Calculation of Value of Lost Load With a New Approach Based on Time and Its Effect on Energy Planning in Power Systems

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Received: 30.11.2020 Accepted:17.02.2020

Abstract- Stable developments in the competition and liberalization of the electricity market have necessitated the need for up-to-date policies in electricity planning and made it necessary to consider some economic costs in addition to generation costs in power plants. Among these economic costs, the socio-economic parameters are taken into consideration and the lost power value is defined as the cost of lost electricity or the lost load value defined as the cost and the value obtained as a result of multiplying the expected energy. The value of lost load is a useful value for planning about the cost of the total capacity of the power supplies. Regarding payments and suppliers made by customers, the marginal price of the system cannot be clearly stated, and it is very difficult to obtain the lost value, which is very important for developed and developing countries. In general, it refers to the monetary value of losses in electricity supply as a result of interruptions in all segments of electrical energy systems. As a result, the lost load value can be considered as a useful variable to measure one of the dimensions of energy supply security in the energy sector in a country, temporarily. In this study, the seasonal lost load value for the power system is obtained by using an innovative method for the national power system. In addition, it is argued that these values change periodically as well as consumer-based, not as a single parameter for countries.

Keywords Power systems economy, electricity market, socio-economic parameters, value of lost load, expected energy not served.

1. Introduction

Generally, electric power system operators make an effort to hold a particular part of generation capacities as Spinning Reserve (SR). Thus, the system can continue to operate regularly without the need for a sudden interruption of some Generation Units (GU) or an unforeseen load increase. Used as a conventional criterion for adjusting this amount, the reserve is equal to or greater than the capacity of the largest online generator [1,2]. Electrical measurements and finite element calculations were done to characterize the thermoelectric generator obtained [3]. This equal does not consider that there may be simultaneous outages so that the relation between the two generators is neglected [4]. Several techniques are used to specify the reserve. In the majority of the studies, it is essential to determine the reserve in the capacity of the largest allocated GU. There are many variations on this criterion. In a given system, offline units were developed to achieve the acceptable risk level [5-11]. This method is simple and practical, but it is insufficient to set the Spinning Reserve Requirements (SRR) on the basis of these standards. The cost of the reserve is not always balanced opposite the socio-economic losses that occur. If the reserve is not enough, consumers may see damage in the face of these losses. In another method, Einstein et al. [12] first considered that the discontinuity in the calculation of the SR equivalent was obtained by probabilistic calculations. This team has proposed a calculating technique that considers the possibility of forced interruption of GU. Gooi et al. [13] made initial studies on optimization in the unit commitment (UC) problem. The advantage of this approach is to optimize the reserve by keeping reserve constraints precisely in UC formulations. In each period, the cost/benefit analysis is compared with the benefit provided by the reserve marginal cost and the most appropriate level is calculated. Another aim is to reduce the expected socio-economic cost of energy not served. The disadvantage of this way is that it requires intense digital processing to perform several UC calculations before achieving the target risk value [14]. Consumption of electricity should also be flexible. This means that when the production units cannot meet the demand, they will have to be stored or converted into electricity [15, 17].

Sustainable electrical energy needs to be provided with increasing supply reliability for consumers. For this, important and continuous investment in distribution assets is mandatory. Supply cuts have financial and social impacts on customers, which vary according to the season, time of day, customer burden and customer type. Research on the Value of Lost Load (VOLL) has been done previously and identified these differences. However, it is still practical to use a uniform VOLL based on current customer energy use and allocated value. Current research has identified a number of possible values for operators to use as an incentive to reduce lost load.

VOLL is the amount of energy that corresponds to the estimated total damage caused by interruptions divided by the amount of electricity not delivered within a given time period. It is also defined as the value that an average consumer gives to an insufficient kWh rather than the cost of an insufficient kWh, or the value the customer wishes to pay to avoid a weak surplus.

It is very important to plan the capacity market in power systems and to adjust the levels of supply security generated by the policy maker. These adjustments have a major impact on research and studies on the value of VOLL. Basically, this value is obtained by equalizing the economically efficient supply security levels with the marginal cost of additional capacity and the marginal social cost of power outages. Since the cost of this is very high, it is quite difficult to use supply security efficiently. In this study, it is argued that there is a time dependent change for VOLL value and its value is calculated in this context.

ENTSO-E explains that the obstacle to using VOLL to make money from the reduction of expected energy not served (EENS) due to network supplements has inherent difficulties in obtaining the VOLL value based on the same factors. VOLL may vary considerably from country to country, both developed and developing; for example, as shown in Table 1 [18].

Table 1. VOLL estimation in year 2030

Country	VOLL Maximum range	90% confidence
Developing countries	1-10	2-5
Developed countries	4-40	5-25

Table 1 shows the results obtained from different countries for the VOLL value. The sectoral differences in electricity consumption are due to the level of dependence on electricity and time-dependent changes in the economy. Different methodologies for VOLL measurement lead to minor changes in VOLL.

Table 2. VOLL in different country

Country	VOLL ($/kWh)	Method
Sweden	Households: 0.2 Agriculture: 0.9 Public sector: 26.6 Service sector: 19.8 Industry: 7.1	R&D, WTP, conjoint analysis [19]
Portugal	1.5	Portuguese Tariff Code [20]
Spain	6.35	R&D, production function approach [21]
Norway	Industry: 10,4 Service sector: 15.4 Agriculture: 2.2 Public sector: 2 Large industry: 2.1	Surveys for incentive regulation, using both WTP and Direct Worth [22]
Italy	10.8 Households 21.6 Business	Surveys for incentive regulation, using both WTP and Direct Worth [23]
Netherlands	Households: 16.4 Industry: 6.0 Mean:8.6	R&D, production function approach [24]
Ireland	Households: 68 Industry:8 Mean:40	R&D, production function approach [25]
Great Britain	18,29	Incentive regulation, initial value proposed by Ofgem [26]
Austria	Industry 13.2, Households 5.3 Households 73.5 Industry: 203.93	R&D for incentive regulation, surveys using both WTP and Direct Worth [27]
France	26. Sectorial values for large/small industry, service sector, infrastructures, households, agriculture available	CEER: surveys for transmission planning using WTP, Direct Worth and case studies [28]
Turkey	4,06	Macroeconomic Analysis [29]

2. Effect Parameters at Value of Lost Load

Prior to the deregulation of the electricity market, it was necessary to make planning decisions based on reliability criteria, with integrated auxiliary planning, for both the transmission system and the generation system, along with lost energy costs. Interconnections between neighbouring systems in interconnected networks have been developed primarily for reliability and then to reduce losses. The development of electricity markets with a restructuring has resulted in the separation of long-term planning function for generation and transmission systems and the introduction of socio-economic costs.

On the one hand, there is more energy demand in the restructured market, and on the other hand, the objectives of the two transmission planning approaches are planning and considering the lost energy costs in the planning and decision-making processes for production and transmission.

The interruptions in the electricity generation systems ("lost load value") have financial and social impacts on customers.

a. Defining The Lost Load Value (VOLL)

It is defined as a measure of the economic value given to an amount of electrical power that cannot be provided to consumers in the event of unexpected events, ie a planned or unplanned outage of one or more components in the electricity supply process.

This socio-economic parameter can be basically in three ways:

- The amount that customers want to pay to avoid a deduction.
- The amount they want to be compensated in case of an interruption.
- The actual financial cost of downtime.

In general, survey methods are the most recommended methods to determine the value of the absence of electricity. For example, when an iron and steel plant cannot receive electricity for 1 hour:

- The product cannot produce, the order is delayed,
- Not being able to employ staff, having to work overtime in the evening to compensate for missing production,
- Consume electricity to keep the minimum system open,
- Pays a tax on all of this.

This 1-hour deduction depends on many factors such as time. For example, a weekend interruption and noticeable interruptions are different [30]. A Customer Damage Function is defined. This formula is generally:

Loss ($ / kW) = f (duration, season, time of day, prewiring)

customer loss according to downtime is given below. It is claimed that most damage occurs during interruptions lasting 40-60 minutes. The change in VOLL depending on the time and the consumer is shown in Figure 1.

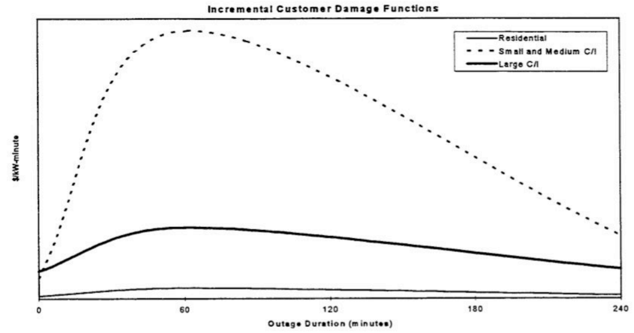

Fig. 1: Value of lost load depending on the time and the consumer

In this study, VOLL value was obtained by using seasonal changes by defending a new method by performing macroeconomic analysis. Compared values are obtained in some generally advocated methods. In one of these approaches, a specified choice of the trial (CT) is used to estimate VOLL in terms of downtime and willingness to pay (WTP) willingness to pay to accept (WTA) payment to avoid an outage for local and SME electricity users.

The CE approach allows us to investigate power outages of WTA and WTP in different lengths of time, seasons, days of the week and hours of the day. Thus, econometric estimation and standard statistical techniques can then be used to convert CT results into $ / kWh VOLL numbers and confidence intervals. This study also includes open-ended conditional valuation (CV) questions in which consumers are asked to specify dollar values for interruptions in the WTA or WTP terms. The CT method is preferred to the CV method because it allows us to examine multidimensional interruptions, reduce the likelihood of "strategic responses, and examine preferences for features above a range of price/pay levels; Nevertheless, the CV method is included as a broad cross-control.

In order to determine the cost of downtime with subsequent studies, 3 methods are proposed in the EPRI report and 3 in the published report for the UK Regulatory Authority OFGEM. Two of these 3 methods are common and a total of 4 methods are given below:

- Direct Value (EPRI): Proof and objectively measurable damage to a power outage (loss of production, labor costs, the shift of working hours, loss, etc.)
- WTP: Willingness to Pay, EPRI, OFGEM: The maximum amount that customers can pay to avoid any deductions
- WTA: Willingness to Accept (EPRI, OFGEM): The minimum compensation that the customer will be required in case of a specified deduction.

- VaR: Gross Value Added or Value at Risk (OFGEM): It is calculated based on the gross value added generated per unit electricity. (Macroeconomic account)

In this study, the gross value added per unit of electricity is calculated. Appropriate VOLL value was determined by considering consumption change according to seasons.

In the report prepared to OFGEM, it was noted that theoretically, WTP and WTA should be equal, but the results always indicate that WTA is always above WTP. In other words, while the consumer does not want to pay more for the quality of electricity, it also demands much higher figures in the event of an outage. ERCOT (Texas System Operator) 's report prepared by London Economics, which also prepares a report to OFGEM, contains interesting details on the subject [31]. In fact, while the losses of commerce and industry can be determined in some way, it is much more difficult to determine the losses of housing consumers. ERCOT argues that there are two new mechanisms to better reflect bad conditions and increase prices that will contribute to suppliers' expense [32]. The first of these is a system-wide offer ceiling of $ 9 / kWh, based on the estimate of the VOLL, which has risen steadily since 2011 and is significantly higher than the covers in other regions [33]. The other is that energy generation prices do not only reflect System Marginal Prices (SMP) but also represent the value of online reserve capacity. It also advocates taking into account the Operating Reserve Demand Curve (ORDC), a collector curve that provides potential price suppression from actions. [34].

Table 3 shows how the cost of non-electricity is determined by different methods according to the literature review in the ERCOT report.

Table 3. Cost of VOLL is determined by different methods

Region	Method	VOLL ($/mWh)	Residential
Austria	Survey	$1,544	$1,544
Australia-Vic.	Survey	$44,438	$4,142
Australia	Survey	$45,708	$44,438
New Zealand	Survey	$41,269	$11,341
United Stated	Macroeconomic analyis	$9,283	$13,925
Irleand	Macroeconomic analyis	$9,538	$17,976

The research on the Summary of VOLL Prediction Methodologies has reached the following conclusions.

- Surveys are used to estimate VOLL with the described preference (market behaviour) method to determine the customers' spending to provide reliable production (ie backup generators and cut table contracts). Uses reliable real customer data in general. Valid only if customers truly invest back-up generation - Limited consideration for the duration and/or timing of outages, which is difficult to measure the cost of residential customers.
- Specified selection (conditional valuation and combined analysis are achieved by using questionnaires and interviews to determine VOLL, a customer's request for payment, willingness to accept and swap preferences. This technique combines more direct customer preferences and includes some indirect costs. It also takes into account Downtime and/or timing. However, the experiment and survey design is time-consuming and effortful. It needs to manage potential biases and residential customers can provide unreliable answers due to lack of experience.
- Uses macroeconomic data and other observable expenditures to estimate VOLL with the proposed macroeconomic analysis. The most important advantage of this method is very few variables and easy data is obtained. In addition, a reasonable GDP proxy for commercial VOLL is provided. The only drawback is that it does not take into account the links between sectors or productive activities, and the cost attorneys of housing cuts can be arbitrary or biased.

In general, VOLL results for all consumers are presented as $/kWh in this study. These results yield a range of VOLLs based on different times and seasons for hypothetical interruptions for regional-based customers. Thus, it is expected that regional users will typically have a different value for power failure over time. The new method we obtained in this study shows that VOLL levels have changed. The highest payment for the demand-side response occurs in the event of a power outage during the winter, peak hours and weekends.

Using the method, four of the eight values are important. However, there are also some power outage scenarios that indicate that participants in the system will not be willing to pay a statistically different $ 0 value to avoid these outages.

The operating costs of the GU are paid directly by the operator, while the cost of shedding is known as a socio-economic cost, which represents the damage suffered by individual consumers and businesses deprived of electricity, depending on the economy [35, 36]. This additional cost is obtained by multiplying EENS by VOLL. VOLL, on its own, represents the average loss energy value calculated in case of an unplanned disconnection of 1 kWh of consumer power [37,38]. It is also estimated on the basis of consumer surveys [39]. Since it is impossible to predict whether the interruptions will occur at the scene, an estimated cost can only be calculated for a given programming period [40].

In all systems, the actual cost of an interruption depends on the nature of the interrupted load, but this load information is a piece of prior information that is not available. VOLL proves its accuracy using the average multiplication factor. If these data were available, the time-dependent value of VOLL could easily be included in this formulation. However, since this value depends on the conditions, it is very difficult to determine the energy not served due to certain problems as prior information. A standard technique for EENS calculation is also described [41].

3. Calculation of VOLL value based on time.

In the calculations made with different VOLL values, only slight differences in the methodological approaches to the prediction problem can occur. The economic characteristics between the power markets underlying the VOLL estimate generate data for electricity consumption models. A rural area has a linear transmission system throughout the region with a very low customer density. As a different infrastructure and investment profile is required, it is likely to have a different consumption profile. Electricity consumption patterns indicated by intensive periods due to consumption and heavy demand and customer profile are also an important factor. It is also important to understand how each customer class contributes to the total system load since VOLL is usually load-weighted in the power system. The first observation that emerges from a comparative analysis of current empirical studies on the estimation of VOLL in the literature is that there are significant differences between the average VOLL values. As a matter of fact, the survey results are particularly skewed for commercial and industrial customers, because they have a small number of customers, whose downtime costs are significantly lower than those of other participants.

The lost load value can be estimated in three ways. First used by Beenstock [42] is based on preferences determined on the basis of consumer surveys. This method is not available to us because no such Irish data is available. In some studies, it has estimated the lost energy value using cost estimates from previous supply cuts [43]. The underlying assumptions used suggest that the past and the future are similar and are not suitable for some countries given the rapid economic and structural changes that have occurred. Based on the results of the macroeconomic analysis, an average value was obtained and the parameters included in the calculations were obtained.

As a result of this approach, the electricity consumed by consumers can be obtained through a macroeconomic analysis method, using the state of the interruptions associated with the testing system, associated with the output of the manufacturer or the time spent on free work at home. [44].

As a new method, by calculating macroeconomic analysis, VOLL is calculated. In the researches, the deviation of the value obtained by macroeconomic analysis was found to be less. The value calculated by the macroeconomic analysis method for VOLL; real events were obtained using case studies of interruptions. First of all, it is necessary to obtain the value of the requests sent to the energy provider to determine the cost of the event. The average hourly wage (AHW) value is obtained as shown in equation (1) with the ratio of Disposable Income (DI) and Working Hours (WH). For the HG value, the minimum wage calculated without any deductions in our country compared to 2017 is expressed as 1.777.50 $. In the Labor Code of a worker, the monthly working hours are calculated as 225 hours. Thus, the FPS value is obtained as 7.90 $ / hour.

$$AHW = \frac{DI}{WH} \tag{1}$$

Regeneration (R) is the time a person spends on sleeping, eating, and health. (P) the total free time value of the population (FTV) is calculated as shown in equation (2):

$$FTV = AHW \times \left(P \times 365 \times \left(24 - R\right) - WH\right) \tag{2}$$

In order to indicate the loss of leisure time during a power failure, it is necessary to estimate the dependency of leisure time on electrical energy. There are three groups of activities as a dependent, independent and partially dependent. Some leisure activities, such as watching TV, are connected to electricity, while other activities such as jogging are normally independent of electricity, whereas activities such as reading at night require lighting. On the other hand, electricity-dependent activities can be substituted by other independent activities. The substitute factor (SF) indicates the percentage of free time lost if the energy supply is interrupted. The electrical energy-dependent leisure time value (LTV) is calculated by equation (3):

$$LTV = FTV \times SF \tag{3}$$

As a result, the total VOLL is calculated as shown in equation (4).

$$VOLL = \frac{GVA + LTV}{Seasonal\ Electricity\ Consumption} \tag{4}$$

In country, when the total LTV calculated by Gross Value Added (GVA) calculated as 29.855 $ is divided into electricity consumption of 278.3 billion kWh, VOLL is obtained as approximately 4,06 $ / kWh. As shown in Equation 4, since the VOLL value is directly dependent on the Seasonal Electricity Consumption value, the change in season-related electricity consumption changes the VOLL value.

It maximizes the net benefit of consumers with reliable electricity based on the level of production capacity in power systems. The optimal state of the VOLL parameter can be expressed as:

$$\frac{dEC}{dk} = -\frac{dBC}{dk} \tag{5}$$

The resulting cost of electricity and differentiated amounts in the cost of power outages affect the increasing costs. An optimum result is obtained since the increased electrical cost during a power outage is equal to ENS and therefore does not estimate VOLL.

$$\begin{gathered} CONE = \frac{dEC}{dk} \\ BC(k) = EENS(k) \times VOLL \\ CONE = \frac{dEC}{dk} = -\frac{dEENS(k)}{dk} \times VOLL \end{gathered} \tag{6}$$

The result is that the increased consumer cost results from the change in the expected cost of ENS for each incremental change in capacity for a given VOLL level. Interruption scenarios are directly related to interruptions occurring on different days. It is reasonable and intuitive and you need to make a calculation for it. They may have less flexibility in changing lost hours and input costs because staff can only work at designated times and compensate for sales. Residential work requiring electricity may be postponed, which may use alternatives that may be sufficient as a short-term substitution. It can reallocate leisure time or other leisure time that does not require electricity. They are likely to have greater value at risk during peak periods, but in most cases cannot use significantly more electricity than households. Annual seasonal calculations are made for a country with a winter, peak, average week-weighted VOLL value of $ 4,06 / kWh among different users. The comparison of the estimates for the VOLL value with the downtime using the time-varying demand profile for Summer and Winter is shown in Table 4 and 5 below.

Table 4: Variation of downtime depending on summer time

($/kWh)	Peak		Not Peak	
	Non Work	Work Day	Work Day	Non Work
VOLL WTA	9,04	9,54	8,63	8,19
VOLL WTP	5,65	4,98	5,18	6,25

As can be clearly seen in Table 4, the value of VOLL in the working hours for WTA is calculated at a higher value than the non-working hours. As shown in Table 5, this result differs in the winter months.

Table 5: Variation of downtime depending on winter time

($/kWh)	Peak		Not Peak	
	Non Work	Work Day	Work Day	Non Work
VOLL WTA	11,42	10,15	9,18	10,31
VOLL WTP	6,81	5,51	5,61	7,21

Considering the results obtained, VOLL winter months were at $ 11.42 / kWh when nonworking and consumption were highest for WTA. Considering this result, when dependency on electrical energy is maximum, when people are closest to production, they can be considered as peak times during working hours.

The results obtained provide VOLL values for hypothetical deductions for local customers which vary according to different time and seasons. It has typically a different value for power failure depending on the seasonal time of users. However, customers will not be willing to pay a statistically different value of $ 0 to avoid these interruptions. The downtime - local customers' accounts of WTA and WTP $/kWh estimates, based on the seasonally changing electricity demand profile of time, are shown in the following Table 6 and 7.

Table 6: Variation of Weekend and Week day depending on summer time

($/kWh)	Peak		Not Peak	
	Weekend	Week day	Weekend	Week day
VOLL WTA	2,41	1,80	2,39	2,88
VOLL WTP	2,76	2,06	0,38	0,46

Table 7: Variation of Weekend and Week day depending on winter time

($/kWh)	Peak		Not Peak	
	Weekend	Week day	Weekend	Week day
VOLL WTA	2,84	2,35	2,66	3,05
VOLL WTP	0,57	0,48	0,39	0,42

Considering the results obtained, VOLL was obtained as $ 0.38 / kWh during the summer months and at the hour when consumption was not peak for WTP. Considering this result, when the dependency on electrical energy is the least, when people are away from production, which can be considered as rest periods in weekend.

The seriousness of the customers in this regard is usually to lose this service. But they want to pay more than they are willing to pay. The reason for this is that individuals feel a sense of ownership for something they already have. According to the results of the researches, it is seen that the use of WTA estimates is most appropriate in the context of electrical supply security valuation. WTA shows the value of consumers' discomfort in the event that their reliable service is interrupted. In addition, it is a clear result that consumers often do not want to pay more to improve the service. In addition, he/she may think that involuntary disruptions are worth paying some amount for the service they provide when an interruption occurs. In international energy policies, it is argued that the degree of consumer impact caused by an outage is the most important factor, which points to WTA estimates. Considering the results for WTA, it is revealed that the VOLL value is higher during the hours when the industry and industry are working intensely and electrical energy is indispensable.

To confirm the accuracy of the WTA for turkey and seasonal and time-dependent change in the value obtained by VOLLA WTP results, comparison made with United Kingdom and the error rate shown in Table 8.

Table 8: Table 8: Comparison of VOLL for Turkey and the United Kingdom

($/kWh)	Peak Non Work	Peak Work Day	Non Peak Work Day	Non Peak Non Work
TR VOLL WTA Summer	9,04	9,54	8,63	8,19
TR VOLL WTP Summer	5,65	4,98	5,18	6,25
TR VOLL WTA Winter	11,42	10,15	9,18	10,31
TR VOLL WTP Winter	6,81	5,51	5,61	7,21
UK VOLL WTA Summer	36,02	40,97	39,83	36,93
UK VOLL WTP Summer	23,61	21,65	20,81	26,1
UK VOLL WTA Winter	47,68	38,32	42,35	43,05
UK VOLL WTP Winter	28,45	21,68	23,03	30,08

In the comparison shown in Table 8, the error rate graph is shown in Figure 2 below. In the calculation, a very low deviation for the UK was obtained as a result of seasonal and time-dependent VOLL change. These results are supported by the accuracy of the calculations carried out for Turkey.

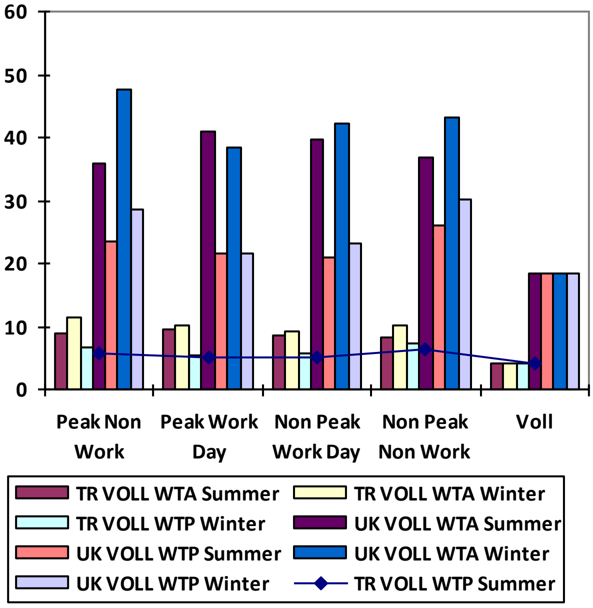

Fig. 2: Table 8: Error rate of VOLL for Turkey and the United Kingdom

4. Conclusion

In an electricity market, the VOLL value is a key parameter and can be applied in markets. Market failures are largely responsible for the difficulties in achieving socially optimal qualification levels in electricity markets only. Thus, some countries or regions aim to keep this value optimum by taking additional measures to maintain competence. It is foreseen to calculate the time-dependent value of how to select the model to be adopted to implement the appropriate methodology for VOLL calculation.

The optimum value of the measurements has been obtained in order to ensure production and system adequacy in the electrical system. In the statement that obtains the VOLL value, the change in season-related electricity consumption shows that it changes the VOLL value as it is directly related to the Seasonal Electricity Consumption value. Among the different users of the winter, annual, periodic calculations were made for a country with the highest VOLL value of $ 4,06 / kWh, weighted on average during the week. It is observed that this value changes according to the seasons. Given that this value is directly related to electricity consumption, it is inevitable that electricity consumption changes every season. In the continuation of these studies, it is aimed to examine the change in VOLL value according to consumer type. Also, obtained for Turkey VOLL, WTP and WTA results accuracy of seasonal and time-dependent change it is supported by a comparison with the United Kingdom.

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