Conference Proceedings

Solar World Congress 2015
Daegu, Korea, 08 – 12 November 2015

# Effect of Day-ahead Forecasts on Curtailment Planning of PV Power in Japan

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**Abstract**

The objective of this study is to evaluate the effect that the accuracy of day-ahead forecasts of photovoltaic, PV, power generation has on forecast based curtailment of PV power. Two main regions of Japan were targeted, Kanto, which has a high potential for installations of roof-top PV systems; and Kyushu, which already has high levels of PV power penetration. To provide a qualitative measure of the importance of accurate PV forecasts with different levels of PV power generation, for each region, 2 penetration scenarios were assumed. One year of regional and day-ahead forecasts of PV power were done using numerical weather prediction data, support vector regression, and measured PV power generation data. The PV power generation data comes from to a set of 52 PV systems in Kyushu and to a set of 62 PV systems located in Kanto. The curtailment of PV power was planned one day ahead of time, using the PV power forecasts and a method based on residual loads. The results show that with current day-ahead forecasts it is possible to correctly predict the hours when curtailment will occur most of the time. For example, for Kyushu, curtailment was properly detected 83.1% of the time in a scenario of 8.64 GW of PV installed. For Kanto the values were between 73% and 80.5%. Regarding the effect of the forecast error, we found that it annualy represents near to 35% of the amount curtailed, indicating the importance of improvement of day-ahead forecasts in the curtaiment problem. Finally, the study shows that the relation between the months and hours of curtailment with the period of high forecast errors is crutial to the efficient use of the forecasts, and must be considered before using the forecasts to plan curtailment.

Keywords: *photovoltaic power generation, day-ahead regional forecasts, curtailment planning, support vector regression.*

## 1. Introduction

In Japan, since the enactment of a new feed-in tariff plan for renewable energy in June of 2012, the number of installations of photovoltaic, PV, power had a 4-fold increase, reaching 25 GW in February of 2015 (METI, 2015a). Such rapid growth is cause of concern, as Japan`s power systems are not prepared to deal with high levels of PV power penetration. In Kyushu region for example, the penetration of PV power has already reached particularly high levels, with 4.5 GW of installed capacity and other 4.1 GW authorized and waiting for grid connection as of December of 2014. Considering that the region has a minimum annual demand of power near to 7 GW, to keep the balance between demand and supply of power throughout the year became a difficult task for Kyushu's power utility. Problems derived from the inadequacy of current power systems to deal with high penetration of PV power are also affecting other regions in Japan, although at different levels.

Measures such as power market liberalization, increase of power transmission capacity between different power balacing areas, demand response systems, and power storage solution, can mitigate such problems.


doi:10.18086/swc.2015.07.17 Available at http://proceedings.ises.org

Nevertheless, their implementation requires time and significant resources. Thus, while these measures are being considered and implemented, a short-term solution to deal with the current situation is necessary. In this regard, curtailment of PV power is seen a key measure to guarantee the stable operation of power systems without restricting the growth of PV systems installations.

Japanese power utilities will start to integrate renewable energy curtailment planning in their power systems and grid operation scheduling from 2016. The curtailment will be based on regional forecasts of PV power done at different forecast horizons, and with different levels of accuracy. As the forecast have variable accuracy throughout the year, it is crutial to know the impact that such variable accuracy will have on curtailment of PV power.

Although there is a variety of studies on methods to forecast power generation of renewable energy systems such as (Lorenz et al., 2012), (Diagne et al., 2012), (Paulescu et al., 2012), (Lauret et al., 2015), studies on their application to or of their impact on curtailment of PV power are scarce. On the other hand, available studies about curtailment, usually are focused on estimates of the total amount curtailed per country (Lew et al., 2013), local practices regarding curtailment (Rogers et al., 2010), or estimates of required curtailment given scenarios of renewable energy penetration (Garrigle et al., 2013), for example.

In this initial study we evaluate the impact of day-ahead regional forecasts of PV power generation on its curtailment plan. The study focus on two regions in Japan, the Kyushu region, which already has high levels of PV power penetration, and the Kanto region, which has the highest potential for roof-top PV installations in the country. For each region, data of 2010 was used; but the levels of PV power penetration were based on values of 2014. The forecasts of PV power were done one day ahead of time, in regional scale, and regarding current penetration of PV power in each prefecture within the regions. For each target day and PV power scenario, we compare curtailment based on regional PV power forecasts with the actual curtailment that would be necessary to avoid excess of PV power generation, and analyze the effects that the forecast errors will have on the curtailment plan.

## 2. Methods and Data

To plan curtailment for a day and region, first the corresponding regional PV power generation was forecasted. This section contains the description of the forecast method, curtailment method, data used and PV power penetration scenarios studied.

### *2.1. Forecast Method*

To forecast regional PV power generation we used a method that employed support vector regression and numerical weather prediction, NWP, data. The support vector regression used was the ν support vector regression (Schölkopf et al., 1998), implemented on the LibSVM library (Chang et al., 2001). The NWP data included cloudiness, temperature and relative humidity; they came from the meso-scale model (5 km by 5 km of spatial resolution) of the Japan Meteorological Agency (Saito et al., 2006), released at 12h of the day preceding the target day. The forecasts were done hourly from 6h to 19h of each target day. This method was developed in previous studies, where further details are available (Fonseca et al., 2015).

The regional forecasts were calculated from sets of point forecasts for single PV systems installed in different locations within each region. Given the location of a single PV system, and for a given hour, the corresponding predictions of cloudiness, temperature and relative humidity, as well as the calculated extraterrestrial insolation are entered in a trained support vector regression algorithm, which then returns the corresponding amount of PV power generation. For each day of forecasts, we trained the algorithm before using it. The training used input data and PV power generation data of the 60 days preceding the target day. Thus, one forecast model was set for each day of forecasts. Once the point forecasts were done, the regional yield was calculated using a upscaling procedure described in Eq. 1 and Eq. 2.

$$|P_{pf}| = \frac{1}{P_{rt,pf}} \sum_{i=1}^{n} P_i \qquad (1)$$

$$P_{reg} = P_{rt,reg} * \sum_{pf=1}^{m} |P_{pf}| * \alpha_{pf} \qquad (2)$$

As Japan is geopolitically divided in prefectures, in Eq. 1 $|P_{pf}|$ is the normalized PV power generation per prefecture inside the target region. The PV power generation of each system $i$ inside a prefecture is $P_i$ (in kW), and $P_{rt,\mathrm{pf}}$ (in kW) is the total rated power of the PV systems inside the same prefecture. In Eq. 2, $P_{ref}$ (in kW) is the regional yield, $P_{rt,pf}$ (in kW) is the regional installed capacity scenario, and $\alpha_{pf}$ is the ratio between the PV rated power in each prefecture by the total regional rated power.

### 2.2. Curtailment Method

To calculate the total amount of PV power to be curtailed in a target day we used a methodology based on the base and residual loads. The base load was regarded as the minimum amount of power demand that has to be supplied by power systems using conventional and non-renewable energy. This amount was assumed to be the minimal regional power demand value in a year. Any power demand higher than the base load is regarded as residual load. The residual load can be supplied by conventional power system or by PV power, if available. Nevertheless, PV power generation cannot exceed the residual load: if it does, curtailment happens. It should be noted that this method to identify when curtailment occurs does not consider wind power generation, optimized unit commitment planning, dispatch to other regions, or other ways to control excess of PV power. In spite of that, this method provide good reference values and it is a simplified version of the method suggested to power utilities by the Ministry of Economy Trade and Industry of Japan, when calculating acceptable levels of renewable energy penetration and estimating amounts of PV power to be curtailed (METI, 2015b), [13]. An example of forecast based curtailment plan and the required one, using this methodology, is in Fig. 1. The example shows the load curve for a few days of May of 2010, Kanto region, and a PV power penetration scenario of 14 GW.

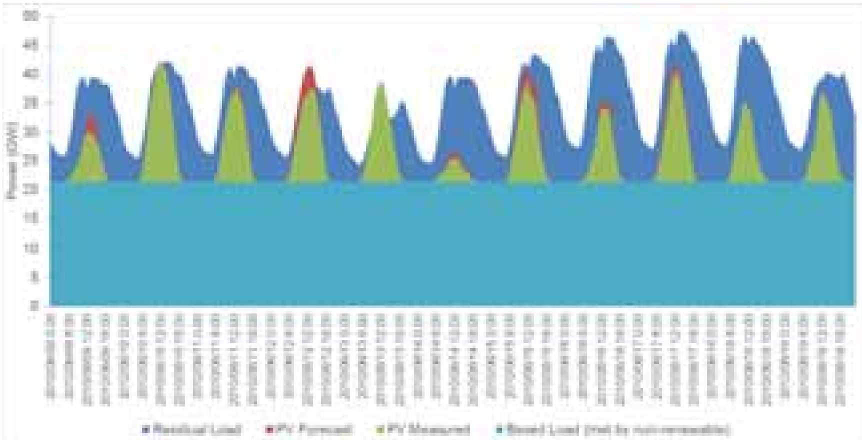


**Fig. 1:Examples of planned versus required curtailment of PV power with the curtailment method used.**

Following the proposed curtailment plan, on 2010/06/09, 2010/06/10, and 2010/06/17 in Fig. 1, there are forecast errors, but as the total PV power generated and forecasted are lower than the residual demand no curtailment is applied. On the other hand, on 2010/06/12, the forecast of PV power indicated that no curtailment would be required but in fact, as the PV power generated was higher than what was forecasted, curtailment was in reality required.

### 2.3. Target Regions' Data

To calculate the regional forecasts of power from single PV systems, data from systems installed in Kanto and Kyushu areas were used. The sets of PV systems and their power generation data are part of the Field Test Project sponsored by the New Energy and Industrial Technology Development Organization, NEDO. For Kanto region the set included 62 PV systems and for Kyushu, 52 PV systems. Both sets of PV systems are fairly dispersed within the regions so that they provide a good estimate of the regional yield normalized by the corresponding PV rated power. The sets included only PV systems for which there were complete power generation data of the period studied. In spite of that, due to the availability of power demand data, for Kyushu only 9 months of curtailment plan was done, from April 2010 to December 2010.

In addition to the PV power and power demand data for each region, current PV power penetration scenarios by region and prefecture were necessary to perform the analysis. Kyushu region is already facing a high penetration scenario, with 4.5 GW of PV power installed and another 4.1 waiting for grid connection as of December of 2014 (METI, 2015b). Therefore, for Kyushu both values were used in the scenarios studied. To calculate the equivalent penetration of PV power in 2010, both the PV power penetration values were divided by the peak demand of power in December of 2014. These ratios then were applied to the peak demand of power in Kyushu in December of 2010. To compare Kanto and Kyushu, the equivalent PV power penetration scenario for 2010 power demand in Kanto was calculated using the same logic. Thus PV power penetration ratios of Kyushu were applied to the power demand of Kanto in 2010. The PV rated power for both regions in 2 scenarios are presented in Tab. 1.

**Tab. 1: PV rated power for Kanto and Kyushu and two penetration scenarios in 2010.**

| | Kanto Region | Kyushu Region |
|---|---|---|
| Scenario 1 | 14.93 GW | 4.55 GW |
| Scenario 2 | 28.44 GW | 8.64 GW |

Finally, to calculate the regional PV power measured and forecasted in each scenario it is necessary information about the ratio between the PV rated power of each prefecture and the total regional rated power ($\alpha$ in Eq. 2). These ratios are also based on the real PV power installed in Kanto and Kyushu as of December of 2014. The same ratios were used for the scenarios of 2010; their values are in Tab. 2.

**Tab. 2: Prefecture's PV rated power by the regional one (Kanto and Kyushu, December of 2014 [1]).**

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Kanto | Gumma | Tokyo | Chiba | Tochigi | Saitama | Ibaraki | Kanagawa |
| % of the regional value | 0.1380 | 0.0782 | 0.1895 | 0.1467 | 0.1573 | 0.198 | 0.0923 |
| Kyushu* | Saga | Oita | Miyasaki | Kumamoto | Fukuoka | Nagasaki | Kagoshima |
| | 0.078 | 0.1253 | 0.1228 | 0.1482 | 0.2542 | 0.093 | 0.1785 |

*Okinawa although it is geopolitically part of Kyushu, it is out of the power balacing area of Kyushu power utility.

## 3. Error and Evaluation Parameters

The effect of the accuracy of the regional forecasts of PV power were evaluated in two ways: from the point of view of the error of the amount curtailed, and from the point of view of the detection error of the hours when curtailment should be applied. The performance of the forecasts and their impact on curtailment from the first point of view is evaluated using the annual mean bias error, MBE, and the mean absolute error, MAE. Both errors of the curtailment planning were calculated using the forecasts of PV power and the required curtailment. The MAE and MBE are calculated in GW as showed in Eq. 3 and Eq. 4.

$$MAE = \frac{1}{n}\sum_{i=1}^{n}\left|Cr_{pln} - Cr_{req}\right|_i \qquad (3)$$

$$MBE = \frac{1}{n}\sum_{i=1}^{n} Cr_{pln} - Cr_{req_i} \qquad (3)$$

In Eq. 3 and Eq. 4 $Cr_{pln}$ , for each target hour *i*, is the amount of curtailment of PV power planned, in GW, and $Cr_{req}$ is the amount of curtailment that was actually required, in GW. Both errors were calculated with all the *n* hours of the target periods excluding night periods when forecasts were not made.

To analyze the impact of the forecasts' accuracy on curtailment plan from the point of view of required curtailment detection, a confusion matrix or contingency table as showed in Tab. 3 was used. From the confusion matrix several performance parameters can be inferred. However, in this study the main parameter used is the precision (also showed in Tab. 3) of the curtailment plan based on the forecasts: it shows in how many of all planned curtailment hours, curtailment was actually required. The precision in this case provides information of how reliable the detection of required curtailment hours is when day-ahead regional forecasts of PV power are used. The calculation of the precision variable was done using data of all target period excluding night hours (the period outside the interval from 5 h to 19 h).

**Tab. 3: Confusion matrix used to evaluate the PV power forecast based curtailment plan in Kyushu and Kanto.**

| | | Required Curtailment | | |
|---|---|---|---|---|
| | | YES | NO | |
| Planned Curtailment | YES | A | B | Precision = A/(A+B) |
| | NO | C | D | |

## 4. Results

As the analyses included 1 year of data of Kanto and 9 months of Kyushu, first, in subsection 4.1 we present the complete results for Kanto. In the subsection 4.2 the results for Kyushu are presented and compared with the results of the same period in Kanto.

### *4.1. Forecast based Curtailment for Kanto Area*

For Kanto, with a minimum annual power demand of 21.4 GW, two PV power penetration scenarios were studied, 14.93 GW and 28.44 GW. For each penetration scenario day-ahead regional forecasts of PV power were made and used to decide when curtailment should be applied. Figures 2(A) and 2(B) contain the matrix confusion resulting from the comparison between forecast based and required curtailment for both scenarios.

(A) 14.93 of PV Power

| | | Required | | |
|---|---|---|---|---|
| Curtailment | | yes | no | Precision |
| Forecast based | yes | 58 | 17 | 77.3% |
| | no | 13 | 5840 | |

(B) 28.44 of PV Power

| B | | Required | | |
|---|---|---|---|---|
| Curtailment | | yes | no | Precision |
| Forecast based | yes | 369 | 78 | 82.6% |
| | no | 66 | 5840 | |

**Fig. 2: Confusion matrix for the curtailment of PV power based on day-ahead regional forecasts for Kanto in two scenarios of PV power penetration 14.93 GW (A) and 28.44 GW (B) (values in hours).**

The results in Fig. 2 show that in Kanto with a scenario of 14.93 GW of PV power, during one year, only 71 hours curtailment of PV are required. Of those hours the forecast based curtailment plan was able to detect 58 hours, and issued false alarms in 17 hours, yielding a precision of 77.3%. For a scenario of 28.44 GW, curtailment PV power becomes more common, being required on 435 hours. In spite of the increase of the hours in which PV must be curtailed, and therefore increasing the probability that the curtailment planning will include more forecast errors, the precision of curtailment plan based on forecasts of PV did not decrease. In fact, the precision was better reaching 82.6%.

This behavior is explained by the fact that in a scenario where PV power curtailment is seldom such as the one of 14.93 GW of PV rated power, throughout the year curtailment will happen mostly in peak hours of PV power generation (11h to 13h for example). These are also the hours where is more likely that large forecast error occur simply because of the magnitude of PV power generated. As high forecast errors imply in misdetection of required curtailment hours, occurrence of required curtailment exactly in the hours when large forecast errors can occur will result in a low detection of required curtailment. Once PV rated power is increased and curtailment becomes frequent in off-peak hours, the detection of required curtailment is improved because these hours will contain in average lower forecast errors. Increasing even further the PV rated power will cause not only the required curtailment related hours to increase but also the amount curtailed. In this situation, the detection of required curtailment with forecast based plan should decrease again, as even small forecast errors will become cause for misdetection of required curtailment.

The results in Fig. 3(A) and 3(B) show the performance of the forecast based curtailment regarding the error in the amount curtailed. The errors were calculated using the required curtailment (based on a perfect forecast) as reference and, as in the case of Fig. 2, just for the hours within 5h and 19h.

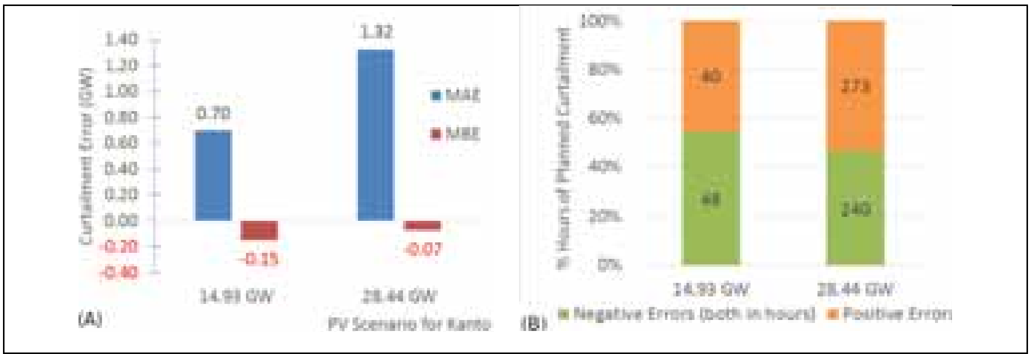



**Fig. 3: Curtailment error with day-ahead regional forecasts for Kanto in two scenarios of PV power penetration (A), and frequency of curtailment errors according to their sign (B).**

Both Fig. 3(A) and 3(B) show that increasing the number of hours when PV power is curtailed had a strong effect on the behavior of the error of the curtailment plan. When curtailment happens only in a few hours, it will happen mostly in peak hours. Forecast errors on these hours will be mainly related with underestimations of the real PV power generated. Thus, such errors will cause required curtailment not to be detected, or they will underestimate the amount of required curtailment. Once PV power penetration increases hours of required curtailment will be dispersed and both underestimations and overestimations of the real PV power generation will affect the curtailment plan. The general effect will be a balanced distribution of curtailment errors related with the accuracy of PV forecasts. This behavior is clear in the MBE of Fig. 3(A) and on the frequency of errors in Fig. 3(B).

Another issue that must be noted is regarding the importance of sign of the curtailment errors. If the error is positive more PV power was curtailed than necessary. The direct effect of this kind error is economic as PV systems owners may loose income of the selling of the amount curtailment in the case it is not compensated. Contrasting with that, if the curtailment error is negative, an insufficient amount of PV was curtailed. The result is excess of PV power on the grid, which may cause balancing and operation problems in the corresponding balancing area. Tab. 4 shows the mean positive and negative errors of the forecast based curtailment. In the same Tab. 4 the average amount of required curtailment in year is showed to provide a measure of the magnitude of the errors in relation to the amount usually curtailed.

**Tab. 4:Mean positive and negative curtailment errors and average required curtailment (per hour of curtailment) in Kanto, 2010.**

| PV rated Power | Mean Positive Curtailment Error (GW) | Mean Negative Curtailment Error (GW) | Annual Average Curtailment Required (GW) |
|---|---|---|---|
| 14.93 GW | 0.604 | -0.772 | 1.76 |
| 28.44 GW | 1.17 | -1.49 | 3.96 |

The results in Tab. 4, Fig. 2 and Fig. 3 show that for Kanto, 14.93 GW was a relatively low penetration scenario. Moreover, this scenario yielded more and higher negative curtailment errors than positive ones. Increasing the the PV rate power to 28.44 GW partially reversed such trend.

### *4.2. Forecast based Curtailment for Kyushu Area*

For Kyushu area, the 2 PV power penetration scenarios were 4.55 GW and 8.64 GW. The first scenario is already realized and the second one should be reached in near future as another 4.1 GW are waiting for grid connection. Considering that Kyushu's minimum annual demand is 7.1 GW, both scenarios are of high penetration of PV power. In these cases, the required number of curtailment hours with the forecast based curtailment plan, for 9 months of data, was 207 hours and 644 hours. Both numbers are considerably higher than the corresponding values for Kanto region. The precision, calculated as showed in Tab 3, of the forecast based curtailment plan compared with Kanto, and for the same period, is in Fig. 4.

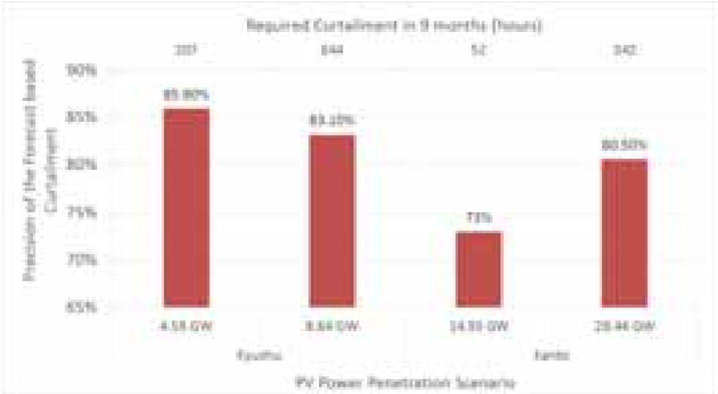
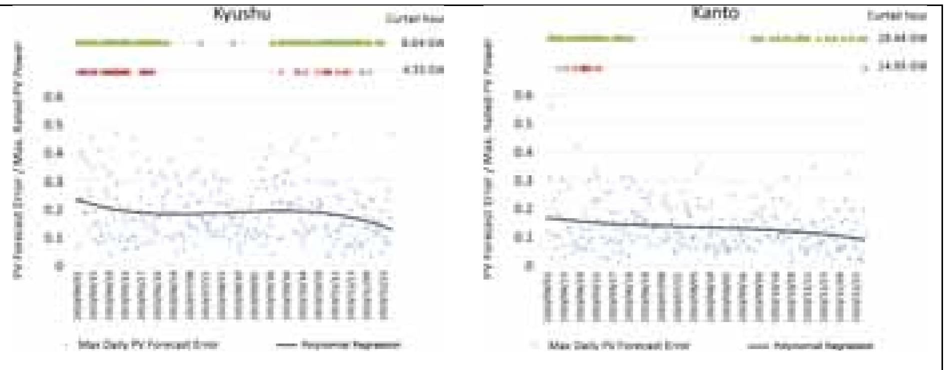



**Fig. 4: Precision of required curtailment detection with a forecast based curtailment for Kyushu and Kanto in two PV power penetration scenarios.**

Due to difference of power demand in both regions, Kyushu is clearly more sensitive to penetration of PV power than Kanto. In Fig. 4, the required curtailment hours in Kyushu for a PV rated power of 4.55 GW reached 207 hours. Doubling the PV rated power increased 3 times the required curtailment. For Kanto the situation was different, as even with 28.44 GW required curtailment hours were just slightly higher than half the number obtained with the highest PV power penetration scenario in Kyushu. This variation in the numbers of required curtailment hours affected signficantly the precision of the forecast based curtailment plan. This variation of the precision in detecting required curtailment hour is related with the PV forecast error magnitude and the period of the year when curtailment is required. To understand these relations, Fig. 5(A) and Fig. 5(B) show the normalized error of the PV power forecast throughout the year and the months and hours where curtailment was required.




(A) (B)

**Fig. 5:Occurrence of required curtailment and maximum daily value of the PV forecast errors throughout the year for Kyushu (A) and Kanto (B).**

Starting with Kyushu, the results show that even with 4.55 GW of PV power, curtailment is happening in most of the 9 months studied with the exception of the months of July to August, when it is summer in Japan and the power demand is high enough to use all PV power generation. Increasing further the PV rated power to 8.64 GW, causes further curtailment and some occurrences of it now in July and August. Looking at the behavior of forecast error of PV power, curtailment is happening in situations where the forecast error is high and when is low in an uniform fashion, regardless the scenario. Thus, the precision in detecting required curtailment presented low variation.

Focusing now in Kanto, with the lowest PV power scenario, curtailment is seldom and it is happening in April to May, where there is occurrence of high PV forecast errors. Increasing the requirement of curtailment to other months and hours, yield the use of forecasts with lower errors improving the precision of the forecast based curtailment from 73% to 80% as showed in Fig. 4.

The results in Fig. 6 show the variation of the effect that the forecast error of PV power has on curtailment planned using these forecasts.

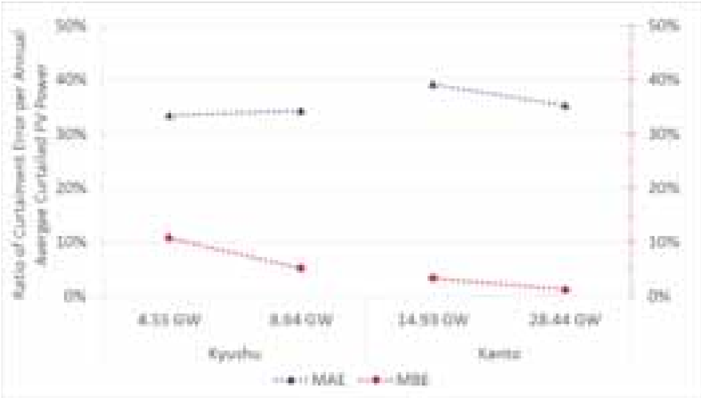



**Fig. 6: Effect of the forecast error of day-ahead regional PV forecasts on curtailment planning according to the region and PV penetration scenario.**

In this case a similar trend can be noted, increasing the amount of hour curtailed in Kanto caused the use of more forecasts with low errors. This yields lower errors on the execution of curtailment. For Kyushu, there was a slight increase of MAE, but the MBE was significantly reduced with the increase of PV power installed similarly to what happened in Kanto.

## 5. Conclusions

The objective of this study was to verify the impact that the accuracy of day-ahead regional forecasts of PV power has on a curtailment plan based on such forecasts. Two regions of Japan were analyzed, Kyushu where high penetration of PV power is already a reality, and Kanto, which has a high potential for roof-top installations of PV system. The impact of the accuracy of the forecasts was evaluated from the point of view of properly detecting the hours of required curtailment, and from the point of view of the error in the amount curtailed with a forecasts based curtailment plan.

The results showed that when required curtailment hours are few, the precision in detecting them was near to 70%. Increasing the number of hours of curtailment yielded the use of forecasts with a variety of errors, improving the precision parameter to near 80%. These results mean that in at least 70% of the time, a forecast based curtailment plan correctly determined the hours that curtailment is necessary. This means that, in the worst case, 30% of the curtailment hours will have to be located with intra-day forecasts or with improvements of day-ahead forecasts.

Regarding the effect of the forecast accuracy on the amount of PV power curtailed, the results show that annualy the curtailment error represented near to 35% of the average amount of PV power curtailed. The effect was strong as excessive curtailment yield financial losses to PV systems owners. However, considering the possibility of intra-day corrections on the curtailment plan, balacing area interconnections, storage solution and an optimized unit commitement plan, the effect of the forecast error can be significantly mitigated.

Finally, comparing both regions, it is clear that Kyushu, due to its low power demand, is already facing problems with high PV penetration. Even with 4.55 GW, curtailment was required in 207 hours of 9 months. In Kanto, the high demand of power (minimum annual value of 21 GW) yields a more confortable situation, as even with 14.93 GW of PV rated power only 70 hours in a year required curtailment. In spite of that, the required curtailment in this scenario happened exactly in months where high errors of PV forecasts occur, decreasing the forecasts usefulness. The obtention of these values provide important information about the efficacy of the forecast of PV power and about how they should be used. Moreover, they can be used to guide the use of forecasts and improvements of their accuracies. A limitation of this initial study is the use of base load and residual demand related assumptions to characterize when cutailment happens. In following studies, these simplifications will be removed, and the analysis of the forecast error on curtailment of PV power will be further advanced by considering optimal unit commitement planning.

## Acknowledgements

This work was supported by the New Energy and Industrial Development Organization, Japan, in the project Research and Development of PV Performance and Reliability Characterization Technologies.

## References

[1] METI, なっとく！再生可能エネルギー　各種データの公開.. [Online in Japanese], Available: http://www.fit.go.jp/statistics/public_sp.html, [Accessed: 26-May-2015].

[2] Lorenz, E., Heinemann, D., and Kurz, C., 2012, Local and regional photovoltaic power prediction for large scale grid integration: Assessment of a new algorithm for snow detection, Progress in Photovoltaics Research and Applications, 20, 6, 760–769.

[3] Diagne, H. M., David, M., Lauret, P., and Boland, J., 2012, Solar Irradiation Forecasting: State-of-the-Art and Proposition for Future Developments for Small-Scale Insular Grids, in Proceedings of the World Renewable Energy Forum, Denver, USA.

[4] Paulescu, M., Paulescu, E., Gravila, P., and Badescu, V., 2012, Weather Modeling and Forecasting of PV Systems Operation, Springer.

[5] Lauret, P., Voyant, C., Soubdhan, T., David, M., and Poggi, P., 2015, A benchmarking of machine learning techniques for solar radiation forecasting in an insular context, Solar Energy, 112, 446–457.

[6] Lew, D., Bird, L., Milligan, M., Speer, B., Wang, X., Carlini, E. M., Estanqueiro, A., Flynn, D., Gomez-Lazaro, E., and Menemenlis, N., 2013. Wind and solar curtailment, in International Workshop on Large-Scale Integration of Wind Power Into Power Systems, 1–9.

[7] Rogers, J., Fink, S., and Porter, K., 2010, Examples of wind energy curtailment practices, NREL Subcontract Rep. NRELSR-550, 48737.

[8] Mc Garrigle, E. V., Deane, J. P., and Leahy, P. G., 2013, How much wind energy will be curtailed on the 2020 Irish power system?, Renew. Energy, 55, 544–553.

[9] Schölkopf, B., Bartlett, P., Smola, A., and Williamson, R., 1998, Support Vector Regression with Automatic Accuracy Control, Proc. ICANN98 Perspect. Neural Comput., pp. 111–116.

[10] Chang, C.-C., and Lin, C.-J., 2001, LIBSVM : a library for support vector machines.

[11] Saito, K., Fujita, T., Yamada, Y., Ishida, J., Kumagai, Y., Aranami, K., Ohmori, S., Nagasawa, R., Kumagai, S., Muroi, C., Kato, T., Eito, H., and Yamazaki, Y., 2006, The Operational JMA Nonhydrostatic Mesoscale Model, Monthly Weather Review, 134, 4, 1266–1298.

[12] Fonseca, Jr, J. G. S., Oozeki, T., Ohtake, H., Takashima, T., and Ogimoto, K., 2015, Regional forecasts of photovoltaic power generation according to different data availability scenarios: a study of four methods, Progress in Photovoltaics Research and Applications, 23, 10, 1203–1218.

[13] METI, 総合資源エネルギー調査会 省エネルギー・新エネルギー分科会 新エネルギー小委員会 系統ワーキンググループ（第 3 回）‐配布資料（METI/経済産業省）, [Online in Japanese], Available: http://www.meti.go.jp/committee/sougouenergy/shoene_shinene/shin_ene/keitou_wg/003_haifu.html, [Accessed: 28-Sep-2015].