Study on Planning of Smart GRID using Landscape Ecology

Sunglim Lee, Susumu Fujii, Koji Okamura

Abstract**—**Smart grid is a new approach for electric power grid that uses information and communications technology to control the electric power grid. Smart grid provides real-time control of the electric power grid, controlling the direction of power flow or time of the flow. Control devices are installed on the power lines of the electric power grid to implement smart grid. The number of the control devices should be determined, in relation with the area one control device covers and the cost associated with the control devices. One approach to determine the number of the control devices is to use the data on the surplus power generated by home solar generators. In current implementations, the surplus power is sent all the way to the power plant, which may cause power loss. To reduce the power loss, the surplus power may be sent to a control device and sent to where the power is needed from the control device. Under assumption that the control devices are installed on a lattice of equal size squares, our goal is to figure out the optimal spacing between the control devices, where the power sharing area (the area covered by one control device) is kept small to avoid power loss, and at the same time the power sharing area is big enough to have no surplus power wasted. To achieve this goal, a simulation using landscape ecology method is conducted on a sample area. First an aerial photograph of the land of interest is turned into a mosaic map where each area is colored according to the ratio of the amount of power production to the amount of power consumption in the area. The amount of power consumption is estimated according to the characteristics of the buildings in the area. The power production is calculated by the sum of the area of the roofs shown in the aerial photograph and assuming that solar panels are installed on all the roofs. The mosaic map is colored in three colors, each color representing producer, consumer, and neither. We started with a mosaic map with 100 m grid size, and the grid size is grown until there is no red grid. One control device is installed on each grid, so that the grid is the area which the control device covers. As the result of this simulation we got 350m as the optimal spacing between the control devices that makes effective use of the surplus power for the sample area.

Keywords**—**Landscape ecology, IT, smart grid, aerial photograph, simulation.

I. Introduction

THIS chapter is about the background and purpose of the research and structure of this paper.

A. The Background and Purpose of the Research

Traditionally electric power supply was a one-way process from the power plant to the consumer. Recent developments and deployments on solar generator for home made the power transfer a two-way process, where the surplus power generated at home is sent back to the power plant. Considerable power loss occurs when the surplus power is sent to the power plant and then sent to another consumer who needs the power.

The power loss above becomes a problem when the output of the solar panel is considerably bigger than the consumption of the house where the solar panel is installed. The surplus power may be stored at the house or sent to buildings nearby. A control device should be installed on the power cable to interchange power among neighboring buildings. More control devices may enable more complex sharing of electricity, but also results in increased cost for the control devices. On the other hand, less control devices will result in larger area covered by each control device, which results in more power loss when transferring electricity inside the area. This paper conducts a simulation using landscape ecology to find out the optimal spacing between the control units installed in a lattice, keeping the surplus power inside the area covered by each control unit zero.

B. Structure of This Paper

The second chapter explains smart grid as an enhanced power supply system and projects some problems on them [1]-[3]. The third chapter explains landscape ecology which visualizes the power status using smart grid [4], [5] and [10]. The fourth chapter presents a simulation results as implementation of above idea. The fifth chapter summarizes this paper and introduces further questions.

II. Current Issue and Smart Grid

This chapter explains current issue and smart grid as an enhanced power supply system to address the issue.

A. Smart Grid to Address Current Issue

Current power grid collects the surplus power from home to the power plant and sends to where needed. To reduce the power loss during the transmissions, it is preferable to directly send the surplus power to the neighboring buildings. Smart grid technology may be used for controlling the power to be sent to the neighboring buildings.

Smart grid can be defined as an electric power grid enhanced with information technology, which adds communication and control to the electricity grid. Historically the study of smart grid started in United States to overcome weak electricity distribution network and stabilize power supply at low cost using computers.

Some applications of smart grid are as follows:

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- Smart meters are installed in homes for real time accounting of electricity use and billing.
- HEMS (home energy management system) can be used to remote control home appliances.
- Automatically adjusting power used by home appliances according to power available.
- Automatic scheduling of rechargeable batteries or EV (electric vehicle).
- Storing the electricity generated by solar or wind power systems, which have unstable power outputs.

In Japan, stable power supply was already established over the country, so that smart grid did not receive much attention in the beginning. However with the development of solar and wind power generators smart grid started to receive attention for controlling complex electric power grid.

A. Issue ofSurplus Power fromSolar Power Generation

Solar or wind power generators have unstable outputs as they are affected by environments such as weather, and consumerelectricity need to have fixed voltage and frequency, so solar or wind power generators need to regulate their outputs. The surplus of power may occur where the solar or wind power generators generate more than regular outputs due to the weather, and currently this surplus power may be abandoned even when a battery is used to store some power.

III. Making Effective Use of the Surplus Power and Landscape Ecology

This chapter proposes a way to effectively use the surplus power and explains landscape ecology.

A. Effective Use of the Surplus Power by Power Sharing

Currently the surplus power from a houseis once sent to the power plant and then distributed. If the area covered by one power plant is large, there is a big loss of power during such transfers. Smart grid may control the route of power transfer, so that the surplus power is sent directly from home to where needed, without going through the power plant, thus reducing the power loss. Planning of such smart grid depends on the amount of power production and consumption from the houses or buildings. Landscape ecology is introduced to analyze real world land for planning the smart grid.

B. Visualizing the Power Status Using Landscape Ecology

Landscape ecology provides a way to make use of aerial photograph forplanning the smart grid.

Landscape ecology is originally used to analyze the ecology of animals and plants in relation over a certain scope of the landscape. It is highly interdisciplinary science involving geography, ecology and more. A characteristic of the landscape ecology is that it consists of spatially heterogeneous areas, in contrast to the alternative approach using statistics assuming the space to be homogeneous. In landscape ecology, an aerial photograph is analyzed, a mathematical model is built, and the model is used to understand the real world. A mosaic map is used to analyze the aerial photograph. The aerial photograph is segmented into lattice and each block of the lattice is studied to catch the property of the block. The blocks are classified and colored according to the property. From this work the ecology of each area is clarified, and used for further activities such as nature protection or ecology control.

This mosaic map has three important concepts as follows:

- Patch
  Patch is a landscape element which has the specific property of interest. A patch has shape of a point or a sphere.
- Corridor
  Corridor is a landscape element which has shape of a line or a band. A corridor acts as connection or discontinuation between patches.
- Matrix
  Matrix is the area surrounding patches or corridors, which is neither a patch nor a corridor by itself.

Applying above concepts to electric power grid, the buildings which consume or produce electricity are patches, the power transmission network such as power lines are corridors, and all the surrounding landscape shown in the map are matrices.

IV. Planning Smart Grid Using Landscape Ecology

In this chapter we provide a method for planning a smart grid for effective power usage using the mosaic map of landscape ecology.

A. Estimating the Amount of Power Generation Using Aerial Photographs

We calculated the amount of power generated assuming that all the buildings are equipped with solar panels. When 1 m^2 solar panel is installed facing south and tilt 30°, approximately 100kWh of power is produced per year. Based on this figure, we estimate the amount of power production based on the area and direction of the roofs on the buildings. First we measure the area where solar panels can be installed from an aerial photograph. The measuring of area is done manually using tools in Google Maps. However because aerial photographs only show pictures of the landscape taken from directly above, it is impossible to figure out at what angle the roofs of the buildings are tilt. We used the statistic that average tilting of the roofs on the buildings in Japan is 30°, and made assumption based on this figure. In case that the tilting angle of a roof is obvious from the aerial photograph, such as when the angle is 0°, we used that figure.

Given the installation angle of solar panel θ, the actual area of solar panel is given by the following formula:

$$\text{area of solar panel } S[m2] = \frac{\text{area shown by aerial photograph}[m2]}{\cos\theta}$$

The amount of sunlight a solar panel may get also depends on the direction the solar panel is facing. Given that the amount of sunlight received when a solar panel is facing the south is 100, the amounts of sunlight received when the solar panel is facing other directions are as shown in the Fig 1 [6]-[8].

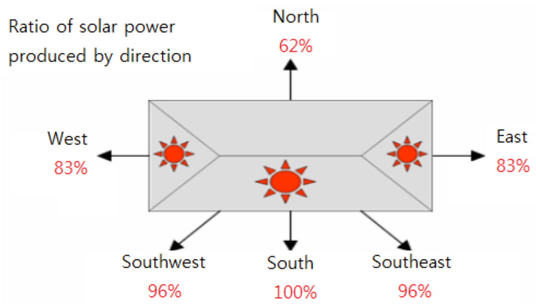

Fig. 1 Ratio of solar power production by direction

A solar panel may get about 62% sunlight when facing the north, and the surface of the polar panel facing the north is tilt away from the sunlight which makes the efficiency of the solar panel even worse. So basically we do not install solar panels on the roofs facing the north. The resulting amount of power generation is given by the following formula:

$$\text{Power generation per year}\left[{}^{kWh}\!/_{\text{year}}\right] = 100\left[{}^{kWh}\!/_{\text{year}}\right] \times \text{Area of solar panel } S[m2] \times \text{Ratio of solar power}$$

B. Coloring the Mosaic Map According to Productionand Consumption of Power

We segment the aerial photograph into a mosaic form, and color the mosaic map according to the production and consumption of the power. The following formula is used to decide the color:

$$\frac{\text{power generation per year } [kWh\ /\ \text{year}]}{\text{power consumption per year } [kWh\ /\ \text{year}]} \times 100$$

We used year 2010 census data to getaverage power consumption per year per household in Table I[9].

TABLE I
STATISTICS ON NUMBER OF PEOPLE PER HOUSEHOLD

Number of people in a household	Single house	Multi-house building
1 person	2,700	2,200
2 person	4,110	3,310
3 person	4,970	3,850
4 person and more	6,070	4,690

The resulting estimated averagepower consumption per household from above data is as follows:

- Single house: 4,268 kWh
- Multi- house building: 3,355 kWh

We used estimations below for buildings other than households.

- Stores such as super markets or convenience stores: 100,000 kWh
- Factories: 10,000 kWh per 100 m2

The ratio of the amount of power generation to the amount of power consumption is calculated from the above results.

Three colors (red, yellow, blue) are used to classify a grid as producer, consumer or neither as show in Table II, with said ratio used as thresholds for the classification. Two more colors are used to denote that there is no building in the grid, specifically grey for plains such as grounds or parking yards, and green for green field such as forest or farmland.

TABLE II
CLASSIFICATION OF THE GRID

Power generation/ consumption ratio	Color	In case there is no building in the grid	
110% ~	(red)	Kind of land	Color
90% ~ 110%	(blue)	Bare land with no building	(grey)
0% ~ 90%	(yellow)	Green field such as forest or farmland	(green)

C. Analysis and Consideration

We used the landscape of part of Umi City, Fukuoka Prefecture, Japan for the simulation. Shown in Fig. 2 is the aerial photograph of the area. Some part on north-west is excluded, because the power line there belongs to some other network and is not connected to the rest of the area.

Fig. 2 Original map of Umi City, Fukuoka Pref., Japan

We segmented the above area by squares each having edge length of 100m, 150m, and 200m. The amount of power production and consumption are calculated for each square, and the ratio of them is used to decide a color for that square.

Detailed description of the calculation is shown below. We manually measured the area of the roof using the area measurement tool in Google Maps, except part of the roof facing the north, as show in Fig. 3.

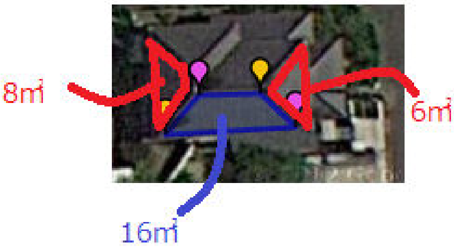

Fig. 3 Measurement of the area of the roof

The installation angle of the solar panel is assumed to be tilt at 30°, except for the roof which is obviously not tilt (0°) from the aerial photograph. Given that the amount of sunlight received by a solar panel facing the south is 100, the amount of sunlight received are assumed to be 96 and 83 for solar panels facing south-east, south-west and east, west, respectively. The above example will lend the following results:

$$100 \times \left(\frac{16}{\cos 30} \times \frac{100}{100} + \frac{(8+6)}{\cos 30} \times \frac{83}{100}\right) \approx 3186$$

We repeated this process for all the buildings to calculate the amount of power generated.

The example in Fig. 4 shows a magnified map corresponding to one square in the grid, where each building is marked with the amount of power generated. If a building lies on the boundary of two grids, the building is considered to belong to the grid where the larger area of the building belongs to.

Fig. 4 Magnified map corresponding to one square in the grid

The sum of amount of power generated inside this square in the grid is 146,174 kWh per year, according to our calculations. Using 4,268 kWh per year as the amount of consumption per one household according to our assumptions, the power generation/consumption ratio is calculated as follows:

$$\frac{146{,}174}{4{,}268 * 47} \times 100 \approx 72.9\,\%$$

Therefore we color this square in the grid yellow. Fig. 5 showsthe result of this calculation repeated for all grids.

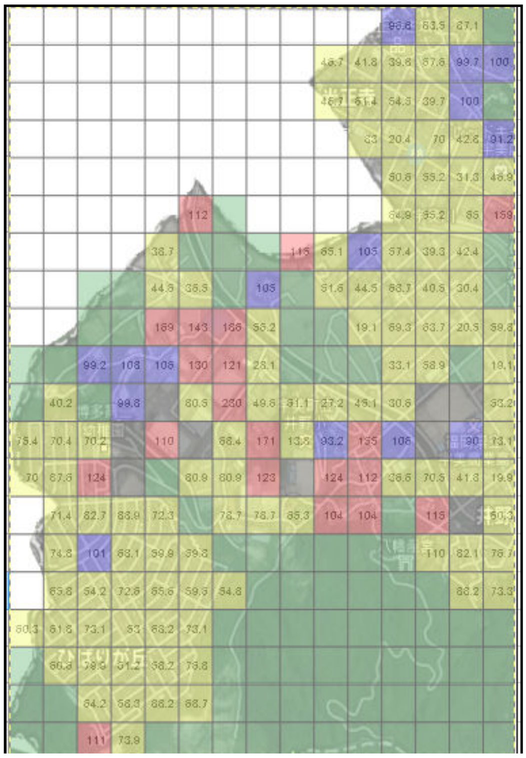

Fig. 5 100 m square mosaic map

The parts colored in red have power surplus, so that they can supply power to the surroundings. The following is the algorithm for distributing the surplus power.

1. If a grid is red, try to make cluster with another grid which has the lowest ratio among the grids which are located up, down, right or left to the red grid and adjacent to the red grid. If the clustering occurs, the ratio is calculated again.
2. If there is no adjacent grid to unite, the red grid will unite with most closely located grid, and the ratio is calculated again.
3. If the grid color changes from red to blue or yellow, the algorithm stops.
4. If the grid color is still red, go back to 1.

The result of running this algorithm is shown in Fig. 6, with the black line showing where the clustering took place.

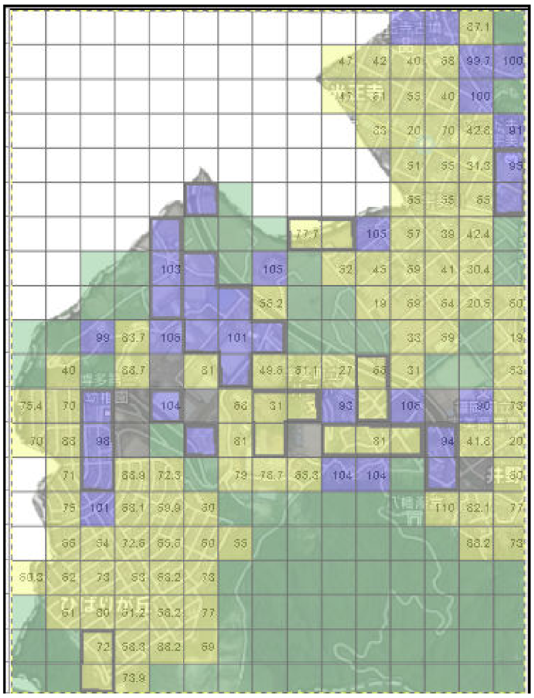

Fig. 6 100 m square mosaic map after clustering

After total of 21 clustering, there is no red grid left, and all the surplus power is used effectively. The biggest block after the clustering includes 7 grids, which accounts to an area of 70,000 m^2.The results of the same process for 150m square mosaic map are shown in Figs.7 and 8.

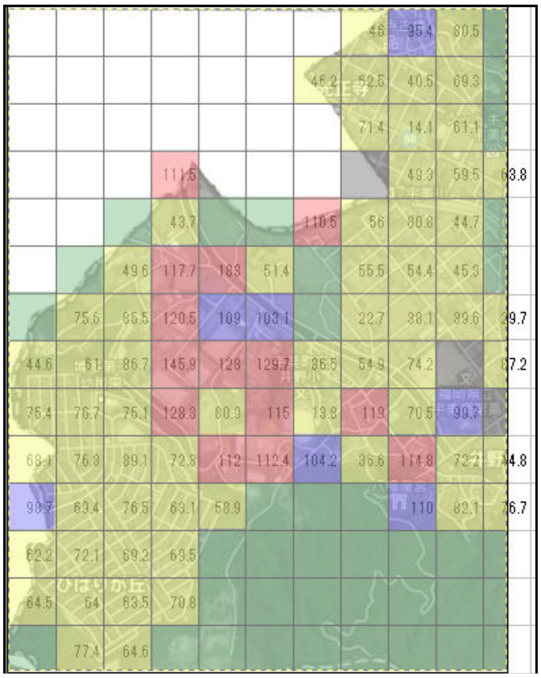

Fig. 7 150m square mosaic map

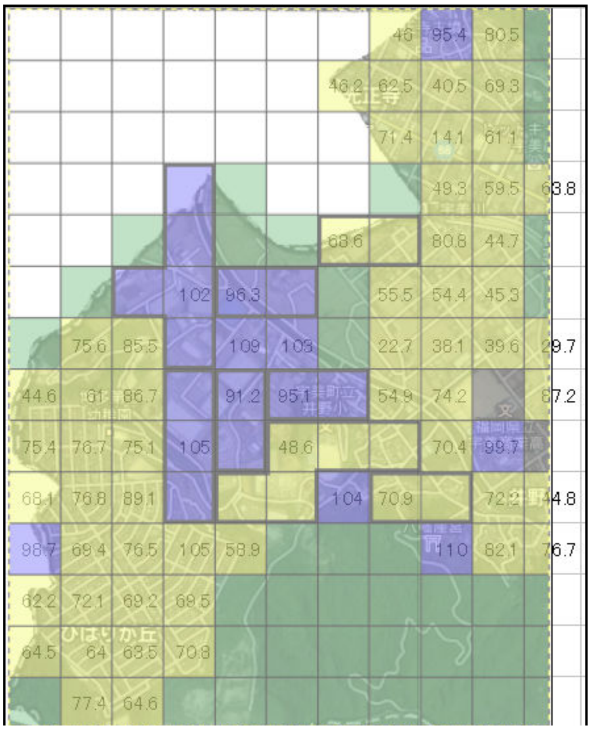

Fig. 8 150m square mosaic map after clustering

Total of 15 clustering took place, and the biggest block includes 5 grids, accounting to 112,500 m^2.The results for 200m square mosaic map are shown in Figs. 9 and 10.

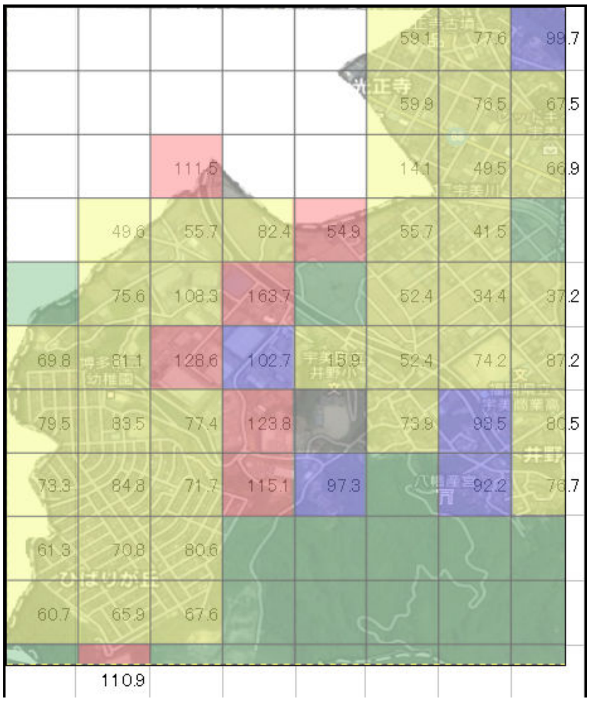

Fig. 9 200m square mosaic map

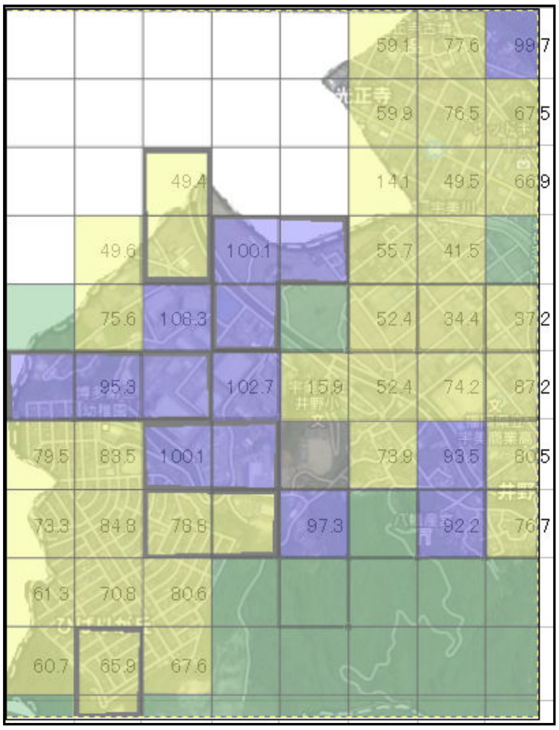

Fig. 10 200m square mosaic map after clustering

Total of 7 grid clustering took place, and the biggest block includes 3 grids, accounting to area of 120,000 m^2.

In each case with different square size, the biggest block sizes after clustering to resolve surplus power were as follows:

- 70,000 m^2
- 112,500 m^2
- 120,000 m^2

Calculating the length of the edge for each square having area above, will lend the following results:

- 264.6 m
- 335.4 m
- 346.4 m

The average of above lengths is 315.5m. Thus we may conclude that if we install the power control device in a form of lattice, it will be preferable to have about 300m as the distance between the control devices. To justify the validity of this figure of 300 m, we build a 300 m square mosaic map as shown in Fig. 11.

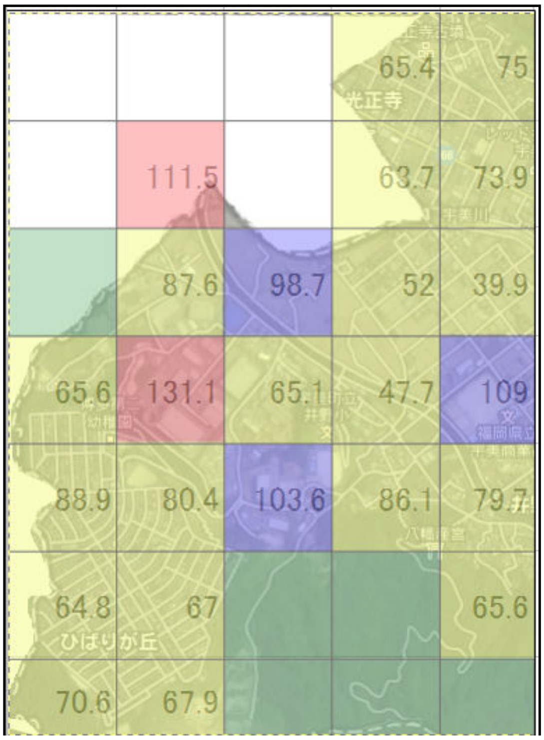

Fig. 11 300 m square mosaic map

In the 300m square mosaic map above, still 2 red grids could be found. So we tried again with a 350m square mosaic map as shown in Fig. 12.

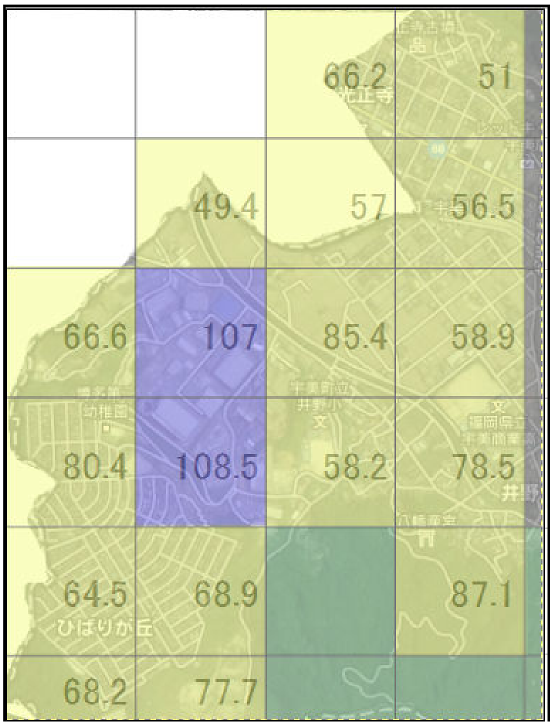

Fig. 12 350m square mosaic mapafter clustering

The figure above shows 0 red grids, so we conclude that installing the power control devices with 350m distances between them will eliminate any waste of the surplus power.

V. CONCLUSION

A. Summary

Effective use of surplus power generated by solar panels is the issue in this study. Smart grid provides a way to address above issue by installing multiple power control devices to transfer the surplus power to neighboring buildings. However, if the control devices are placed too far apart then there will be increased power loss due to the increase in the length the surplus power is transferred, Whereas if the control devices are placed too close the number of the control devices increase which will result in increased cost for installing and maintaining the control devices. We propose a way to figure out the optimal number of the control devices, from the view point of landscape ecology. As a result, for the example region used in this study, we found 350 m to be the optimal distance between the control devices, where no surplus power is abandoned at the same time the area covered by one control devices is kept minimal to reduce power loss in transferring.

B. Further Problems

This study used estimation of amount of power generation per year. However, in reality, the output of the solar generator is unstable and fluctuates over time. One way to get more accurate results will be using month, day, or hour instead of year as unit of time. This study shows a simulation on a specific region as an example. It is desirable to conduct the simulation on more regions. The example area used in this study included all of residential, commercial and industrial areas. Further study will be needed to adapt to other regions where the entire region is biased to have only a specific kind of area. The simulation in this study is done manually, measuring each size of roof by human work. Automating the job using image processing technology will greatly improve the efficiency of the simulation.

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