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Study of Peak Load Demand Estimation Methodology by Pearson Correlation Analysis with Macro-economic Indices and Power Generation Considering Power Supply Interruption

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Abstract - Since the late 2000s, there has been growing preparation in South Korea for a sudden reunification of South and North Korea. Particularly in the power industry field, thorough preparations for the construction of a power infrastructure after reunification are necessary. The first step is to estimate the peak load demand. In this paper, we suggest a new peak demand estimation methodology by integrating existing correlation analysis methods between economic indicators and power generation quantities with a power supply interruption model in consideration of power consumption patterns. Through this, the potential peak demand and actual peak demand of the Nation, which experiences power supply interruption can be estimated. For case studies on North Korea after reunification, the potential peak demand in 2015 was estimated at 5,189 MW, while the actual peak demand within the same year was recorded as 2,461 MW. The estimated potential peak demand can be utilized as an important factor when planning the construction of power system facilities in preparation for reunification.

Keywords: Demand estimation, Peak load demand, Load duration curve, North Korea, Unification, Correlation factor

1. Introduction

There has been heated discussion on reunification since South and North Korea experienced mutual cooperation in the economic field in the early 21st century. Particularly in the power industry, technical problems, including facilities standards, power supply policies, and power quality, have become critical issues in the preparation for a reunified Korea [1, 2]. Meanwhile, various statistics and news articles indicate that North Korea has been suffering from a severe power shortage. Unlike other energy resources, it is difficult to transmit a specific amount of power to the final load center. Additionally, once the two separate systems are connected, they may be required to work as one system. Therefore, connecting South and North Korea's power systems immediately after reunification could be a technically challenge. Therefore, systematical power system planning for North Korea is required as part of an effort to prepare for a stable connection of South and North Korean systems after reunification.

Power system planning should include plans for electric power generation, transmission and substation facilities required to meet the expected load demand. Above all, load estimation should be performed preferentially. The peak load demand estimation is mainly divided into short and long term. Various methods for load estimation have been studied, including regression and statistical analysis [3-7]. Most estimation methods have been performed using past statistical data. For this reason, there are almost no studies estimating peak load demand, especially for North Korea with the absence of such past statistical data owing to its exclusive social policy [8].

Some estimations of power generation in terms of energy (MWh) have been performed for North Korea and related statistical data is available for those studies, but there has been no research in terms of instantaneous power (MW), which is essential for power system planning. In particular, the estimation of instantaneous peak power demand in developing countries that experience frequent power supply interruptions, such as North Korea and Bangladesh, is even more important. However, South Korea should develop a power system planning strategy by using only limited information and various peak demand estimation methodologies.

Many economic experts have predicted that both South and North Korea will achieve dramatic economic growth after reunification, and various related studies have been conducted [9-12]. In this study, we suggest a methodology to estimate the peak demand based on the correlation between economic growth and growth-induced power generation (consumption) increases [13], as well as North Korea's power supply interruption and power consumption patterns. For the case study, North Korea's potential peak demand and actual peak demand until 2050 were estimated with a long-term perspective, based on the assumption that

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South and North Korea were reunited in 2015.

2. Status of Power Supply in North Korea

According to Statistics Korea, as of 2012, North Korea had a generation facility capacity of 7,220 MW, among which hydro-power generation facilities accounted for 4,260 MW and fossil fuel power generation facilities for 2,960 MW [14]. However, because the statistical data included only the capacity of large-scale power plants with capacities of >100 MW and excluded small-capacity power facilities, the estimation differed from the reality in North Korea. According to reports issued by the Korea Finance Corporation, news articles and other data analysis results excluding the data from Statistics Korea, North Korea might have a total power generation capacity of 8,610 MW, with 5,600 MW from hydro-power generation facilities and 3,010 MW from fossil fuel power generation facilities [15]. North Korea transmits 900 MW of electric power to China, and operates a separate power generator at 50 Hz exclusively for transmission to China (North Korea's nominal frequency is 60 Hz). As of 2012, North Korea had a gross generation of 21.5 billion kWh, without substantial changes since 2008. Owing to the deterioration of electric power generation, and transmission and substation facilities, the actual available generation capacity is estimated to be approximately 3,000 MW.

North Korea is mainly focused on the power supply to military facilities and some upper class families; therefore, ordinary people suffer severe energy shortages, including frequent power outages. According to the reports issued by the Korea Finance Corporation, North Korea is estimated to have a power supply interruption rate of about 30% and a transmission and distribution loss of about 30% [15]. In this paper, the proposed methodology was verified by a case study for comparison with North Korea's estimated actual peak demand and available generation capacity considering the power supply interruption rate.

3. Correlation Analysis between Economic Indices and Power Demand

3.1 Correlation coefficient analysis method (Pearson correlation coefficient)

The Pearson correlation coefficient is one of the most representative methods that evaluates the correlation between two variables with mutually different physical quantities. The Pearson correlation coefficient describes a linear relationship between two variables, with a range from -1 to +1, and can be calculated with the following equation. A negative value means a negative correlation between the two variables, while a positive value indicates a positive correlation [16].

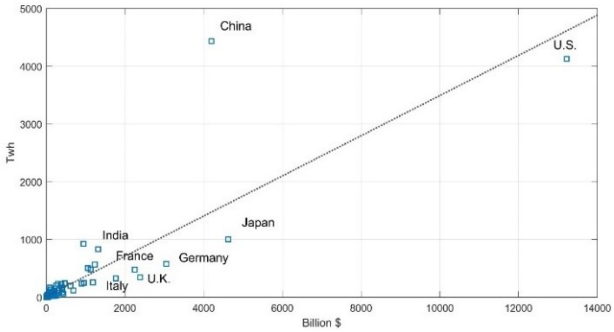

Fig. 1. Analysis of total GDP and total power generation by country with the first order trend line

$$r = \frac{\sum(x-\bar{x})(y-\bar{y})}{\sqrt{\sum(x-\bar{x})^2 \sum(y-\bar{y})^2}} \tag{1}$$

Generally,

$0.7 < |r| \le 1.0$ a strong linear
$0.3 \le |r| < 0.7$ relationship
$0.1 \le |r| < 0.3$ a clear linear relationship
$0.0 \le |r| < 0.1$ a weak linear relationship an almost insignificant linear relationship

Fig. 1 presents a graph showing the relationship between other countries' total GDP as of 2012 and their gross power generation [17]. The analysis results of the correlation between the two variables indicate a highly significant correlation coefficient of 0.85. In particular, countries with relatively lower total GDPs were closer to the first order trend line. In the case of North Korea, the estimation of the correlation between its total GDP and total generation quantity was also reasonable [18]. In this paper, the results of other economic indicators, such as gross GDP, per capita GDP, gross GNI, and per capita GNI, are not described, but these parameters exhibited high correlations, as demonstrated in the GDP results.

3.2 The composition of the secondary regression equation

The Pearson correlation coefficient showed a significant relationship between the two variables. Next, a second regression model is constructed by using the past data for two variables, consisting of x_i (economic indices by year) and y_i (total power generation amount by year). Sub-sequently, the coefficients a_0, a_1, a_2 are calculated to minimize the errors (ε_i).

$$\text{Statistical data : } (\tilde{x}_i, \tilde{y}_i) \tag{2}$$

$$\text{Regression model : } y_i = a_2 x_i^2 + a_1 x_i + a_0 + \varepsilon_i \tag{3}$$

$$\text{Min } \sum_{\tilde{x}_i} \varepsilon_i^2 = \sum_{\tilde{x}_i} (\tilde{y}_i - (a_2 x_i^2 + a_1 x_i + a_0))^2 \tag{4}$$

Since this paper does not claim to be original with regard to the regression equation models (or methods) used, we will not provide further pertinent details. However, the total power generation quantity was estimated by applying economic indices that included the year of interest as a parameter. In addition, we did not evaluate nor validate the estimated results' appropriateness for future economic indices after reunification, but only used them as application parameters for the second regression equation's input elements, as well as the power consumption patterns.

4. The Estimation of Power Consumption Pattern (Load Duration Curve)

The load duration curve reflects the instantaneous power demand for the 8,760 hours or 365 days in one year in descending order. The Y axis intercept of the load duration curve is the peak demand, and the size of the lower bound area indicates the yearly total generation quantity (≒power consumption amount). The load duration curve is an important indicator of power consumption patterns because it contains information about peak demand and a duration time for each load level. Previously, there was a significant correlation between economic indices and total generation quantities, indicating that countries at the same economic level may have the same power consumption patterns.

As the load duration curve itself contains information about physical quantities in the measurement unit of kW (or MW) from the viewpoint of hourly-specific instantaneous power for the respective hour, it was necessary to perform a normalization process that divided the data by the peak demand in order to extract only power consumption patterns [19, 20]. The size of the lower bound area of the normalized load duration curve is the sum of the index for 8,760 hours, which no longer has a direct physical meaning but indicates a relative instantaneous power by hour, as well as power consumption patterns.

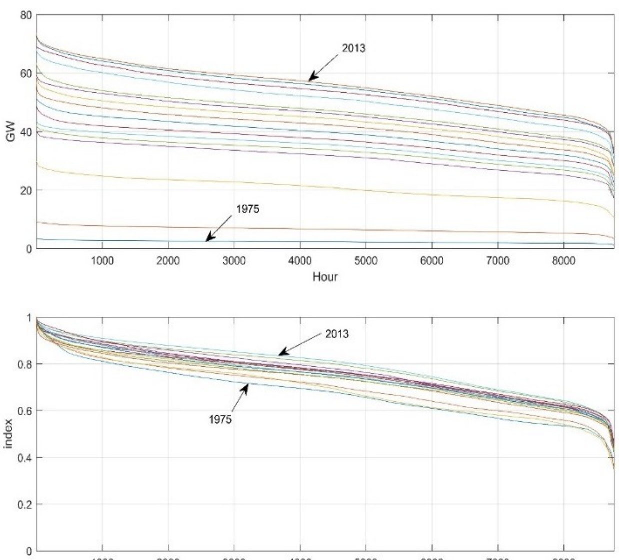

Fig. 2. South Korea's load duration curve and its normalized figure from 1975 to 2013

The top of Fig. 2 shows the load duration curve for South Korea from 1975 to 2013, whereas the bottom of Fig. 2 indicates a normalized load duration curve, in which physical quantities are divided by the peak demand [21]. These normalized load duration curves can be defined as load consumption patterns.

5. Power Supply Interruption Model

North Korea, along with southeastern Asian countries like Pakistan and Bangladesh, suffers from severe power shortages as a result of fuel supply problems, lack of power generation capacity, and the absence of effective power supply policies [15]. The occurrence of power supply interruptions leads to failure of the country to meet the load demand. Generally, continuous power supply is possible in the case of off-peak loads, but power supply interruptions occur more frequently as demand reaches the peak load (the peak demand).

These power supply interruptions can be classified as consumer-centric and supplier-centric. As of now, North Korea can be seen as a supplier-centric under the control of the central government, but it is expected to switch to a consumer-centric power supply system after reunification with the South. Consumers want to have an uninterrupted power supply if possible, as seen in the following graph. In this paper, the "Flat"-patterned power supply interruption model was defined, which can be mathematically expressed as Eq. (5).

If this "Flat"-patterned power supply interruption model is to be applied, the maximum value of '1' for the Y axis intercept of the normalized load duration curve indicates a potential peak demand index, while the Y axis intercept of the load duration curve of the "Flat"-patterned power supply interruption model indicates a relative actual peak demand against the potential peak demand. Here, the potential peak demand means an estimated demand based on the assumption of no power supply interruptions, whereas the actual peak demand indicates an estimated peak demand considering that consumers cannot use as much power as they want because of power supply interruptions.

$$\begin{cases} g(t) = C & if, f(t) > C \\ g(t) = f(t) & else \end{cases} \tag{5}$$

where, C : constant

6. The Methodology of Peak Demand Estimation

6.1 The peak demand estimation procedure

In this section, the above-mentioned methodologies and assumptions are comprehensively analyzed to suggest a method to indirectly estimate the potential and actual peak demand. The potential peak load is defined as the maximum peak power that must be available for individual customers under the assumption that a supply interruption does not exist. The actual peak load is defined as the maximum peak power that is transmitted to actual customers under a restricted power supply, when the situation of power supply interruptions is factored in. The methodology associated with the two peak loads is illustrated in Fig. 3.

The overall procedure to estimate those two peak demand is schematized in Fig. 4. First, the economic indices and total generation quantities, which are the past statistical data, were used to derive a second regression equation model consisting of the two variables. The regression equation model and the predicted future economic indices were used to estimate future total generation quantities.

Next, we determined the reference year in which South Korea's economic indices had a similar level, as compared with North Korea's predicted future economic indices. When South Korea's load consumption patterns of the

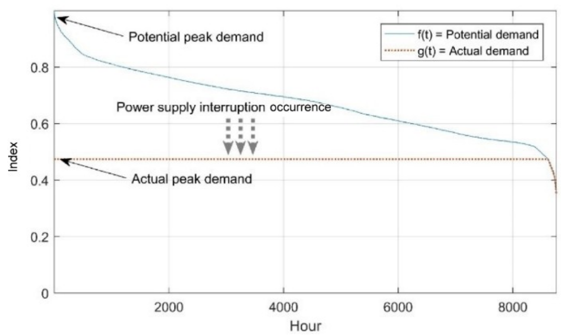

Fig. 3. Concept of the "Flat"-patterned power supply interruption model

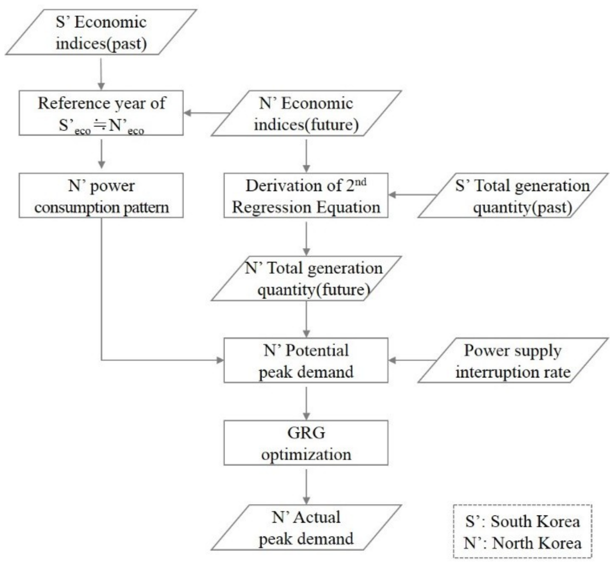

Fig. 4. Peak demand estimation methodology flow chart

reference year were extracted, they were applied as North Korea's normalized load consumption patterns for the future year of interest. Most economic reports assume that the reunification will be ultimately led by South Korea and such an assumption indicates that North Korea's industrial patterns will follow South Korea's economic structure. Since economic structures are highly correlated with electric consumption (load patterns), it is feasible to apply South Korea's load pattern to North Korea. Lastly, North Korea's total generation quantity, which was estimated in a previous stage, normalized load consumption pattern, and power supply interruption rate in the future year of interest were used to estimate the potential peak demand. In case of the occurrence of power supply disruptions, a load consumption pattern to which the "Flat"-patterned power supply interruption model was applied was used to estimate the actual peak demand.

6.2 The estimation of potential peak demand

As described in Section 5, the size of the lower bound area of the load duration curve means a total generation quantity, and the maximum value (the Y axis intercept) at the time indicates the peak demand. By following the method suggested in Section 6.1, North Korea's future normalized load duration curve (load consumption pattern), total power generation quantity and power supply interruption rate were used to estimate the potential peak demand using Eq. (6).

$$P_{poten} = \frac{1}{S_n} \times \frac{P_{gen(pred)}}{1 - \frac{R}{100}} \tag{6}$$

where

P_{poten} : Potential peak demand
S_n : Size of the lower bound area of normalized load duration curve
$P_{gen(pred)}$: Predicted annual total generation quantity
R : Power supply interruption rate

Here, the expected total generation quantity means the expected power consumption quantity in case of power supply interruptions, and the potential total generation quantity can be estimated reversely by using the power supply interruption rate. The potential total generation quantity divided by the size of the lower bound area of the normalized load duration curve is the potential peak demand. This potential peak demand is the final goal for a power system planner in consideration of the construction period, and a strategic goal from the viewpoint of power system planning.

6.3 The estimation of actual peak demand

The actual peak demand is the actual peak instantaneous power demand by customers during power supply interruptions regardless of customers' intention to use the power. This actual peak demand can be estimated by multiplying the potential peak demand value by the value of the Y axis intercept of the "Flat"-patterned power supply interruption model.

$$P_{actual} = P_{poten} \times index \tag{7}$$

where P_{actual} : Actual peak demand
Index: A value of Y axis intercept of the "Flat"-patterned power supply interruption model

The Y axis intercept of the load duration curve in the "Flat"-patterned power supply interruption model, which is defined as the "index" in this paper, can be calculated by a nonlinear equation, in which the value obtained by multiplying the size of the lower bound of the normalized load duration curve with the power supply availability rate (1 - the power supply interruption rate) is the same as the size of the "Flat"-patterned power supply interruption model. This paper used the GRG (Generalized Reduced Gradient) method among various nonlinear optimization algorithm. The GRG nonlinear optimization algorithm has the advantage of allowing easy exploration of solutions to various types of nonlinear equations. However, its disadvantage is that integer optimization is not possible. Explanation of the GRG algorithm in detail is beyond the scope of this paper [22, 23].

An objective function to minimize differences between two sizes and a constraint condition for the index's effective range of 0-1 can be expressed as Eqs. (8-11).

$$\mathrm{B} = (1 - \mathrm{R}) \times \int_1^{8760} f(t)\,\mathrm{d}t \tag{8}$$

$$B_{index} = \int_1^{8760} g(t)\,dt, \begin{cases} g(t) = index & if\ g(t) < f(t) \\ g(t) = f(t) & else \end{cases} \tag{9}$$

$$\text{Objective function: } \min(\mathrm{B} - B_{index}) \tag{10}$$

$$\text{Constraint: } 0 \le \text{index} \le 1 \tag{11}$$

Herein,

- R : Power supply interruption rate
- f(t) : A normalized load duration curve function
- g(t) : A normalized power supply interruption-load duration curve function
- B : A value obtained by multiplying the normalized load duration curve with the power supply availability
- B_{index} : A size of the lower bound area of "Flat"-patterned power supply interruption model of normalized load duration curve
- Index : A value of Y axis intercept of the "Flat"-patterned power supply interruption model

If a solution to the above nonlinear equation is obtained, an index value that meets the above constraint conditions can be determined. If the potential peak demand is set at '1', the index value is a relative proportion, and the actual peak demand can be estimated by multiplying the potential peak demand by the index value.

7. Case Study

We estimated the future peak demand of North Korea using the proposed methodology in this paper to establish systematic power system planning after Korean reunification. In the previous section, the preconditions and assumptions used to estimate the peak demand are already mentioned considering the lack of information in the North and the uncertainty of reunification. We used the GDP (gross domestic product), which is commonly used to indicate the economic size of a country for case studies. Additionally, the most recent statistical data for the South and the North, including those from the National Statistical Office, were used.

7.1 Estimation of North Korea's gross generation quantity after reunification using regression analysis

Correlation between the total GDP and the gross generation quantity was analyzed using the data collected from the statistical data and other sources [14, 15]. Since the economic reports cited in our paper focused mainly on the GDP issues in predicting North Korea's economic indices after reunification, we performed a case study by using the GDP as one of the input elements. If the estimated results of other economic indicators including GNI are available, the same methodology as ours may be applicable. The correlation coefficient between the two variables for the South from 1970 to 2012 was 0.98, compared to 0.60 for the North during the same period, with statistical significance. North Korea's coefficient is lower than that of South Korea owing to the characteristics of its closed society. Under the assumption that the reunification will be led by the South, South Korea's economic and political characteristics as well as its power supply system and policy could be applied. In other words, North Korea will follow South Korea's past power consumption pattern after reunification. Accordingly, regression analysis was conducted using South Korea's past total GDP and the gross generation data to derive the regression equation between the two variables. The related 2nd regression analysis result is shown in Eq. (12).

$$\mathrm{y} = -0.0000015632x^2 + 0.4510556517x + 71.9924821441 \tag{12}$$

Eq. (12) shows that the expected total GDP after reunification is the input (known value) and the gross generation quantity is the output. The future North Korea GDP published by Hyundai Research Institute in 2014 was quoted as the input element, i.e., North Korea's expected

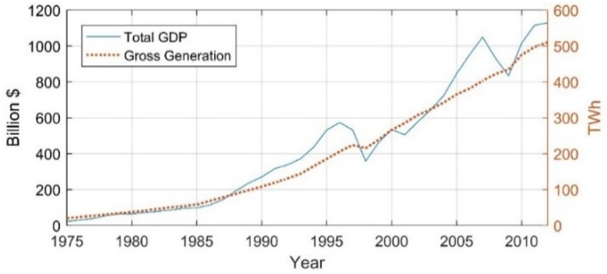

Fig. 5. South Korea's correlation between total GDP and gross generation from 1975 to 2012

Table 1. North Korea's estimated gross generation after reunification

Year	Total GDP (Billion$)	Gross generation quantity (TWh)
2015	31.8	21.5
2020	50.9	30.1
2025	86.9	47.5
2030	128.2	64.8
2040	273.6	129.5
2050	499.1	2,284

Table 2. North Korea's expected total GDP by year alongside years when the GDP of the south is similar to that of the north

Estimated year	(Expected) total GDP of the North (Billion$)	South Korea's economy in the past	
		Year	Total GDP of the South (Billion$)
2015	31.8	1976	29.8
2020	50.9	1978	53.5
2025	86.9	1983	85.9
2030	128.2	1987	143.4
2040	273.6	1990	270.3
2050	499.1	2000	533.5

total GDP after reunification [9]. Table 1 shows the North's estimated gross generation quantity after reunification, obtained with Eq. (12).

The results from the Hyundai Research Institute referenced in this paper assumed that the reunification would take place in 2015 and the overall East Asia economy would grow after reunification. Many scenarios for the reunification time and economic growth are possible but their relevance was not addressed in this paper.

The year of reunification was assumed to be 2015, which has passed. However, if additional future studies are performed on economic growth after reunification, the proposed methodology in this paper will be applicable to them and more realistic estimation results will be possible.

7.2 The load duration curve of North Korea

Table 2 shows the expected total GDP for North Korea by year after reunification alongside years when the previous GDP of the South is similar to that of North Korea. For instance, North Korea's expected total GDP in 2020 is US$50.9 billion, which is similar to the South's total GDP in 1978 of US$53.5 billion. Thus, North Korea in 2020 will have similar power consumption patterns to South Korea in 1978.

As previously shown in Fig. 2, the normalized load duration curve, which represents the power consumption pattern of that year in South Korea, is applied to North Korea's normalized load duration curve in a target year. North Korea's 2012 predicted power supply interruption rate was 30% [15]. After reunification, the existing aging power facilities or infrastructure will be pulled down and new ones will be constructed. The power supply interruption recovery is expected to be slow owing to the time required for construction but will be gradually improved because the fuel supply situation and the expansion of power plants will make things better. Therefore, we assumed a scenario in which the power supply interruption rate was 30% in 2015, 30% in 2020, 25% in 2025, 15% in 2030, 5% in 2040 and 0% after 2050. A normalized load duration curve is modified to the load duration curve in the "Flat"-patterned power supply interruption model in the case of power supply interruptions.

7.3 The potential peak demand estimation

It was assumed that the North and the South were reunified in 2015. The estimated gross generation quantity for the North is 21.5 TWh and the power supply interruption rate is 30%. As presented in Table 3, the power supply interruption rate applied in our case study is one of the input elements that assumes that government policies and their application may vary according to each scenario, but this does not affect the methodology presented in this paper. In the case study, we postulated that North Korea's power supply interruption recovery after reunification is expected to be slow during the initial period owing to the time required for constructing new electric facilities, but that it may accelerate after building new electric infrastructures.

Using Eq. (6), the potential gross generation is 30.7 TWh (215/(1-0.7)) in the case of no power supply interruptions. This potential gross generation result is divided by the area of the normalized load duration curve in 1976, then the

Table 3. North Korea's estimated potential peak demand after reunification until 2050

Estimated year (year in the South)	Estimated gross generation quantity (TWh)	Supply interruption rate (%)	Potential gross generation quantity (TWh)	Potential peak demand (MW)
2015 (1976)	21.5	30	30.7	5,189
2020 (1978)	30.1	30	40.1	7,259
2025 (1983)	47.5	25	55.9	10,326
2030 (1987)	64.8	15	68.2	12,426
2040 (1990)	129.5	5	129.5	22,508
2050 (2000)	228.4	0	228.4	37,736

Table 4. North Korea's estimated actual peak demand after reunification until 2050

Estimated year (year in the south)	Potential peak demand (MW)	Supply interruption rate (%)	Actual peak demand (MW)
2015 (1976)	5,189	30	2,461
2020 (1978)	7,259	30	3,443
2025 (1983)	10,326	25	5,445
2030 (1987)	12,426	15	7,536
2040 (1990)	22,508	5	16,243
2050 (2000)	37,736	0	37,736

potential peak demand can be calculated. Finally, the peak demand until 2050 can be estimated as follows.

7.4 Actual peak demand estimation

The actual peak demand is the peak demand when power supply interruption is considered and it can be calculated by multiplying the potential peak demand by the index of the Y axis intercept for the normalized load duration curve in the "Flat"-patterned power supply interruption model. Here, the actual peak demand is not obtained simply by multiplying the potential peak demand and the power supply interruption rate. If the GRG optimization problem is solved according to Equations 8-11, then the index of the Y axis intercept for the normalized load duration curve in the "Flat"-patterned power supply interruption model is 0.4743484. Previously, the potential peak demand was obtained, and actual peak demand can be calculated by using these values. Table 4 shows the estimated actual peak demand until 2050.

$$\begin{aligned}\text{Actual peak demand} \\ &= \text{Potential peak demand } \times \text{index} \\ &= 5{,}189 \times 0.4743484 = 2{,}461\text{ MW}\end{aligned} \tag{13}$$

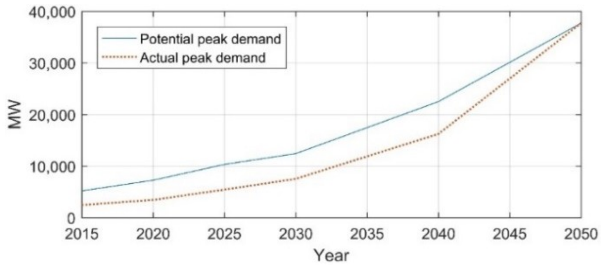

Fig. 6. North Korea's estimated potential peak demand and actual peak demand after reunification

North Korea's power supply status in 2012 indicates that the country's available power generation capacity is about 3,000 MW and the transmission and distribution loss rate is about 30%. When the methodology in this paper is applied, the estimated peak demand (the actual peak demand in 2015 right after reunification: 2,461 MW ≒ 3,000 MW × 0.7) is reasonable and appropriate.

The estimation of peak demand is critical to long-term power system planning. In particular, for preparations after reunification, systematic power system planning with estimated peak demand using various methodologies is required. Although the case study was conducted by assuming that the reunification took place in the past, i.e., 2015, we proposed a theoretical methodology for estimating peak demand based on predicted economic indices in North Korea after reunification. The proposed methodology can be applied to future power system planning studies for reunification and will yield more realistic results if more recent studies on economic analysis after reunification are performed.

8. Conclusion

In this study, we estimated future gross generation quantity using the correlation relation between economic indices and gross generation quantity. In addition, the methodology to estimate peak demand was proposed by applying the power consumption pattern according to the power supply interruption rate and economic level. Importantly, this paper has originality owing to the integration of different coupling elements to estimate peak demand, in addition to a previous methodology with simple bivariate regression analysis.

Based on the results, North Korea's peak demand was estimated assuming that the South and the North were reunified in 2015. North Korea's potential peak demand was 5,189 MW and actual peak demand was 2,461 MW in 2015. In 2050, both the potential peak demand and actual peak demand will be 37,736 MW as the issue of power supply interruptions is resolved.

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