradiation values (December, 2015)

E. Statement

- EDEL is significantly lower than the others
- Sometimes EDEL-Nyír, other times PECS-SZEGED runs in parallel.
- The six regions have different irradiations so it is not worth unifying these distinct measurement curves (Fig. 22-23.). The weather is different, so the forecast should be realized independently in each region.

Conclusion

Analysing the data series of the PV plants we find some significant behaviours that can be used in forecast applications.
The continuous monitoring and evaluation of measurements allows for enhancing the forecast algorithms with self-learning capabilities, so the prognosis can be more precise.

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