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Power Systems Reliability Assessment based on Load Shaping Consideration

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***Abstract* – The load shaping technique is an important key that has been widely implemented inelectrical power systems. The benefits of this activity involve system reliability enhancement and operation requirement satisfaction. In this study, the benefits of load shaping are investigated based on reliability impact. First, the reliability indices have been assessed with no original load. Secondly, the same indices are assessed when load shaping is considered. Results show that the proposed model yields higher accurate reliability assessment and, therefore, a more robust strategy to be implemented. Monte Carlo simulation is utilized to calculate predicted energy not supplied.The paper demonstrates IEEE reliability test system. It describes a comparison of reliability of generating systems based on real time assessment.**

***Keywords* – Demand-side management, Peaking unit, Reliability, Adequacy of supply.**

1. Introduction

Electric utilities must effectively deliver electricity to end users with acceptable level of adequacy of supply and environmental friendliness.

It is not practical to implement fully reliability with zero pollution level in electrical power grids. Thus, power grids designers implement a system with a tolerable level of adequacy and environmental pollution while keeping the production costs low [1]. The generation systems' production cost is a vital key in power system design for manoeuvring the existing alternatives [2]. As a sequence of rising pollution and industrial growth, satisfying demandrepresents a major challenge. Although reliability of generating units can be enhanced by increasing the quality and quantity of system facilities, this expense must be justified by the cost of adequacy enhancement. In this regard, the economic and reliability restrictions are diametrically opposed and competing [1]. Thus, finding the best managerial option throughout the planning stages is therefore advantageous for guaranteeing customer happiness at all times.

Reliability of generating systems is referred to as the capacity of generation units' side to meet load side demand. Transmission and distribution systems facilities are not taken into account in such assessment[1]. Demand shaping is an important strategy for lowering the risk level [3].

As peak demands are minimized, the reliability of generation systems will be improved [4], [5]. It works by clipping, filling, shifting the load demand with level specified by the operator. In this study, six models and two case studies of investigation are achieved based on load shaping impacts on electrical power systems' dependability and production cost.

The assessment of the power system reliability at generation side is commonly achieved with a two-state model, where all generating units, regardless of generator category, move between down and up states. The partial outage of producing units is not taken into consideration in the two-state model. Furthermore, the two-state model can't be utilized to represent peak and cycle producing units since they could not be required if both are out of commission owing to an unanticipated outage. To address this point, a fused model is necessary that takes into

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account all of the aforementioned assumptions in order to arrive at an appropriate estimate of generation system reliability.

Given that the major goal of load shaping is risk reduction, an accurate assessment of the influence of shaping on system efficiency is critical. Load shaping approaches are often used to reduce system risk or to compensate for load reductions caused by unforeseen outages. Corrective load shaping is used immediately after an adequacy shortfall occurs, whereas preventative load shaping is used before risk periods occur [6], [7].

However, there is still no comparison methodology and assessment in the published related research that has been handled on a quantitative basis the load shaping benefits based on reliability of generating systems and production cost. The reliability benefits were compared with that of the operation to highlight the mutual link between them.

Considerable work has been conducted on the load shaping impact. Battery energy storage systems has been integrated with load shaping to reduce the production cost [8]. load shaping as peaking units is investigated [9], [10], [11], [12]. The load shaping impact has been assessed based on reserve margin [13]. Corrective and preventive load shaping activities are applied to assess their impact on the reliability of generating systems [6], [7]. Load shaping has been addressed to estimate production reliability and cost [14]. Renewable energies and load shaping have been integrated in [15], [16], [17] to evaluate the adequacy of supply. Load shaping has been integrated with reserve buffer for Indiana's power generation [18]. Economic benefit is commonly decreasing production costs and enhance the efficiency [19]. If demand fluctuations are maintained to a minimum, the system will become the most secure and reliable. At customer's side, therefore, load shaping minimises cost [20],[19]. Industrial load shaping has been modelled to enhance the efficiency of generation systems [21-29]. Load shaping program offers financial risk mitigation tool for real-time pricing[30] and lead to decreasing production cost by moving load from costly to low cost time, resulting in decreased manufacturing costs [31]. Environmental benefit based on load shaping is commonly decreasing the emission dispatch [32]. Reduction of energy production leads to dwindling greenhouse gas emissions and therefore mitigates the negative environmental impact [33-37]. Generators' shutdowns and restarts leads to extra fuel burning. Hence, lessening startup can decrease emissions [38], [39] and dependability. Furthermore, no quantitative foundation has been presented in the literature. However, there has been minimal research on the impact of load shaping on production costs, and reliability. Furthermore, the literature hadn't provided a quantitative basis load shaping measures under reliability assessment of hybrid model after taking into consideration the partial and unplanned outage of the generating units and load uncertainty. The current studiesintend to fill these gaps. The remaining of the paper is organized as follows. Frameworks of load shaping and reliability indices are presented in Section two. Section three encapsulates the findings and discussions. Concluding remarks of this work is given in Section four.

2. Method

Electric generation systems are organized into three hierarchical levels (HLs): generation, transmission, and distribution. HL1 solely covers generating systems; HL2 includes both generating and transmission lines; and HL3 adds extra distribution systems. The power system adequacy study is also known as the HL1 assessment. The only emphasis of evaluating generating systems' adequacy is their capacity to fulfill customer demand. The evaluation of HL1 is the topic of this research. Load shaping operates by decreasing demand during the following; (1) peak period (2) high production cost (3) high electricity price (4) when emission exceeds a prespecified value. The utility replenishes the clipped energy sequentially during the off-peak, low production cost period, low electricity price and less affected period due to emission. Taking these actions as needed is called load shaping.

To estimate generating capacity adequacy, a two-state model is commonly employed, where all generators pass solely between up and down states, without taking into account the generating units types and their partial outages [1]. To compute Expected Energy Not Served (EENS), sequential MCS is used in conjunction with a load model. MATLAB programming language is used to model and simulate the system. The sample size for sequential MCS is 3000 trials. Power systems and the IEEE reliability test system (RTS) load profile are realized. The IEEE-RTS power model has 8736 load data points and a total installed generating capacity of 3405 MW [40], [41].

To determine the dependability indices of the power systems, sequential MCS is used in conjunction with a load model. MATLAB programming language is used in this study to model and simulate the system. The sampling size is 3000 trials. This is because, in this work, all of the simulations converged about the 2500th trials. Therefore, 3000 trials were chosen as a cautious strategy to ensure that an appropriate number of simulations were run to achieve convergence. In this work, the IEEE-RTS power systems and the load profile are realized [40], [41]. The generating systems feature 32 generators of 3405 MW total capacity, servicing a peak load of 2850 MW every year. The IEEE-RTS generation system model has 8736 data samples of loads profile.

By adding the generation and load models, the risk model or the system's probable margin model is constructed. A positive available margin value indicates that the energy delivered is adequate to fulfill system demand, while a negative value shows system insufficiency. As a result, part of system requirement must be reduced. EENS depicts average amount of load loss owing to generation inadequacy. The energy not provided (ENS_i) in MWh is determined by available capacity in each sampled year.

The HLI reliability assessment of the generation system may be described using a variety of indicators.The loss of load expectation (LOLE) displays the average length of being unable to meet electrical demand, whereas the loss of load probability (LOLP) represents the likelihood of the system load surpassing available producing capacity. The terms LOLP and LOLE are tightly linked. The LOLE is derived instead of the LOLP when the time period utilized for the LOLP is given in time units rather than percentage values [42]. The average of load loss due to producing insufficiency is depicted by EENS. The predicted period of encountering a generation shortfall in a particular time is known as the loss of load frequency (LOLF) [1], [43],[44]. EENS, LOLE,LOLF and LOLD in s sampling years are calculated using :

$$\boldsymbol{EENS = \frac{\sum_{i=1}^{s} ENS_i}{s} MWh/year} \tag{1}$$

$$\boldsymbol{LOLE = \sum_{i\epsilon s} P_i} \quad (\textbf{Hour/year}) \tag{2}$$

$$\boldsymbol{EENS = \sum_{i\epsilon S} 8736 C_i P_i} \quad (\textbf{MWh/year}) \tag{3}$$

$$\boldsymbol{LOLF = \sum_{i\epsilon S} (F_i - f_i)} \quad (\textbf{Interruption/year}) \tag{4}$$

$$\boldsymbol{LOLD = LOLE/LOLF} \quad (\textbf{Hour/interruption}) \tag{5}$$

Load shaping models are discussed in [6], [7], [9]. Equations (6-9) provide the mathematical model of load shaping based on the risk mitigation.

$$\overline{\mathrm{A}}_{\mathrm{t}} = \mathrm{A}_{\mathrm{t}} - ((\mathrm{A}_{\mathrm{t}} - \mathrm{e})\mathrm{H}_{\mathrm{t}})$$

$$\text{where } \mathrm{H}_{\mathrm{t}} = \begin{cases} 1 & \text{if } \mathrm{A}_{\mathrm{t}} > e \\ 0 & \text{otherwise} \end{cases}$$

$$\overline{\overline{\mathrm{A}}}_{\mathrm{t}} = \overline{\mathrm{A}}_{\mathrm{t}} + (\mathrm{Y} \frac{\sum_{\mathrm{a}}^{\mathrm{b}} \{\mathrm{A}_{\mathrm{t}} - (\mathrm{A}_{\mathrm{t}} - \mathrm{e})\mathrm{F}_{\mathrm{t}}\}}{n} \mathrm{R}_{\mathrm{t}})$$

$$\mathrm{F}_{\mathrm{t}} = \begin{cases} 1 & \text{for } \mathrm{t}_7 \leq \mathrm{t} \leq \mathrm{t}_8 \\ 0 & \text{otherwise} \end{cases}$$

Where A_t represents the initial value of system's requirement, $\bar{A}_t$ and $\bar{\bar{A}}_t$ represent changed curves that result from performing a load-shifting operation, e is the maximum pre-specified peak load level, Y is the recovered energy percentage during off-peak hours bounded by a value range from 0 to 1, and a and b are the first and last hours respectively. When the starting load is more than e ($A_t > e$), t_7 and $t_8$represent the beginning and last hours respectively for energy recovery during off-peak hours, and n is the length estimated from t_7 and t_8 difference.

System risk model is produced by combining the generation and load models. After that, the EENS value is determined. In this study, EENS is analysed by sequential Monte Carlo simulation (MCS). The real-world process of generating systems and their unpredictable behaviour is modelled by sequential MCS. EENS is determined by multiplication of load data and production units' total available capacity and energy shortage.

The fixed production involves fuel cost of generation units during operation and start-up and shut-down actions. While variable cost involves the maintenance cost. Production cost can be calculated by determining the forecasting load model and the commitment of each generators in the system in terms of the predicted energy served and not served [45].

The proposed framework encapsulates nine steps as follows:

Model 1, in which EENS, LOLE, LOLF and LOLD are computed with the original load model using two-state model to create a scenario in which all of the generating units fail.

Model 2 is identical to Model 1, with the exception that the 350 MW and 400 MW units are considered to be capable of 50% de-rated capacity.

Model 3 that uses a four-state model to represent peaking and cycling units and a two-state model for other units.

Model 4 is a fused model that combines following models: two-state, three-state, and four-state. Peaking and cycling units are simulated with the four-state model, 400 MW and 350 MW units with the three-state model, and other units with the two-state model.

Model 5, where Step 1 is repeated while taking into account scheduled maintenance and LFU.

Model 6 is a mixed mode hat takes into account planned maintenance and LF

Model 7 Impact of load shaping is investigated based on the 6 models.

3. Results

The results are divided into six categories, each with two case examples. The most prevalent situation is Case 1, in which reliability indices and production are obtained without load shaping. The second case is identical to the first, except that the shaping is implemented separately in each model. Table 1 presents the results of reliability indices.

Table 1. Case study one and two

Case study one: Without load shaping						
indices	**Model 1**	**Model 2**	**Model 3**	**Model 4**	**Model 5**	**Model 6**
LOLE (hr/yr)	**9.3716**	**5.5404**	**6.8280**	**3.9403**	**46.1563**	**18.9140**
EENS (MWh/yr)	**1197.4448**	**642.0654**	**843.5645**	**446.5633**	**6377.4311**	**2171.0449**
LOLF (occ/yr)	**1.9192**	**1.2140**	**1.4120**	**0.8850**	**9.6435**	**4.6546**
LOLD (h/int)	**4.8830**	**4.5637**	**4.8356**	**4.4523**	**4.6152**	**4.0634**
Case study two: With load shaping						
LOLE (hr/yr)	**4.9753**	**4.2215**	**5.1036**	**3.1945**	**33.2321**	**15.5501**
EENS (MWh/yr)	**724.0161**	**348.9096**	**499.0190**	**212.1098**	**4498.0652**	**1974.7148**
LOLF (occ/yr)	**0.8330**	**1.0034**	**1.1564**	**0.5945**	**7.9932**	**3.2341**
LOLD (h/int)	**5.9727**	**5.7761**	**5.0021**	**5.8821**	**5.9761**	**54391**

The two-state model's EENS value is 1197.4448 MWh/year [6], [7]. The influence of load shaping on system reliability and production cost is as discussed below:

The load shaping has a considerable influence on the reliability indices, as shown in Table 1. Load shaping improves the LOLE and LOLF, while having a minor influence on the LOLD, as depicted in this table. Load shaping, on the other side, aims to reduce the need of peaking load units, resulting in increased dependability and lower average generation costs. Determining load shifting measurements will be more precise than two-state model since suggested hybrid model considers the duty cycle of peaking and cycling generating units as well as partial outages of the biggest generation units. As a consequence, the findings significantly contribute to more useful decisions during power systems' planning phase. These findings will allow power system designers to make more correct choices, resulting in a more realistic evaluation of reliability indices. The findings support the notion that reliability indices varied significantly. It should also be highlighted those dynamic concerns of available system capacity and load have a significant influence on power system adequacy and should therefore be appropriately modeled.

Increasing the availability of supply at the planning phase can improve the reliability of generation networks, even though it raises the initial costs. The additional cost may not be worth it in terms of greater reliability. To attain an optimal planning choice of reliability level, a compromise between investment cost and load shaping programs may be accomplished. Peak load units are normally required for few hours each year, while base load units required virtually every time. Because of load levels variation at the time of necessity, cycling units have a frequent starting and shut down running each year. To do this, all generating units must commit to an ideal balance. Peaking load units are often needed throughout peak periods, as well as when total available capacity is inadequate to meet demand. It should be noticed that peaking load units are rarely used to generate electricity. Peaking load units are excessive to produce than base load units. They are commonly employed during peak demand. The aim of the load shaping program is to minimize peaking load units, which lowers the average production cost.

All reliability indices, in case of load shaping is not employed, are greater than load shaping case study. This highlights the benefits of load shaping measures in terms of reliability. EENS enhances by almost twice when load shaping is taken into account. As a result, load shaping has a significant impact on the reliability of generating systems. Load shaping effects the demand curve and impressively enhances the cost, reliability and environmental impact.

4. Conclusion

This study investigates the integration of a load-shaping tool with electrical power grids to enhance reliability of generating systems and to reduce production cost. The benefits of load shaping are system reliability enhancement and production cost reduction. Load shaping is the essential contributor to demand management. This paper describes a comparison between production cost and reliability of generating systems based on load shaping assessment. Additionally, the results show that the hybrid model yields higher accurate reliability assessment and is, therefore, a more robust strategy to be implemented. The results provide indicators for electric power utilities involved in the planning phase of electrical power grids. This study is conducted using the IEEE reliability test system. Monte Carlo simulation is utilized to calculate predicted energy not supplied.

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