# DEVELOPMENT OF ELECTRICITY DEMAND ESTIMATION MODEL IN DISTRIBUTION NETWORK BASED ON GRID-SQUARE STATISTICS

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## *ABSTRACT*

*In order to realize effective asset management of a number of distribution networks, utilization status of individual network should be evaluated by taking into account not only the current situation but also the future situation. As a first step for this purpose, this study proposes a model to estimate the time-series of electricity demand for a year in arbitrary distribution network and examines the usefulness of the proposed model. The model is based on the publically available statistics. The aggregated electricity demand in each distribution network is calculated by determining the service territory based on map information. This study evaluates the accuracy of estimated model by comparing the estimated demand with observed demand for typical distribution networks. As an example of application of proposed model, the residual load characteristics in the case of high penetration of photovoltaic power generation and increased electrification ratio of energy demand is evaluated for various distribution networks in the Chubu region, Japan.*

## INTRODUCTION

In order to realize effective asset management of a number of distribution networks, utilization status of individual network should be evaluated by taking into account not only the current status but also the future status. Because huge amount of demand data is getting available by using a smart meter, such a data will be useful for estimating the current status of electricity demand characteristics. However, it seems difficult to estimate overall demand characteristics in a distribution network by using the smart meter information only. Although the past record of current sensor information at the sending-end of substation would be useful, records may not be available in some distribution networks. Besides, in order to estimate the future characteristics of electricity demand in consideration of the future high penetration of renewable power generations, electric vehicles, storage battery, etc., the modelling of spatial distribution of electricity demand using publically available statistical data is needed in addition to the past records.

Therefore, this study proposes an electricity demand estimation model in distribution network based on a Grid-square Statics of national census provided by Statistics Bureau, Ministry of Internal Affairs and Communications and other publically available data regarding such as future population growth, purpose of land use, etc. The proposed model consists of two sub-models. The first one estimates hourly value of electricity demand in each 500m x 500m area (hereinafter grid square) for a year based on Grid-square statistics provided by Statistics Bureau of Japan and some other statistics. The second one estimates a service territory of each distribution network in a whole electric power system service area based on the map information, and calculates the aggregated electricity demand in each territory.

This paper explains the calculation procedures of the model and examines the usefulness of the model. Then, this paper demonstrates the application of proposed model to evaluate the residual load characteristics in the case of high penetration of PV and increased electrification ratio in energy demand.

## CALCULATION PROCEDURE

### Electricity Demand in 500m Square Area [1]

The proposed model in this study utilizes a Grid-square statistics of national census, which provides various statistics for each grid square. First, the proposed model estimates the total floor space of residences and commercial buildings in each grid square. The data on the number of household dwelling in detached house and apartment house of 6 types of floor space (0-29m$^2$, 30-49m$^2$, 50-69m$^2$, 70-99m$^2$, 100-149m$^2$, 150m$^2$ < ) are utilized to calculate the total floor space of residences in each grid square. The data on employees for 7 business categories (office, office-OA, store, hotel, hospital, school, foods) are utilized to assume the total floor space of commercial buildings.

Then, by multiplying the total floor space with the unit

*Table 1 Assumption on current electricity share*

| | Space heating | Space cooling | Hot water | Power |
|---|---|---|---|---|
| Detachd house | 0.2 | 1.0 | 0.3 | 1.0 |
| Apartment | 0.4 | 1.0 | 0 | 1.0 |
| School/hospital | 0.3 | 0.7 | 0 | 1.0 |
| Others | 0.3 | 0.7 | 0.5 | 1.0 |

*Table 2 Assumption on current COP*

| | Space heating | Space cooling | Hot water | Power |
|---|---|---|---|---|
| Detachd house | 2.0 | 2.5 | 2.0 | 1.0 |
| Apartment | 2.0 | 2.5 | 1.0 | 1.0 |
| School/hospital | 2.0 | 2.5 | 2.0 | 1.0 |
| Others | 2.0 | 2.5 | 2.0 | 1.0 |

value in MJ/m$^2$ of annual energy load and ratio of month and time in four energy usage purposes, i.e. space-heating, space-cooling, lighting, and power, the model estimates the hourly value of aggregated energy load $E_k(h)$ ($h$ = 1 to 8760) of usage purpose $k$. The data of unit value and ratio is investigated and collected through the literature survey. The time-series $E_k(h)$ of hot-water met by electricity is modified from the original data in consideration that the hot-water supply is operated between 11 pm – 7 am when the discount electricity rate is applied.

Finally, by using the following equation, the model estimates the hourly value of aggregated electricity demand $D(h)$ in each grid square.

$$D(h) = \sum E_k(h) \times s_k \,/\, COP_k \quad (1)$$

where $s_k$ is electricity share in each energy load, $COP_k$ is coefficient of performance of appliance of each energy load. Table 1 and 2 shows the assumption on the current $s_k$ and $COP_k$ of each consumer type in this study. $D(h)$ corresponds to the aggregated electricity demand fed by the 6.6 kV class distribution network.

In order to take into account the temperature effect on the electricity demand, the model assumes 3 % increase in the unit value by 1 degree increase in hourly average ambient temperature in the season when the ambient temperature is high. When the ambient temperature is low, 1.5 % increase is assumed by 1 degree in ambient temperature. In order to take into account the different temperature effect by the difference in location, this model utilizes the temperature data of AMeDAS (Automated Meteorological Data Acquisition System) for a year at the nearest point of each mesh provided by Japan Meteorological Agency (JMA).

The proposed model is developed to estimate the electricity demand in residential and commercial sectors in an arbitrary distribution network as described above. In order to evaluate the estimation accuracy compared with the observed real demand including the electricity demand in other sectors, the electricity demand in other sectors is estimated in the following simple way. The electricity demand in industry sector in each grid square is estimated by using the total electricity demand data in industry sector in a whole electric power system and the grid square data on land usage. The remaining electricity demand is estimated based on the total value in a whole system and the spatial distribution of detached house.

## Aggregated Electricity Demand in Distribution Network Territory [2]

As a preparation step, the data sheet of location distribution substation is developed and the substation number $j$ is given in ascending order of the electricity demand estimated by using the above described model in grid square include substation and surrounding eight grid squares. In this study, the data sheet is developed based on the satellite image, etc. so that the model can be developed based on the publically available data set only.

The electricity supply territory of each substation is determined in the following procedure.
Step-1. In ascending order of the substation number $j$, grid squares are added to territory based on the following rule. First, the North adjacent grid square of substation location is added. If the candidate grid square is already included in other territory, the searching process skips to the next substation territory. In the next round, the North-west adjacent grid square is added. In this way, by searching in the counter-clockwise rotation, adjacent grid square is sequentially added to territory one by one in ascending order of substation number.
Step-2. Repeat Step-1 until to meet either following conditions: i) the number of the grid square added to territory reaches to the maximum (440 areas), ii) all the grid squares surrounding territory is already included in other neighboring territories.

The territory of almost all substation is determined in the above procedure. In a rural area with low demand density, however, some grid squares slightly apart from the main territory may not be added to territory. Therefore, following additional calculation is proceeded.
Step-3. Remaining grid squares are added to territory if they contain customers and is locate next to the determined territory by previous steps. Repeat this step until all such grid squares are included in a territory somewhere.
Step-4. Still remaining grid squares are added to territory if they contain customers and locate only one grid square away from the determined territory. Repeat this step until all such grid squares are included in a territory somewhere.

As shown below, the proposed model is applied to determine the service territory of calculates the electricity demand characteristics in each distribution network territory. The estimated annual maximum electricity demand in each territory distributes around 20 – 40 MW, which is the typical size of distribution substation in Japan. Therefore, the proposed method seems to work well to determine the territory of distribution network based on the publically available data set.

### PV Power Output in Distribution Network Territory

In the proposed model, future installed capapcity of PV in each grid square is estimated in the following procedure. As for the larger scale PV than 20 kW mainly for commercial use, the capacity and location of approved PV in Feed-in-Tarif (FIT) is publically available. Based on this information, the proposed model calculates $w^C{}_j$, i.e. the ratio of approved capacity in distribution network $j$ to the total approved capacity. Then, the model calculates the future capacity in distribution network $j$ by multiplying the assumed future total capacity $C^C$ with $w^C{}_j$.

As for the smaller scale PV than 20 kW mainly for residential use, the approved capacity in each municipality only is publically available. Therefore, at first, the model calculates the future capacity in municipality $m$ by multiplying the assumed future total capacity $C^R$ with the ratio $w_{Rm}$, i.e. the currently approved capacity in the municipality $m$ to the total approved capacity. Then, the model calculates the future capacity in grid square $i$ by using $n_{im}$, i.e. the ratio of the number of the detached house in the grid square $i$ to the number of the detached house in the municipality $m$. Finally, by summing up the capacity in grid square included in the same territory, the model calculates the future capacity of smaller scale PV in each distribution network.

The time series data of PV power output is estimated by multiplying the ground observation of irradiance at the nearest meteorological observation point of JMA with the estimated capacity.

## CALCULATION RESULTS

This study applies the proposed model to estimate the electricity demand in distribution networks in a whole power system in the Chubu region, Japan. First, in order to evaluate the performance of proposed model, the electricity demand is estimated for three distribution network territories with a typical characteristics depending on location, i.e. residential area, residences and factories complex area, and rural area.

Figure 1, 2 and 3 shows the time-series of monthly average value of electricity demand on weekdays in January, May, and August, respectively. As a comparison, the measured value in the same distribution network territory is also shown with black solid line. The measured value is the residual load subtracting PV power output from the actual electricity demand. Therefore, the electricity demand is calculated by adding the PV power output installed in each territory estimated by using the above described method. The time-series characteristics of estimated electricity demand is similar to the observed one independently of area and month.

Figure 4 shows the estimation accuracy of hourly average demand on weekday in each month. The mean absolute error (MAE) relative to the total electicity demand varies in 6% - 15% depending on month in every area. Because the annual trend of MAE is not so different among three areas, the time-series of electricity demand seems well estimated by using the proposed model as a first order analysis. For further improvement of proposed model regarding the midnight electricity demand in January, however, the recent penetration of heat electric pump water heaters, the change in lifestyle, etc., should be taken into account.

The performance of proposed model is also evaluated with the aggregated electricity demand of all 726 distribution networks in the Chubu region calculated by using the proposed model. The estimated value is about 90 TWh, while the observation in the last several years past is also around 90 TWh. As a result, the performance of proposed model seems acceptable level as a first order analysis regarding future characteristics of electricity demand in various distribution networks.

## EVALUATION OF FUTURE SITUATION

### Assumption on Future Senario

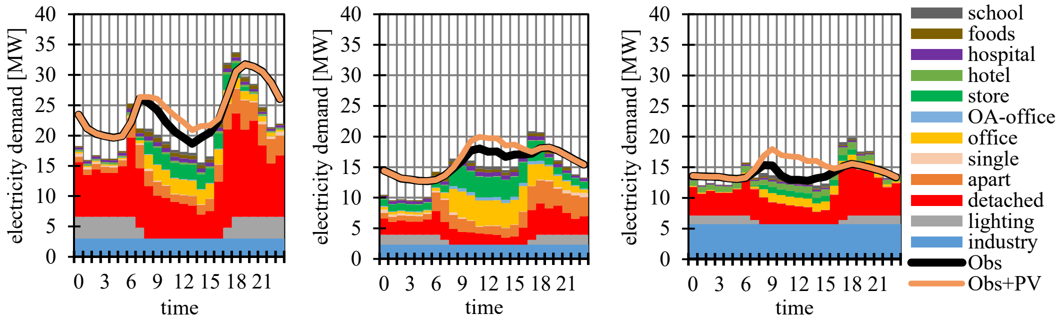
The proposed model can be used to analyse future electricity demand characteristics of each distribution network by assuming the scenario on future penetration of photovoltaic power generations, electric vehicles, etc. Such the analysis would be useful for the asset management of distribution networks toward the future.

As an example of such the analysis, this study assumes the following scenarios regarding PV penetration and electrification of energy demand. As for the PV capacity, three scenarios on the total capacity in the Chubu region is assumed, i.e. 10 GW, 16 GW, and 24 GW, which corresponds to the total capacity of 64 GW, 100 GW, and 150 GW in Japan.

As for the electricity share in energy demand in residential and commercial sectors, two scenarios is assumed, i.e. the same share with the current as assumed in Table 2 (E-share scenario-1) and 100% share for all four kinds of energy demand (E-share scenario-2). Assuming that the efficiency of appliance can be improved according to the increase in the share of electricity, the future COP of appliance of each energy load as shown in Table 3.

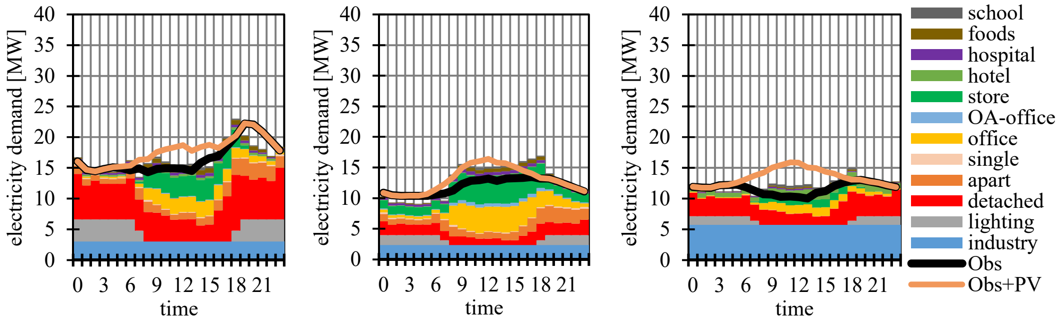
### Results

As an example of future characteristics of residual electricity load, which is calculated by substituting the PV power output from the electricity demand, annual average of reverse power from each distribution network is calculated. Figure 5 shows the result for Aichi Prefecture



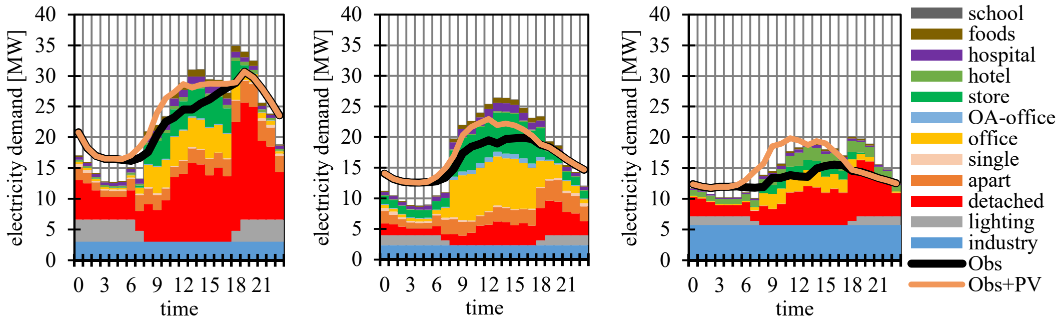

*(a) residential area* *(b) complex area* *(c) rural area*

*Figure 1. Monthly average of estimated electricity demand on weekday in January*




*(a) residential area* *(b) complex area* *(c) rural area*

*Figure 2. Monthly average of estimated electricity demand on weekday in May*




*(a) residential area* *(b) complex area* *(c) rural area*

*Figure 3. Monthly average of estimated electricity demand on weekday in August*

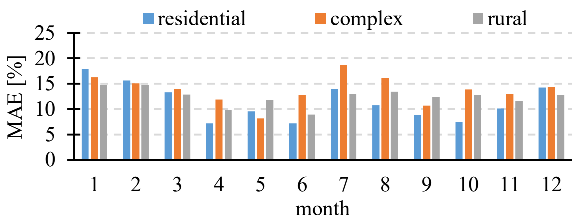


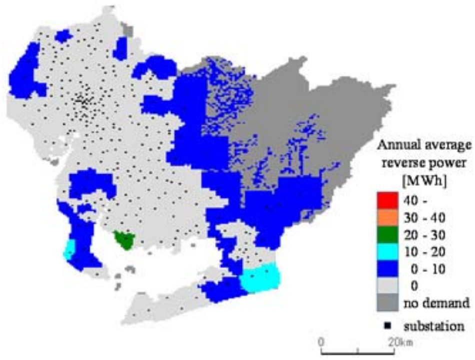

*Figure 4. Mean absolute error of estimated electricity demand on weekdays using proposed model in three distribution networks*

in the map, in which 298 distribution networks are included. The population centre is located in left side in the map, in which no reverse power flow occurs in all results.

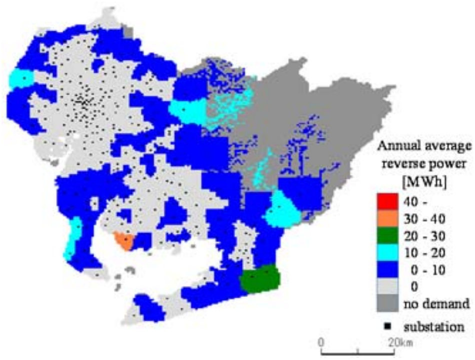
In E-share scenario 1 with PV capacity of 10 GW in the Chubu region, the reverse power is large in rural areas surrounding the population centre as shown in Figure 5 (a). When PV capacity is increased to 16 GW, the reverse power occurs in some distribution networks closer to population centre as shown in Figure 5 (b). When the electricity share in residential and commercial sectors is increased to 100%, however, the reverse power flow is cancelled in some distribution networks closer to city centre as shown in Figure 5 (c). On the other hand, the reverse power flow in rural area still occurs because the increase in electricity demand due to the increase in share is not so significant due to the low demand density.

*Table 3 Assumption on future COP*

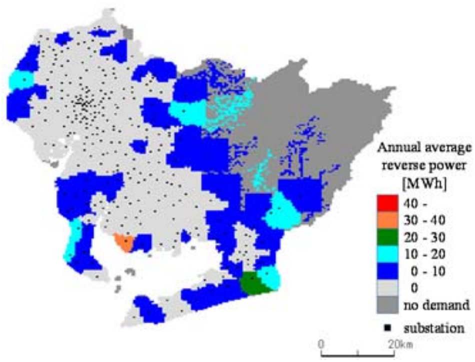
| | Space heating | Space cooling | Hot water | Power |
|---|---|---|---|---|
| Detachd house | 3.5 | 3.0 | 3.0 | 1.0 |
| Apartment | 3.5 | 3.0 | 3.0 | 1.0 |
| School/hospital | 3.5 | 3.0 | 3.0 | 1.0 |
| Others | 3.5 | 3.0 | 3.0 | 1.0 |




*(a) E-share scenario-1 (PV: 10 GW)*



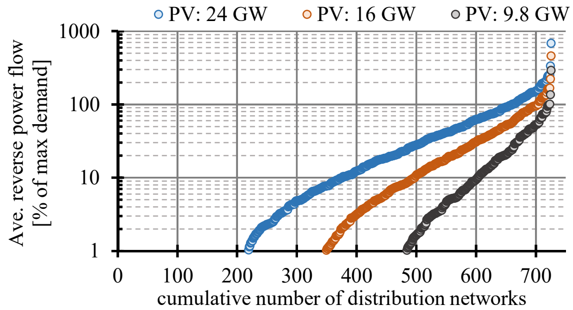

*(b) E-share scenario-1 (PV: 16 GW)*



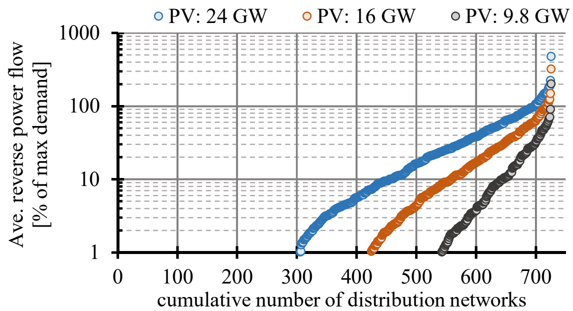

*(c) E-share scenario-2 (PV: 24 GW)*

*Figure 5. Annual average of reverse power from each distribution network in Aichi Prefecture, Japan*

Figure 6 shows the annual average of reverse power from 726 distribution networks in the Chubu region in ascending order. The annual average of reverse power is shown in the relative value to the annual maximum value in each distribution network. In E-share scenario-1 shown in Figure 6 (a), no reverse power flow occurs in 470 distribution networks in the case of 10 GW PV capacity, while it decreases to 335 and 200 networks with the increase of PV capacity to 16 GW and 24 GW, respectively. As shown in Figure 6 (b), if the electricity share in residential and commercial sector increases to 100%, the number of distribution networks with no reverse power flow increases to by about 100 networks. Such a characteristics of future electricity demand or residual load can be examined by using the proposed model.




*(a) E-share scenario-1*




*(b) E-share secenario-2*

*Figure 6. Annual average of reverse power from each distribution network in Chubu region, Japan*

## CONCLUSION

In order to assess the characteristics of electricity demand or residual load by high penetration of PV generators, this study proposed a model to estimate hourly electricity demand for a year in arbitrary distribution network based on publically available data. The estimation accuracy seems acceptable level in three distribution network with different characteristics of electricity demand for a first order analysis. As an example of application of proposed model, residual load characteristics in the case with high penetration of PV and increased share of electricity was demonstrated.

## REFERENCES

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[2] J. Kitayama, M. Kurimoto, T. Kato, Y. Suzuoki, 2015, "Aggregated Photovoltaic Power Output Fluctuation Characteristics in Power System Considering Power supply Limitation in Each Power Distribution Area", Proc. of the 31st Conf. on Energy, Economy, and Environment, No.3-3, 51-5 6 (In Japanese)