Effect of Calculated VOLL and EENS Parameters on Reserve Planning in Power System

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***Abstract*—The steady development in the liberalization of the energy sector has made it necessary to consider new policies on energy planning and to consider some socio-economic costs in addition to production costs. These socio-economic parameters are the value of the lost load (VOLL), which is defined as the lost power value or non-electricity cost, and the expected energy not serve (EENS). VOLL is a useful measure for making decisions about the total capacity of power supplies. In terms of consumer payments and suppliers, the marginal price of the system cannot be clearly stated and therefore the lost value cannot be obtained. This value is crucial for countries that are rapidly expanding and structured in terms of electricity supply, and the possibility of supply shortages is predictable. In general, VOLL refers to the monetary value of losses in electricity supply as a result of failures in the production, transmission or distribution sections of electrical power systems. As a result, VOLL can be used as a useful variable to measure one of the dimensions of the energy supply security of a country, region or economic sector. In this study, we obtained an average VOLL and EENS value for the power system with a new approach. In addition, the effects of these values on the planning were examined and their importance was emphasized.**

Keywords— value of lost load; expected energy not served; reserve planning; unit commitment; power systems economy

I. INTRODUCTION (*HEADING 1*)

The UC is defined as a plan for the costs of production units in an audited electric power system while meeting the demanded power. Such production cost function is called UC problems based on cost, and such UC problems are defined as objective function. In addition, the cost-based UC problem and the reliability problem that is desired to be solved is the UC problem, which is based on cost-reliability. There are three main purposes of this type of UC problem.

- Cost minimization,
- Meeting the requested power,
- Reliability is the provision of constraints [1].

The liberalization of the electricity market implies that market players and regulators are facing increasing uncertainty, investment risks and flexibility requirements [2]. Sustainable development policy implemented within the framework of targeted strategies; to reduce the consumption of traditional energy resources (oil, gas and coal) to create a competitive, low-carbon economy [3]. In order to compensate for this ambiguity, a reliable load distribution and UC must be made in the system. UC problems arise in the determination of the operation of the Generation Units (GU), and a determination is required for the reliability of this operating system. It is necessary to provide Spinning Reserve (SR) at a minimum cost and appropriate production levels of the units to meet short term demand [4,5,6]. There are some restrictions on the operation of these units. Furthermore, the problems of the UC are large nonlinear mixed integer programming problems. Consumption and electricity generation must be balanced at any point in time. That is why different technologies are used for production and balancing with their own specific technological capabilities and constraints for different applications [7].

Generally electric power system operators make an effort to hold a particular part of generation capacities as 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, SR is equal to or greater than the capacity of the largest online generator [4]. Electrical measurements and finite element calculations were done to characterize the thermoelectric generator obtained [8]. This equal does not consider that there may be simultaneous outages, so that the relation between the two generators is neglected [9]. Several techniques are used to specify the SR. In the majority of the studies, it is essential to determine the SR 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 [10,11,12,13,14]. This method is simple and practical, but it

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is insufficient to set the 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. [15] 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 consider the possibility of forced interruption of GU. Gooi et al. [16] made initial studies on optimization in the UC problem. The advantage of this approach is to optimize the SRR by keeping reserve constraints precisely in UC formulations. In each period, the cost / benefit analysis is compared with the benefit provided by the SR 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 [17]. 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 [18].

II. Reserve Requirements and Calculations in Power Systems

There are commonly used decisive criteria to adjust the SR to the desired amount so that the system can tolerate YU without resorting to any UU interruption. These criteria are also known as the N-1 criterion [4]. It is necessary to calculate the following constants in order to obtain the minimum SR quantity in period t in the system is shown in equation (1).

$$\left(u_{i,t}P_{i,max}\right) - \sum_{i=1}^{N} r_{i,t} \leq 0 \quad i = 1,2, \dots .N \tag{1}$$

Where $r_{i,t}$ i is the SR contribution over time t for i units. $P_{i,max}$ is the maximum production value of the i unit and $u_{i,t}$ is the state of the value unit i (1: allocated, 0: unallocated). As can be understood from the equation above, it is necessary to consider all possible disruptions individually to set up the backup. However, by setting SR requirements, a certain amount of SR is provided to cover the loss of the largest on-line generator is shown in equation (2).

$$r_{d,t} = \max(u_{i,t}P_{i,max}) \tag{2}$$

Where: $r_{d,t}$ defines the system-wide SR requirement. These criteria are used in systems in the southern PJM lake. In order to meet these criteria, no load will have to be cut in the case of any unit that is suddenly interrupted, and there is no guarantee that if both units are cut at about the same time, they will produce the same positive result. In essence, this criterion is given the possibility of simultaneous losses, such as the interruption of a single unit, which increases the risk.

$$r_{d,t} = \max(u_{i,t}P_{i,t}) \tag{3}$$

The amount of SR provided in the system can be explained based on the SR requirement is shown in equation (3) since it is higher than the active maximum ICU output. However, any single UU will cause an uninterruptible load. Thus, this criterion is not supplied as SR (3). The SR requirement in Yukon Electric consists of the combination of the largest UC and peak demand percentage is shown in equation (4).

$$r_{d,t} = max\left(u_{i,t}P_{i,max}\right) + 10\%(peak\ load) \tag{4}$$

A. Overview of the Recommended Method Used and its flow operations

The methodology used in the study consists essentially of two parts, first of which is the determination of the optimum SR requirement as time-separated, and planning it taking into account the optimum SR requirements by the traditional UC program. Then, temporal matches are made between the production units and the solution is added taking into account the socio-economic parameters. The flow diagram of the schematically suggested approach is shown in Figure 1.

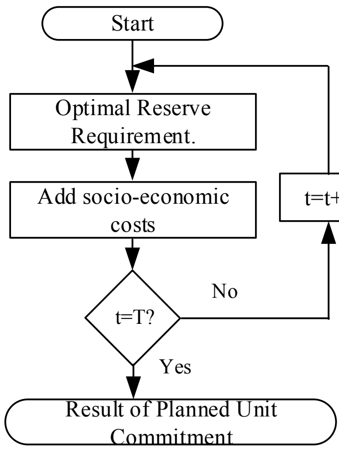

Fig. 1. *Flow of Planned Unit Commitment with Reserve Evaluation*

At the start, information about the power systems is collected (starting costs, production costs, constraints of the units, availability of the units, etc.), and at the same time the load case forecast information for optimization is obtained. Then, the optimal SR requirement for each period of optimization is calculated. Optimal SR requirements are then determined for each period by adding the calculated socio-economic costs to the resulting cost. This information is supported for UC optimization to find a solution to all inter-time constraints considered.

B. Calculation of production cost and required parameters

In order to obtain the minimum total cost of the operating system, it is necessary to plan the possible combinations of the units by making a programming which includes all the probability distributions of the probabilities and the socio-economic costs for each case.

This is not a trivial calculation, and it is only a matter of probability that the supply of SR is a fundamental question. It is due to the fact that there are no parameters used directly in calculations, including the distribution of downtime in the optimization process. In order to obtain the load or energy estimates, the interruption states of the production units are not obtained considering the ramp up / down rates of the different production units. The ramp up / down speeds of production units limit the available spare production capacity in case of ramp up. Thus, the distribution of production units will play an important role in the allocation of SR between the units, and the interruption will occur according to the value of EENS. The proposed UC formulation minimizes the following objective function shown in equal (5):

$$UC = min\left\{\sum_{t=1}^{T}\left[\sum_{i=1}^{N}\left[SE_c(c_{els,t}) + s_{gui,t}(u_{i,t}) + c_{gui}(u_{i,t}, p_{i,t})\right]\right]\right\} \quad (5)$$

The generation costs of thermal power plants are often a non-convective function, but these functions are often evaluated in terms of convective quadratic functions of economic distribution and topology solution algorithms [4, 19]. Therefore, the generation cost of unit i is modelled as equal (6):

$$c_1(u_{i,t}, p_{i,t}) = u_{i,t}\left[c_i + b_i . p_{i,t} + a_i(p_{i,t})^2\right] \quad (6)$$

The cost of start-up a thermal power plant is a function of when the unit is off. In other words, a unit that produces hot is a unit that is cold and has a cheaper price. This effect is usually approached by exponential is shown in equation (7).

$$s_{i,t}(u_{i,t}) = (1 - u_{i,t-1})k_1 u_{i,t} \quad (7)$$

When $t = 1$, the initial cost will depend on history of the unit's $u_{i,t}$, ie if $u_{i,t} = 1$, the initial cost is zero since the unit is pre-allocated. Furthermore, if $u_{i,t} = 0$, the initial cost is k_1. The objective function minimization includes an extra term according to the classical UC formulations SE_c. This term represents the expected cost in the event of a load shedding against the generation interruptions at time t. This approach includes all conventional constraints except that a fixed SR amount is provided. This study offers a method that equalizes the cost of SR provision with the utility of electricity market reserves. The utility of the reserve is measured with respect EENS, which is the reason for the deficit of generation capacity. As the amount of SR provided raises, the operating cost of the system raises and the expected socio-economic cost of discontinuities reduces, because the possibility of a load shedding in response to interruptions of GU is reduced [20].

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 [21, 22]. This additional cost is obtained by multiplying EENS by VOLL (8). VOLL, on its own, represents the average loss energy value calculated in case of unplanned disconnection of 1 kWh of consumer power [23]. It is also estimated on the basis of consumer surveys [24]. Since it is impossible to predict whether the interruptions will occur at the scene, an estimate cost can only be calculated for a given programming period. The expected cost of socio-economic is as follows [25]:

$$SE_c = VOLL \times EENS \quad (8)$$

In all systems, the actual cost of an interruption depends on the nature of the interrupted load, but this load information is a prior information that is not available. VOLL proves its accuracy using 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 the priori information. A standard technique for EENS calculation is also described [26].

III. Calculation of Parameters According to Test Model and Flow Diagram

A probabilistic reserve determination can be achieved by taking into account the reliability of individual planned units and providing the correct level of reserve with the correct load estimate. In the proposed approach, this evaluation occurs at two stages between UC minimization and maximization [27]. Figure 2 shows a general view of the method of UC determination. The two-stage UC is concerned with assessing the risk and setting reserve requirements for each interval. The cost of socioeconomic parameters is added after the need is determined.

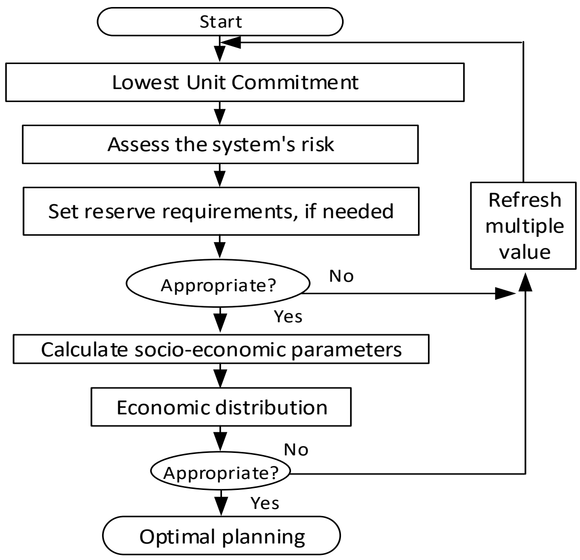

Fig. 2. *Recommended flow chart for UC determination method*

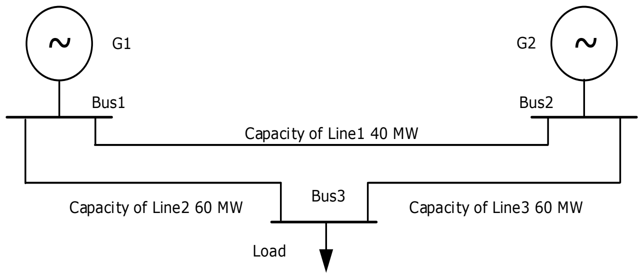

Fig. 3. *Model of recommended test system*

As shown in (8), which uses the VOLL value without calculating, all distribution interruptions in the power system must be included in the optimization. However, since the number of permutations of the units has large values for the UC program, it is very difficult to determine and incorporate, and it is not possible. The test system used in this study is modelled as two basic generators and loads and is shown in Figure 3 [28].

TABLE I. INFORMATION OF GENERATORS

Generators	1	2
Minimum capacity of generators	40 MW	20 MW
Maximum capacity of generators	100 MW	80 MW
Cost of generation	10 $ / hour	12 $ / hour
Start-up cost of generation	180 $ / hour	110 $ / hour
Outage Replacement Rate (ORR/1-ORR)	0.01 / 0.99	0.02 / 0.98
Capacity of Load	80 MW	120 MW

Information of generator and load data are given in Table 1. The problem is described as follows: The initial state of G1 and G2 is OFF. The minimum up / down time is one hour. Ramping constraints are not considered here. Commitment Capacity (CC) is the total generation capacity, Outage Replacement Rate (ORR) and the maximum EENS is obtained (5) according to Table 1. In a particular program, the Loss of load probability (LOLP) parameter is used to measure the associated risk.

$$\sum_{i=1}^{N} EENS^t = (ORR) \times (LOLP) \times (Time) \quad (5)$$

TABLE II. INFORMATION OF POWER TEST SYSTEM

Status	G1 (MW)	G2 (MW)	CC (MW)	EENS (MW) $t_1 - t_2$	LOLP $t_1 - t_2$	LOLE (MW)	SR (MW) $t_1 - t_2$
1	0	0	0	0-0	0-0	0-0	0-0
2	1	0	100	79,2-118,8	80-120	0-18,8	0,8-1,2
3	0	1	80	78,4-117,6	80-120	0-37,6	1,6-2,4
4	1	1	160	77,6-116,4	80-120	0-0	2,3-3,5
			Total	235,2-352,8	240-360	0-56,4	4,7-7,1

Information of Power Test System input data are given in Table 2. According to Table 2 $\sum_{i=1}^{4} EENS_{t1} = 235{,}2\ MW$ and $\sum_{i=1}^{4} EENS_{t1} = 352{,}8\ MW$ is obtained. The production capacities allocated in the power systems differ in real time in four cases, morning, noon, evening and night, which are allocated according to day ahead and intraday planning. At some time during the day, production can compensate for consumption, but supply peak demand such as morning and evening cannot provide a supply-demand balance. If the value of capacity obtained from the CC is larger than the load value, the difference between the value of actual generation and the load amount is taken as the basic SR demand, which is $SR_{t_1} = 4{,}7\ MW$ and $SR_{t_2} = 7{,}1\ MW$ for 2 hours.

The lost load value can be estimated in three ways. First used by Beenstock [29] 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 [30]. 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, it associates the electricity used by consumers with the output of the producer or the time spent on unpaid work in the household. The VOLL can be obtained by a macroeconomic analysis method using the state of the cuts related to the test system [31]. First, the value of the requests sent to the energy provider must be obtained to determine the cost of the incident. Then, the average hourly wage (AHW) value for Turkey is obtained as shown in equation (9) with Discretionable Income (DI) and Working Hours (WH) ratios [32].

The HG value is expressed as TL 1777.50 which is calculated by excluding the discontinuities in our country by 2017. The labor law of a worker is calculated as 225 hours per month. Thus the AHW value is obtained as 2,25 $ / hour.

$$AHW = DI / WH \quad (9)$$

Regeneration (R) is time when people spend on sleep, eating and health. (P) is calculated as shown in equation (7) of the total leisure time (TLT) of the population:

$$TLT = AHW * (P * 365 * (24 - R) - WH) \quad (10)$$

As a result, the average VOLL value is calculated as shown in equation (10). The total of TLT calculated by the Gross Value Added (GDP) calculated as 8.530 $/TL in our country is divided into electricity consumption of 278.3 billion kWh, VOLL is obtained as approximately 3,94 $ / kWh is shown in equation (11).

$$VOLL = \frac{(GDP + TLT)}{Electricity\ consumption} \quad (11)$$

As a result of these calculations, VOLL for Turkey was approximately 3,94 $ / kWh. Respectively, according to equations (5) and (8), and socio-economic cost $SE_{c1} = \$\ 926{,}6$ and $SE_{c1} = \$\ 1.390$ This value is a socio-economic cost to be added to the UC process. As a result, the optimum cost of UC is obtained as $UC_{t1} = \$\ 1.906{,}6$ and $UC_{t1} = \$\ 2.740$ according to equation (5).

IV. Conclusion

In energy systems, it is claimed that socio-economic costs, initial costs and production costs should be taken into consideration when it is desired to have planned optimum UC. In this study, it has been shown that the cost of UC has changed by adding the cost of socio-economic parameters to the extent of planning and economic gain. Thus, as the demand for electricity in a country increases, both the production capacity and the burden on the distribution networks increase, which in turn depends on the consumer's dependence on a reliable source of electricity. Increasing electricity use in developing countries necessitates new planning for production and new network requirements, which should increase the reliability of the system compared to evolving requirements.

In this study, the mean value for the VOLL of the EENS value according to the test system was calculated by macroeconomic analysis and UC optimum distribution was obtained according to the result obtained. According to the results, it is presented that it increases the reliability of the system by considering the socio-economic costs while performing the UC

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