A proposal for setting electric power saving rate to avoid risk of electric power shortage occurrence

— Probability evaluation system of electric power shortage occurrence under tight electric power supply —

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Japan has to urgently build a new system for securing electric power supply including renewable energy and for saving electric power. The electricity demand and the electricity supply based on renewable energy are influenced by the weather. Thermal power generation may also be affected by equipment failure. Therefore, plotting of a plan is required to avoid electric power shortage under inaccurate prediction for supply and demand of electricity. In this article, we propose a probability evaluation system to avoid electricity shortage. We also propose a method for setting the electricity saving rate to avoid electricity shortage while maintaining the present level of electricity shortage occurrence risk.

Keywords : Electric power demand-and-supply balance, electric power shortage probability evaluation system, Chebychev probability inequality, Bennett probability inequality, Hoeffding probability inequality

1 Introduction

Prospects for new constructions and resumptions of nuclear power plants are uncertain. Considering the present situation, securing electricity supply from the new electric generating system based on renewable energy in addition to the conventional electric generating systems, e.g. thermal plants, is an urgent issue. At the same time, it goes without saying that a system for planning electric power savings should be developed.[1][2]

From the summer of 2011, the Tokyo Electric Power Company, Inc. and the Kansai Electric Power Company, Inc. have begun to offer electricity demand-supply balance information about the ratio of the expected maximum electricity demand against the expected electricity supply of the electricity consumption peak period of any given day and the next day on the website. It seems that the expected maximum electricity demand and the expected electricity supply in the electricity consumption peak period are estimated by the past data and experience accumulated in each electric power company.

On the website of autumn, 2011, a regression model of the peak electricity demand according to atmospheric temperatures was published for the purpose of enlightening the community on electricity consumption. On this website, the regression models of temperature and the maximum electricity demand of the summers of 2010 and 2011 were illustrated. From this illustration, the difference between electricity consumption behaviors in 2011 and 2010 was quite apparent. Furthermore, it could also be seen that the electricity demand has an uncertainty under the respective regression models. However, because of the change of the electricity consumption behaviors for the present situation of the electricity supply, it is not necessarily easy to grasp the stochastic distribution of the electricity demand precisely.

Yamamoto[3] has presented a research report about the influence of the electricity power shortage caused by the East Japan Great Earthquake disaster to the Japanese economy. In this report, Yamamoto insisted that the temporary electricity savings under tight electric power supply of the last summer did not influence the production and the employment so much. Yamamoto has concluded that although the employment rate has worsened by the prolongation of the electric power savings, not the voluntary electric power savings but rather the enforced reduction of the electric power supply decreases the production and employment. This fact suggests the necessity of showing an appropriate target for electric power savings.

The Kansai Electric Power Company made an announcement requesting for a 15 % reduction in electricity consumption for the summer of 2011, after the earthquake disaster. At that time, Mr. Hashimoto who was the Governor of Osaka Prefecture demanded for a reason for the request to the Kansai Electric Power Company. However, the Kansai Electric Power Company made no reply to this query and remained silent. The summer of 2011 passed and it was

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rumored that the reason for the 15 % reduction in electricity consumption was not necessarily based on a scientific background. The possibility of intentional information control was also suspected. It may be said that this indicates insufficient information disclosure by the electric power companies including the Tokyo Electric Power Company and the Kansai Electric Power Company. In the present situation, it is necessary that each individual behaves so as not to create big societal confusion. However, this can only be done if some kind of convincing information is released that can induce people to reduce electricity consumption

At the same time, as one conclusion to the decarburization of energy, an electric generating system based on renewable energy is considered. The purchase price of electricity based on renewable energy was decided under the Act on Special Measures Concerning Procurement of Renewable Electric Energy by Operators of Electric Utilities. However, since renewable energy is natural energy, the electricity supply based on renewable energy is affected by uncertain elements, e.g. weather and climatic conditions. In addition, the electricity demand is also influenced by weather and climatic conditions, which shows that the electricity demand also has much uncertainty. Moreover, because of the possibility of facility trouble and the need of maintenance check for the aging fatigue of existing facilities, the fluctuation in the electricity supply by the existing thermal power generating system should be considered.

Therefore, when we consider the present situation in our country, both the expansion of electric generating facilities and the planning of electric power saving are required in order to evade electricity shortage outbreaks. In such cases, the uncertainties about the electricity supply and demand have to be put into consideration. Furthermore, considering the electricity demand-supply balance, the construction of a valid system to call for appropriate reductions in the electricity consumption is urgent.

This paper addresses the evaluation of the electricity shortage outbreak probability of a case where there are stochastic fluctuations in the electricity demand and supply, keeping the current situation where there is no elbow room in electricity demand-supply balance in mind. It is supposed that the stochastic distributions of the electricity supply and demand are not exactly known, and that the limited information about the electricity supply and demand, such as the expectation and variance, are given.

In this paper, the system for evaluating the electricity shortage outbreak probability is presented first. As one of the contributions of the electricity shortage outbreak probability evaluation system, a procedure for deciding the electric power saving rate for avoiding electricity shortage outbreaks is presented. The reasonableness of the decided request value of the electric power saving rate can be explained using the considered system.

2 Description of the problem

The greater part of generated electricity is produced in conventional facilities, e.g. thermal power generating systems and others. In addition to this, under the present situation, generated electricity based on renewable energy has become an urgent subject. The ratio of the electricity supply based on renewable energy among all of the electricity supply is around 3 % at present and the target in 2020 is 10 %.

It is appropriate to consider that all of electricity produced by conventional electric generating systems and new generating systems based on natural energy fluctuates as mentioned above. The electricity supply based on renewable energy depends on the weather and/or climate conditions and may not necessarily bring a stable electricity supply. Accordingly, the electricity supply based on renewable energy can be understood as a random variable. Furthermore, since the temporary halts such as those caused by facility troubles or due to maintenance checks are supposed in the conventional generating systems like the thermal power generating system, electricity supply of conventional systems should also be understood as a random variable. The stochastic distributions of these random variables are not known exactly.

Similarly, as mentioned above, by the voluntary reduction in electricity consumption of consumers, the current electricity consumption behaviors have certainly changed from conventional electricity consumption behaviors. Therefore, it is considered that the stochastic distribution of the electricity demand is also unknown.

Under this situation, let us assume that each expectation and variance of the above random variables for the electricity demand and the electricity supply are available as limited information based on the forecast of the climate and weather of the next day. In this paper, the construction of the electricity shortage outbreak probability evaluation system is attempted based on the limited information about the electricity demand and the electricity supplies.

Suppose the three random variables as follows:

- electricity supply in conventional electric generating systems: e_0 ($E[e_0] = \mu_0$ and variance $V[e_0] = \sigma_0^2$),
- electricity supply based on renewable energy: e_1 ($E[e_1] = \mu_1$ and variance $V[e_1] = \sigma_1^2$),
- electricity demand: e_2 ($E[e_2] = \mu_2$ and $V[e_2] = \sigma_2^2$),

where the distributions for e_0, e_1 and e_2 are unknown. Furthermore, the independency among the random variables e_0, e_1 and e_2 is assumed. In this paper, first priority is to construct a system for evaluating the electricity shortage outbreak probability based on the limited information mentioned above, in the present situation where there is no elbow room in electricity demand-supply balance.

Under the assumption mentioned above, we simply define the relationship of $e_0+e_1 \geq e_2$ as the situation that the electricity supply satisfies the electricity demand. Therefore, a system for evaluating the probability $\Pr\{e_0+e_1<e_2\}$ on the safe side is constructed. The phrase, "the safe side," means that the actual electricity shortage outbreak probability is definitely less than the electricity shortage outbreak probability evaluated in the system. In other words, a system for evaluating the electricity shortage outbreak probability in the worst situation under an assumed scenario is intended.

3 Proposal of a system based on probability inequalities

There are some probability inequalities to evaluate the upper bound of the upper probability of the average and sum of random variables based on limited information such as expectations and variances of individual random variables without the information about the distribution. Recently, Takemoto *et al*.[4] have considered the decision making problem of the reorder point in an inventory system by utilizing the probability inequality. Moreover, Shinzato and Kaku[5] have argued for an analysis method for finding safety inventory using large deviation principles.

In this paper, by utilizing three probability inequalities, that is, the one-sided Chebychev probability inequality,[6] the Bennett probability inequality[7] and the Hoeffding probability inequality,[8] the construction of a system for evaluating the probability $\Pr\{e_0+e_1<e_2\}$ on the safe side is proposed.

3.1 Evaluation based on the one-sided Chebychev probability inequality

Consider the upper probability $\Pr\{D>v+k\delta\}$, where D is the random variable following an unknown distribution with expectation v and variance δ^2, and k is a positive number. Then, we have the following inequality according to the one-sided Chebychev probability inequality:[6]

$$\Pr\{D > v + k\delta\} \leq \frac{1}{1+k^2}.$$

We can make the relation of $e_2-(e_0+e_1)>0$ equivalent to the relation of $D>v+k\delta$ for the purpose of evaluating $\Pr\{e_2-(e_0+e_1)>0\}$ by utilizing the one-sided Chebychev probability inequality. Then, the following equations are derived:

$$v=\mu_2-(\mu_0+\mu_1), \tag{1}$$

$$\delta^2=\sigma_0{}^2+\sigma_1{}^2+\sigma_2{}^2, \tag{2}$$

$$k = \frac{(\mu_0+\mu_1)-\mu_2}{\sqrt{\sigma_0^2+\sigma_1^2+\sigma_2^2}}, \tag{3}$$

where it is obvious that $k>0$ because it is natural that the planned generation of electricity should be larger than the assumed demand of electricity. Therefore, the upper bound of the electricity shortage outbreak probability can be evaluated by utilizing the one-sided Chebychev probability inequality as follows:

$$\Pr\{e_0+e_1<e_2\} \leq \frac{\sigma_0^2+\sigma_1^2+\sigma_2^2}{(\mu_0+\mu_1-\mu_2)^2+\sigma_0^2+\sigma_1^2+\sigma_2^2}. \tag{4}$$

3.2 Evaluation based on the Bennett probability inequality

Let us adopt the Bennett probability inequality[7] for a similar problem. In the case of utilizing the Bennett probability inequality, the lower limits a_0 and a_1 for e_0 and e_1, and the upper limit b_2 for e_2 are considered in addition to the expectation and variance for each e_i. It is defined as follows:

$$B = \max\{(\mu_0-a_0),(\mu_1-a_1),(b_2-\mu_2)\}. \tag{5}$$

Actually, the values of a_0, a_1 and b_2 might be given as the maximum values and the minimum values based on the past results.[10] However, in the case where those results cannot be obtained as exact values, we can evaluate these values based on the three-sigma method or the two-sigma method. Under the three-sigma method, the followings are obtained:

$$a_0=\mu_0-3\sigma_0,\ a_1=\mu_1-3\sigma_1,\ b_2=\mu_2+3\sigma_2.$$

Similarly, we have the followings under the two-sigma method:

$$a_0=\mu_0-2\sigma_0,\ a_1=\mu_1-2\sigma_1,\ b_2=\mu_2+2\sigma_2.$$

The upper bound of the electricity shortage outbreak probability can be evaluated by utilizing the Bennett probability inequality as follows:

$$\Pr\{e_0+e_1<e_2\} \leq \exp\left\{-\left(\frac{\delta}{B}\right)^2 h\left(\frac{kB}{\delta}\right)\right\}, \tag{6}$$

where δ and k are equivalent to equations (2) and (3), respectively, and the function $h(u)$ is defined as

$$h(u)=(1+u)\ln(1+u)-u.$$

3.3 Evaluation based on the Hoeffding probability inequality

We can evaluate the electricity shortage outbreak probability by utilizing the Hoeffding probability inequality.[8] The Hoeffding probability inequality gives the evaluation of the upper bound for the electricity shortage outbreak probability as follows:

$$\Pr\{e_0+e_1<e_2\} \leq \left(1+\frac{kB}{\delta}\right)^{-\left(\frac{\frac{\delta^2}{B}+k\delta}{B+\frac{\delta^2}{3B}}\right)} \left(1-\frac{k\delta}{3B}\right)^{-\left(\frac{3B-k\delta}{B+\frac{\delta^2}{3B}}\right)}, \tag{7}$$

where δ, k and B are defined as equations (2), (3) and (5), respectively, and the value of "3" in the right hand of the equation (7) indicates the number of random variables e_0, e_1 and e_2 in the considered system.

4 Specification of range for each random variable

The expectation and variance of the random variable is commonly required in the one-sided Chebychev, Bennett and Hoeffding probability inequalities. The one-sided Chebychev probability inequality is defined only on the expectation and variance. On the other hand, the Bennett and Hoeffding probability inequalities require the range for each random variable in addition to the expectation and variance. Therefore, when we adopt the Bennett and Hoeffding probability inequalities, the range for each random variable needs to be specified.

With the information about the electricity supply and demand, only the expectation and variance for each random variable is considered as mentioned above. It is thought that the lower limit and upper limit for each random variable are specified in conformity with the two-sigma or three-sigma methods. In this paper, the two-sigma method is employed for specified lower limit and upper limit for each random variable.

5 Relation between electricity shortage outbreak possibility and electricity supply

In this chapter, based on the one-sided Chebychev, Bennett and Hoeffding probability inequalities, the behavior of the upper bound of the electricity shortage outbreak probability for the changes of electricity supply is evaluated. Then, the influence on the electricity shortage outbreak probability by the ratio of the electricity supply based on renewable energy in the total electricity supply is examined.

At first, the expectation of the electricity demand e_2 is fixed as $E[e_2]=\mu_2=94.0$. Furthermore, the variance of e_2 is set as $V[e_2]=\sigma_2^2=(0.015\times\mu_2)^2$, because the fluctuation range of the electricity demand was illustrated as about ±3 % against the expectation of the electricity demand on the previously published website of the Kansai Electric Power Company. The total of the electricity supplies is fixed as $E[e_0+e_1]=\mu_0+\mu_1=100$. By changing μ_1 from 0.5 to 10, the fluctuation of the electricity shortage outbreak probability is examined. In this case, the variances for e_0 and e_1 are given as $V[e_0]=\sigma_0^2=(0.01\times\mu_0)^2$ and $V[e_1]=\sigma_1^2=(0.30\times\mu_1)^2$.

The combination of $(\mu_0, \mu_1)=(97.0, 3.0)$ is corresponding to the present situation where the electricity supply derived from renewable energy is approximately 3 %. On the other hand, the combination of $(\mu_0, \mu_1)=(90.0, 10.0)$ is corresponding to the target situation where the electricity supply derived from renewable energy will be approximately 10 % in 2020.

The result based on three probability inequalities mentioned above is illustrated in Fig. 1. In Fig. 1, the electricity shortage outbreak probability evaluated by simulation is also shown. In this case, the simulation was carried out under the situation where the distributions of the electricity supplies and demand are assumed as the log-normal distributions, respectively. The iteration number was 1,000,000.

From Fig. 1, it is found that the electricity shortage outbreak probability by simulation is less than the electricity shortage outbreak probabilities evaluated by the probability inequalities. This result indicates that the electricity shortage outbreak probability can be evaluated on the safe side. Similar results are also confirmed in the cases where the beta distribution, normal distribution and so on are assumed as the distributions of the random variables e_0, e_1 and e_2. Therefore, it can be said that the electricity shortage outbreak probability evaluated in each probability inequality is evaluated on the safe side.

For reference, in addition to the results in Fig. 1, Fig. 2 shows

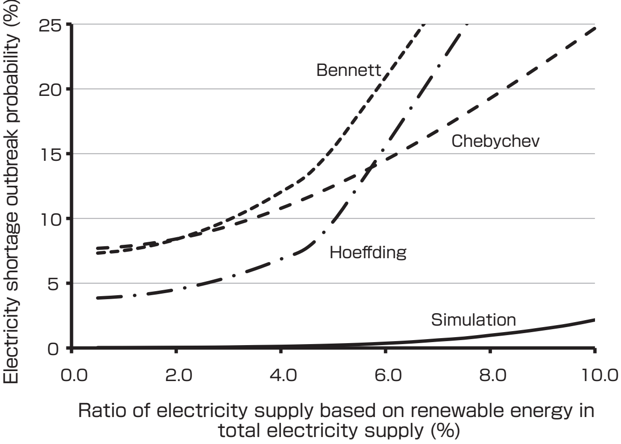

Fig. 1 Fluctuation of electricity shortage outbreak probability in the change of (μ_0, μ_1)

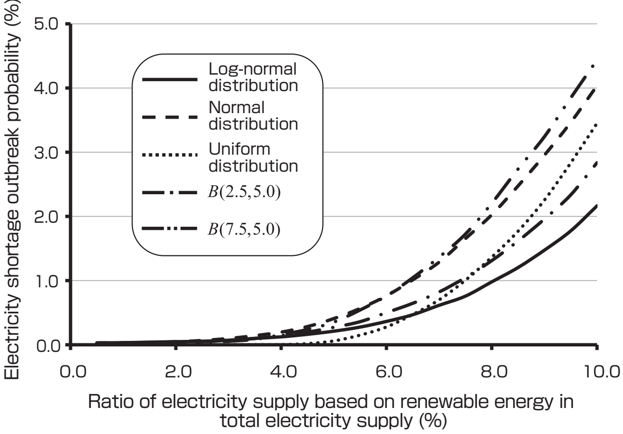

Fig. 2 Results of simulation under assumed distributions

the simulation results in the case that all the distributions for e_0, e_1 and e_2 are assumed as the normal distributions, uniform distributions and beta distributions, respectively. In these simulations, the conditions in the expectations and variables of e_0, e_1 and e_2 are corresponding to the conditions in Fig. 1.

As a matter of course, the difference of the assumed distribution of each random variable brings the difference in the electricity shortage outbreak probability. However, it is confirmed that the electricity shortage outbreak probabilities estimated under the assumed distributions are certainly less than the electricity shortage outbreak probabilities evaluated by the probability inequalities from the comparison with the results of Fig. 1. Accordingly, it is understood that the evaluation system based on the probability inequalities considered in this paper promises decision-making on the safe side.

In Fig. 1, remark that the relationship among the evaluation values of the electricity shortage outbreak probability are varied by the situation. From this fact, we consider that the electricity shortage outbreak probability is evaluated as the minimum value among them based on the one-sided Chebycehv, Bennett and Hoeffding probability inequalities.

In addition, notice that the electricity shortage outbreak probability based on the probability inequality is considerably larger than the value by simulation. Then, since the electricity shortage outbreak probability based on the probability inequality is given as a pessimistic value, the unnecessary confusion by this value should be avoided.

For reference, the electricity shortage outbreak probability by simulation in Fig. 1 is estimated as 0.0717 % , in the case where the electricity supply based on renewable energy is given as 3 % as at present. In addition, it is estimated as 2.180 % in the case where the electricity supply is 10 % in 2020. This fact means that the risk in the electricity shortage increases only by replacing the electricity supply from the conventional electric generating systems with the electricity supply based on renewable energy.

6 Relation between electricity shortage outbreak possibility and electric power saving rate

In the present situation where there is no elbow room in electricity demand-supply balance and it is difficult to increase the electricity supply, the reduction in electricity consumption might be required in order to avoid an electricity shortage outbreak, and the electricity demand-supply balance should be considered. However, excessive savings of electricity consumption without argument suppresses the economic activities and may threaten the social system.[3] In the following section, we illustrate the role of the proposed evaluation system using the probability inequality.

Suppose the stable condition for (e_0, e_1) as (μ_0, μ_1)=(97.0, 3.0), $V[e_0]=\sigma_0^2=(0.01\times\mu_0)^2$ and $V[e_1]=\sigma_1^2=(0.30\times\mu_1)^2$, where this stable condition is interpreted as the condition in which the electricity demand-supply balance is in a stable state from the viewpoint of the electricity shortage outbreak probability. Thereafter, assume that the electricity supply by the conventional electric generating systems decreases 15 %. Then, we consider the required electric power saving rate under the condition of (μ_0, μ_1)=(97.0×0.85, 3.0). In this case, from Fig. 1 it is found that the electricity shortage outbreak probability based on the probability inequality is evaluated greatly on the safe side. It is not suitable to decide on the electric power saving rate by setting the value requested in the real world against the electricity shortage outbreak probability evaluated by the probability inequality.

In this paper, a stable condition mentioned above is interpreted as the condition that the electricity demand-supply balance is in a stable state from the viewpoint of the electricity shortage outbreak probability. We investigate the appropriate electric power saving rate in order to guarantee that the electricity shortage outbreak probability in a situation where the electricity supply with the conventional electric generating systems decreases 15 % is equal to that of a stable condition. The electricity shortage outbreak probability in the stable condition (μ_0, μ_1)=(97.0, 3.0) is evaluated as 5.462 % based on the Hoeffding probability inequality.

Under the condition that the electric power saving rate is achieved as γ, the expectation and variance of the electricity demand e_2 can be described as $((1-\gamma)\mu_2,\ (1-\gamma)^2\sigma_2^2)$. Then, we can evaluate the electricity shortage outbreak probability in the situation of (μ_0, μ_1)=(97.0×0.85, 3.0) as the function of the electric power saving rate γ by the probability inequality. This probability is described as $\Pr\{e_0+e_1<e_2|\gamma\}$.

Figure 3 shows the behavior of the electricity shortage outbreak probabilities in each electric power saving rate.

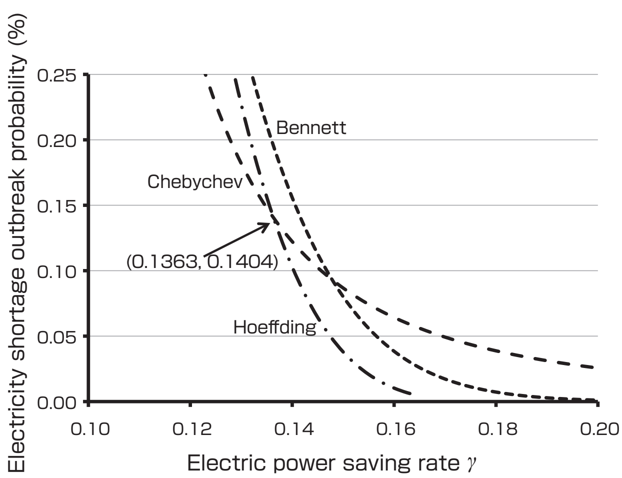

Fig. 3 Electricity shortage outbreak probabilities in each electric power saving rate

We can obtain the electricity shortage outbreak probability in the situation of (μ_0, μ_1)=(97.0×0.85, 3.0) as the minimum value among three values from the reason mentioned above. From Fig. 3, it is found that the evaluation by the probability inequality is shifted to the Hoeffding probability inequality from the Chebychev probability inequality after γ=13.63(%).

The result about the minimum value is illustrated in Fig. 4. In Fig. 4, the appropriate electric power saving rate for ensuring the value (5.462 %) of the electricity shortage outbreak probability is derived as γ=14.66(%).

When the electricity supply with the conventional electric generating systems decreased by 15 %, 14.55 % of the total electricity supply was lost from the viewpoint of the average. Therefore, it is found that, for the purpose of ensuring the value (5.462 %) of the electricity shortage outbreak probability in a stable condition, the electric power saving rate of 14.66 % exceeding the lost total electric power rate of 14.55 % is required. In other word, it can be interpreted that to decide on the electric power saving rate from the viewpoint of expectation is not necessarily enough. The proposed evaluation system concludes that excessive electric power saving is not necessary from the comparison of 14.66 % and 14.55 %. This is the effect of having considered the information of each variance in the electricity supplies and demand. Based on this effect, we can say that the proposed evaluation system for the electricity shortage outbreak probability has the appropriate security-oriented property.

Similar results have been observed under other loss ratios of the electricity supply with the conventional electric generating systems. Therefore, it is understood that the required electric power saving rate can be obtained under the security-oriented property by utilizing the proposed evaluation system for the electricity shortage outbreak probability. Moreover, it is concluded that the proposed evaluation system contributes to the accountability of the electric power saving rate.

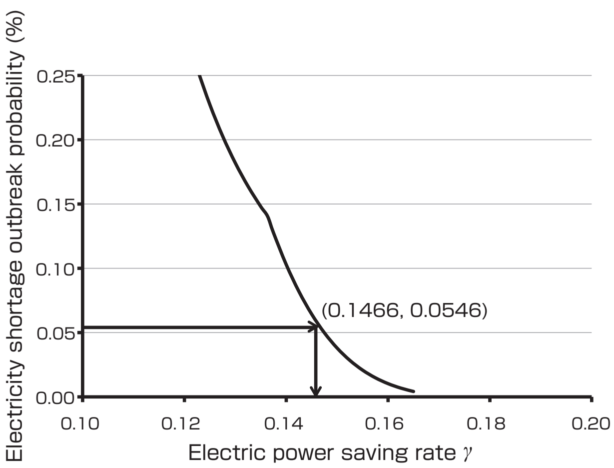

Fig. 4 Evaluation based on proposed system

7 Conclusion

At the moment, the electricity demand-supply balance is in a tight situation. Although renewable energy as a source of electricity supply is anticipated, the electricity supply based on renewable energy contains a lot of uncertainty. In addition, there is also uncertainty in the electricity demand. In view of the present situation, we have considered a system for evaluating the electricity shortage outbreak probability based on the limited information concerning the electricity supply and demand. Concretely, under the uncertainty concerning the electricity demand and supply, an evaluation system for electricity shortage outbreak probability in the worst-case scenario has been proposed by utilizing the probability inequality. Furthermore, the procedure for achieving appropriate accountability for a certain rate in the reduction of the electricity demand has been discussed by using the proposed evaluation system.

In deciding on the required electric power saving rate and the construction planning of a new electric generating system based on renewable energy using the proposed evaluation system, the features of the probability inequality should be fully explained. Basically, the information about the electricity supplies e_0 and e_1, and the electricity demand e_2 should be sufficiently disclosed in order to estimate the expectation and variance of them. We desire more information disclosure by the existing electric power companies and the Japanese government. We can, in fact, request for more information disclosure to the electric power companies and the government on the basis of using the proposed evaluation system.

Recently, the Kansai Electric Power Company has made an effort to disclose information in order to answer many questions from the local inhabitants.[11] From this information disclosure, it is found that the electricity supply and demand fluctuate every day as assumed in this paper. At the same time, the Kansai Electric Power Company announces the estimation of the electricity demand-supply balance as part of the information disclosure. However, it seems that the estimation of the electricity demand-supply balance by the Kansai Electric Power Company depends only on the expectation of the electricity supply and demand. Therefore, we desire more information disclosure for the purpose of making more useful decisions.

In addition, we consider that some new technical innovations in the case of adopting the probability inequality might be required. For example, improvement of forecast precision of the electricity demand directly influences the required electric power saving rate. Therefore, accurate estimation of the expectation and variance based on historical data accumulated in the electric power companies will be an important innovation. Furthermore, considering that the probability inequality is a pessimistic evaluation, more effective policy decision-making is enabled by devising a higher-performance probability inequality which gives tighter probability.

Here, we give some explanations concerning the probability inequalities adopted in this paper. Because the electricity shortage should not happen, the electricity shortage outbreak probability has to be evaluated as a relatively small value. Therefore, some probability inequalities with the feature of giving a pessimistic evaluation have been adopted in this paper. Concretely, we employ three probability inequalities of one-sided Chebychev, Bennett and Hoeffding probability inequalities. The one-sided Chebychev probability inequality[6] which is a well-known and basic probability inequality, gives an evaluation based on the information about the expectation and variance of the random variable. Both the Bennett and Hoeffding probability inequalities need the information about the range in addition to the expectation and variance of the random variable. This information is observable in actuality. The device to give the range using the expectation and variance is presented in this paper. Talagrand[12] and Bentku[13] have mentioned that the Hoeffding probability inequality is extremely useful among the existing probability inequalities evaluated under the same conditions. The Bennett probability inequality is the basis of the derivation of the Hoeffding probability inequality. Therefore, both the Bennett and Hoeffding probability inequalities are also employed in this paper.

There are other probability inequalities not adopted in this paper, for example, the Markov probability inequality, the Chernoff probability inequality and another Hoeffding probability inequality. Although the Markov probability inequality[9] is a basic probability inequality shown in various textbooks about the probability theory, evaluation by the Markov probability inequality based on information of the lower limit and expectation of the random variables is not exactly practical. There is another Hoeffding probability inequality[8] which can evaluate by using the information on only the range of random variables. However, since this Hoeffding probability inequality gives a larger value than the Hoeffding probability inequality in this paper, this Hoeffding probability inequality has not been employed here. There is the Chernoff probability inequality which is considered a well-known probability inequality. The Chernoff probability inequality uses information of probability distributions of random variables.[14][15] Therefore, in the situation considered in this paper, it is not suitable to adopt this Chernoff probability inequality.

Although there may be some critical comments, we consider that the system proposed in this paper is presently of a certain completed form under the available information in order to evaluate the electricity shortage outbreak probability. However, it is important to improve the performance of the probability inequalities. By deriving probability inequalities with better performance, we can make more fruitful decisions. In this sense, the authors would like to pursue the improvement of probability inequality.

The results of this paper are summarized as follows:

1. An electricity shortage outbreak probability evaluation system under the worst-case scenario has been constructed by using probability inequality in the case where limited information about the expectation and variance of electricity supplies and demand is only given.
2. The fact that the disclosure of the past data for the electricity demand and supply is not necessarily enough has been explained. At the same time, if this past data is disclosed, in order to use it effectively, the development of the estimation method of the expectation and variance of the electricity demand and supply is needed and is a future subject to be explored.
3. It has been exhibited that the performance improvement of probability inequality is a subject for more effective and efficient decision-making in using the proposed system based on probability inequality.

From the above, authors pray that this proposed evaluation system is supplemented and upgraded by more researchers to meet social requests. For example, there are many young and energetic researchers in the field of data analysis. If the electric power companies disclose more information, a method for estimating precisely the expectation, variance and range might be developed by such researchers. The proposed evaluation system satisfies the requirements to be at the least a basic system, and it has been suggested with this intention.

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Discussions with Reviewers

1 Significance of this paper

Comment (Hiroshi Tateishi, AIST, Itaru Ishii, National Museum of Nature and Science)

Because the operation of nuclear power plants almost stopped under the influence of the East Japan Great Earthquake disaster, restriction of electricity supply have become severe, and a large-scale blackout is considered as a real risk. On the other hand, all the information about the electricity supply and demand is stashed under the control of the electric power companies. In addition, an objective tool for risk management cannot be found except for the regression model using past data published by electric power companies.

This paper deals with a procedure for evaluating the electricity shortage outbreak probability based on probability inequality using the limited information about the uncertain electricity demand and supply. The objective explanation of the required power saving rate is addressed based on the evaluated electricity shortage outbreak probability. When we consider the background mentioned in the previous paragraph, we conclude that the scenario of this paper is more or less persuasive. Although it is slightly different in content from the journal, *Synthesiology*, which sets the creation of social values as its goal, we conclude that the paper is significant as it shows a rational methodology that leads to value creation.

However, if such an evaluation system does not play a concrete role in real decision-making processes, it only becomes an impractical theory, and might not be received socially. In such a case, it is incomplete in terms of the purpose of *Synthesiology.*

In the case of applying the contents of this paper to a real electric power system, there are some future subjects to be considered. For instance, the authors evaluate the electricity shortage outbreak probability by using the expectation and variance of the electricity demand and supply, without supposing any probability distribution from limitations of available information. How much difference will this simplification cause in the results? Can the fluctuation of the electricity supply from natural energy caused by climatic conditions be handled equally with the fluctuation caused by the influence of artificial factors such as the stop of operation for maintenance?

The authors should explain their intentions of submitting this paper to *Synthesiology* including such future issues.

Answer (Ikuo Arizono)

Under the present situation about the electricity supply and demand, we intend to give some kind of contribution from the viewpoint of our area of specialization such as industrial engineering, operations research and applied statistics. In this sense, we also consider that the decision-making process and the interpretation of decisions based on the proposed evaluation system need to be persuasive in order to be accepted socially. For this purpose, we have arranged the points of argument so that decision-making using the proposed evaluation system could be accepted socially.

On the other hand, we thank the reviewers for their understanding of this study. With that in mind, I explain "our intentions in submitting the paper to *Synthesiology*".

The main intention is in the policy of the academic journal "*Synthesiology*", that is, instead of a passive attitude that the results of research become understood naturally by society, the researcher who understands the possibility and limit of the results of research should popularize the result of research in a positive manner by himself//herself. This research focuses on an extremely contemporary problem. We would like to suggest this research as a starting point for discussions based on a new sense of values after the earthquake disaster and the nuclear power plant accident. Therefore, we believe that this research is suitable for publication in Synthesiology and we submitted this paper. In this sense, there are some future issues in applying the content of this paper to a real electric power generating system.

Under the uncertainty of the electricity demand and supply, an evaluation system for electricity shortage outbreak probability in the worst-case scenario has been proposed by utilizing probability inequality. In addition, the present issues in utilizing this evaluation system have been clarified, and the necessity of adding further knowledge of researchers has been described. We believe the description mentioned above also corresponds to the publication policy of “the journal to discuss together”, and therefore, we think this paper is suitable for *Synthesiology.*

There are some future issues such as the acquisition of data which should be offered in the proposed evaluation system and the performance improvement of the probability inequality. These future issues have been summarized in chapter 7.

2 Development of the model

Comment (Hiroshi Tateishi)

In the introduction, the expectation for renewable energy and the problems in electricity demand predictions are pointed out, and an evaluation model of the electricity shortage outbreak probability is formulated. However, this paper seems to reason that the uncertainty of electricity supply and demand is an essential element of electric power shortage, and the existence of renewable energy is not an essential element. Therefore, I suggest that through the evaluation based on only the balance between the electricity demand and the electricity supply from the conventional electric generating systems, the validity of the proposed procedure should be first shown more logically. Next, I suggest that the effect and the influence of the electricity supply based on renewable energy be shown.

I also think that although the sensitivity analysis for variance is inspected, the sensitivity analysis for the quantity of renewable energy is necessary as the first step.

Answer (Ikuo Arizono)

At the time that the initial manuscript of this study was submitted, the electricity buyback program of renewable energy was just being discussed. The system to purchase at a fixed price started, and it is possible to assume that the electricity from the conventional electric generating systems including the nuclear power plants will be substituted by the electricity from renewable energy at some future date. In this study, we proactively pushed forward the investigation keeping such a situation in mind.

In the revised manuscript, we present the electricity supply based on renewable energy from the present situation to the goal in 2020.

Furthermore, in the revised manuscript, the sensitivity analysis for the quantity of renewable energy has been investigated according to the reviewer’s opinion. Fig. 1 in the revised manuscript shows the influence of the change in the ratio of the electricity supply of renewable energy.

3 Interpretation and utilization of the evaluation results

Comment (Hiroshi Tateishi)

Because the concept behind how to understand and utilize the electricity shortage outbreak probability that is the output of the proposed system is not explained explicitly, it is not obvious how to utilize the proposed system in the real world. In the last part of chapter 4, it is remarked that the results must be used carefully. However, the procedure for use of the results is not sufficiently explained. I think there is no room to be doubted about the logical validity of the proposed model. Rather, it is important how the user is able to make decisions from the results of the proposed system. For reference, if the outbreak probability is less than what percentage rate do the authors think that there is not any problem?

Answer (Ikuo Arizono)

We have considered that this instructed point was the most important content. However, it was vague in the previous manuscript. We can interpret the electricity shortage outbreak probability by the probability inequality as the worst probability. We avoided the explanation in the previous manuscript about how to decide the allowable level of this probability.

In this revised manuscript, it has been added that the allowable level of this probability is decided from the viewpoint of maintaining the present level. In this way, the authors think that the implications of decision-making based on the proposed evaluation system has been made apparent.

4 Definition of the statistical distribution

Comment (Hiroshi Tateishi)

Expression of “the distribution” in the quantity of electricity supply or demand was used. However, it is unknown what “the distribution” means.

Answer (Ikuo Arizono)

The regression model about relations between the highest temperature in the daytime and the quantity of electricity demand was previously published on the website of the Kansai Electric Power Company. Even if the highest temperature in the daytime is the same, the quantity of electricity demand is not constant. In other words, there is some uncertainty in the electricity demand.

The regression model captures the stochastic fluctuation and catches the average feature of the data. Similarly, in reality, the electricity supply derived from renewable energy is also affected by the weather and has some uncertainty. In addition, all conventional electric generating systems are not always functioning due to failure and maintenance.

In this paper, the uncertainty in the quantities of the electricity supply and demand is assumed. Although, in reality, the information such as the expectation and the variance of the quantities of the electricity demand and supply is accumulated in the electricity companies as past data, these data are not always formally disclosed. Therefore, in the numerical examination about the proposed evaluation system, the calculation results based on artificial data have been illustrated. Naturally, the expectation and variance of the quantities of the electricity demand and supply ought to be obtained based on real accumulated data. Moreover, a novel method to obtain the expectation and variance may be developed. In either case, the disclosure of the accumulated data in the electric power companies is a required precondition.

The accumulated information in the electric power companies is necessary in order that the proposed evaluation system functions in practice. Therefore, it is one of objectives of this paper to paradoxically press the electric power companies for more information disclosure by presenting this fact.

The Kansai Electric Power Company is making an effort to disclose information in order to answer to many questions of the local inhabitants (http://www.kepco.co.jp/setsuden/graph/pop/pop_pdf/forecast.pdf). From this information on the website, it is found that the quantities of the electricity demand and supply fluctuate every day as assumed in this paper, and it is estimated that the electricity power saving rate is requested based on these predicted values. From the disclosed information, it is revealed that there is a cause for the uncertainty of the electricity supply in the existing generation facilities. However, although the information about the expectation of the quantities of the electricity demand and supply can be obtained, the information about the variance of them cannot be known.

Therefore, we have changed the quantity of the electricity supply of the conventional electric generating systems treated as a fixed value in the previous manuscript to a random variable in this revised manuscript.

5 Characteristic and selection of the probability inequality

Question (Hiroshi Tateishi)

Three probability inequalities are used without explanation. It is supposed that each probability inequality has an advantage and disadvantage. The authors should explain them. Furthermore, is there an inequality which seems to be usable other than these three inequities?

Answer (Ikuo Arizono)

The authors have represented the reasons for the three probability inequalities. The Bennett and Hoeffding probability inequalities require the range for each random variable that the one-sided Chebychev probability inequality does not need. In this case, this domain information is given based on the two-sigma method using expectation and variance only. The advantage and disadvantage of each probability inequality cannot be definitely shown. Note that the Hoeffding probability inequality, in particular, is recognized as a probability inequality with superior performance. The paper with the probability inequality by Hoeffding[8] was called a “celebrated paper” by Talagrand[12] and Bentkus.[13] From this fact, we consider that the combination of these three probability inequalities is valid. In addition, we are attempting various developments including the performance improvement of the Hoeffding probability inequality.

6 Influence of simulation by the difference in stochastic distribution

Comment (Hiroshi Tateishi)

In chapter 5, a simulation result using the log-normal distribution is shown. However, the simulation results under other stochastic distributions, e.g., the beta distribution and normal distribution should be presented for persuasiveness.

Answer (Yasuhiko Takemoto)

For reference, in Fig. 2, we have illustrated the simulation results in the case where all stochastic distributions for e_0, e_1 and e_2 are assumed as the normal distributions, uniform distributions and beta distributions, respectively. In these simulations, the conditions in the expectation and variance of e_0, e_1 and e_2 are corresponding to those in Fig. 1.

For the beta distribution, the authors have taken the linear conversion because the range of beta distribution is usually from 0 to 1. Considering that the beta distribution greatly changes the shape of distribution by the setting of the parameters, the authors have utilized both situations where the peak of the density is on the left side and on the right side of the center.

From comparisons with the results in Fig. 1, it is confirmed that the electricity shortage outbreak probabilities in Fig. 2 are definitely less than those evaluated based on the probability inequalities in Fig. 1. The authors have added the descriptions mentioned above.

7 Interpretation of the power saving rate

Comment (Hiroshi Tateishi)

The description in chapter 6 is somewhat incomprehensible. For example, when the quantity of the electricity supply decreased 15 %, is it correct to understand that the electric power saving rate is enough at 14.66 % in order not to increase the electricity shortage outbreak probability? If it is true, I think that the authors should show more extensive calculation results.

Answer (Ikuo Arizono)

That is not true and is a misunderstanding. As mentioned in the revised manuscript, when the electricity supply with the conventional electric generating systems decreased 15 %, 14.55 % of the total electricity supply was lost from the viewpoint of the average. It is found that, for the purpose of ensuring the value (5.462 %) of the electricity shortage outbreak probability in a stable condition, the electric power saving rate of 14.66 % exceeding the lost total electric power rate of 14.55 % is required. In other word, it is interpreted that the electric power saving from the viewpoint of expectation is not necessarily enough. At the same time, the proposed evaluation system shows that the excessive electric power saving is not required from the comparison of 14.66 % and 14.55 %. This is the effect of having considered the information of each variance in the electricity supply and demand. Based on this effect, the proposed evaluation system for the electricity shortage outbreak probability has the appropriate security-oriented property.

Since the information disclosure of each electric power company is not enough, the numerical value of the analysis result is not necessarily important. However, it is meaningful to indicate the effect by having considered the information of each variance in the electricity supply and demand. Furthermore, through the existence of the proposed evaluation system, we can demand more information disclosure from the electricity companies and government. We think that this study is also meaningful in this aspect.