Badr Mesned Alshammari[1], Tawfik Guesmi[1], Mohammed Eleiwa[1], Rabeh Abbassi[1], Mohammed Alghassab[2]

University of Ha'il (1), Shaqra University (2), Saudi Arabia

doi:10.15199/48.2020.09.34

Optimal Technique of reliability and quality Assessment of two-area interconnected power systems

Abstract. *The evaluated reliability and quality measures, which are important to assess the reserve capabilities of the power system for various operating scenarios, are probabilistic in nature. To improve the reliability and quality of two area interconnected power systems must be to make sure that the ability of one area to deal with compensate the deficiency in the other area. This paper presents a novel assessment technique of two-area interconnected power system based on the reliability and quality measures, as well as, the capacity and situation of tie line and the Load Not-Served (LNS). Systems with hundreds of buses and tens of complex stations can only be analyzed using advanced and numerically effective large-scale algorithms for reliability and quality assessment as demonstrated in this paper. Practical applications are additionally exhibited, for demonstration purposes, to the Saudi electricity power networks.*

Streszczenie*. Do poprawy niezawodności i jakości energii dwóch obszarów z siecią energetyczną trzeba być pewnym że jeden obszar może zawsze uzupełnić niedostatki drugiego. W artykule zaprezentowano technikę połączenia dwóch obszarów bazującą na pomiarach niezawodności I jakości energii oraz metodę LNS.* ***Optymalna technika zapewnienia niezawodności I jakości energii dwóch współpracujących obszarów z systemami energetycznymi***

Keywords: Power systems, Reliability Assessment, interconnected systems, quality
Słowa kluczowe: system energetyczny, połączenie dwóch systemów

Introcuction

In the recent years, research has been focused on the design of these different generation adequacy mechanisms [1]. But all of them remain based upon engineering planning criteria to measure adequacy (e.g. Loss of Load probability – LOLP) in order to make the adequacy policy setting [2]. The typical adequacy measures with deterministic techniques is capacity generation margin to be equivalent to a fixed level of the peak demand and operating reserve margins adequate to adapt with the most likely contingencies. One of the downsides of these techniques is that they don't consider the stochastic nature of supply and demand. Indeed, random events as uncertainty in customer demand, forced outages of generating units, intermittent production have an impact on the adequacy assessment [3]. Probabilistic methods provide therefore a more meaningful and realistic information about the random events that affect supply and demand [4]. One of the important indices is used in the probabilistic methods, Load Not Served (LNS), which indicates that a system load would be lost, fully or partially, due to randomly occurring single or multiple contingencies (outages) in the system [5]. System reliability and quality evaluation of interconnected power systems is an important issue of investigation, therefor, many research and development studies have been proposed [6, 7]. This paper presents a new practical novel approach for effective evaluating power system reliability and quality of two area interconnected. A new approach investigates the Capacity Reserve Margin (CRM) for two areas, capacity of tie line, the Load Not-Served (LNS) and quality performance measures. The novel technique utilizes a basic linear programming formulation, which offers a general and comprehensive framework to assess the harmony and compatibility of generation and demand in a power system.

Problem formulation

The electrical power system can be defined for the purpose of composite reliability and performance Quality analysis by the three-component model, as shown in Figure 1, in which generation, transmission and load are considered as multi-state elements of the power system.

The novel framework applied in this paper based on the original work of [8], in which three dimensions were introduced to represent the relationship between certain system generation capacity and the demand. These tropes relate to the following demand fulfillment issues:

a) Need of capacity for demand fulfillment
b) Existence of capacity (availability for demand fulfillment)
c) Ability of capacity to reach the demand

The first trope defines whether or not the capacity is needed, the second trope defines whether or not the capacity exists, and the last trope defines whether or not the capacity can reach (delivered to) the demand. The eight possible combinations associated with the 0/1 (Yes/No) values of the three tropes, are illustrated in Table 1.

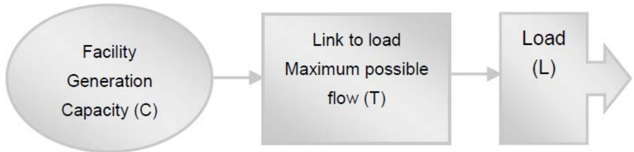

Fig. 1. System model for reliability and quality analysis

Table 1. Illustration of quality assessment tropes

	NEEDED (L >0)		NOT NEEDED (L = 0)	
	Cannot reach	Can reach	Cannot reach	Can reach
Redundant Qg010	Surplus Qg011	Bottled Qg110	Utilized Qg111	Exist (C > 0)
Saved Qg000	Spared Qg001	Deficient Qg100	Short-fall Qg101	Not-Exist (C = 0)

Generation quality indices are defined in terms of the previously defined “1/0” states indicating the (Needed, Exists, Can-reach) true/false values associated with each quality metaphor. We shall use the symbol Qgijk to indicate the generation quality index state. Also, in the following expressions, we shall use Min {x, y,..., z} to indicate the minimum of x, y, .., z. The notation <x> will be used to denote Max {0, x}, that is the maximum of x and zero (= x if x > 0, or 0 otherwise). Therefore, Table 1. summarizes, quality indices, are considered, namely the Utilized Generation Capacity (Q111), Bottled Generation Capacity (Q110), Shortfall Generation Capacity (Q101), Deficit Generation Capacity (Q100), Surplus Generation Capacity (Q011), Redundant Generation Capacity (Q010), Spared Generation Capacity (Q001) and Saved Generation

Capacity (Q000).The evaluation of the above quality indices requires the knowledge of the following data types for the demand and various system facilities:

a) The value of demand required to be supplied

b) The value of generation capacity as well as the maximum site capacity (the limit of potential increase in existing generation capacity).

c) The value of transmission capacity.

Power Systems Interconnection

A loss of load Not Served (LNS) in an individual system occurs when the available generation capacity cannot fulfill the load requirements. On the other hand, in the interconnected systems, the limit inadequacy might be obliged by available assistance from other systems. In general and based on the probability array method in two interconnected systems [9] the assisting system basically attempts to supply its own loads and then provides the assisted system with the available capacity of reserve through the tie line connected. The value of assistance is normally depends on the available generation capacity, the operating reserve, the capacity and forced outage rate (FOR) of the connected tie line. In addition, the extent the loads and the kind of convention between the systems must be take into account in the assisting value. In same regards, the harmony between the capacity reserve margin (surplus if it is not needed (for demand fulfillment) although exists and can reach the demand (Qg011)) for each system and the capacity and constraints of the connected tie line plays important role on the adequacy of assisting as shown in Figurer 2.

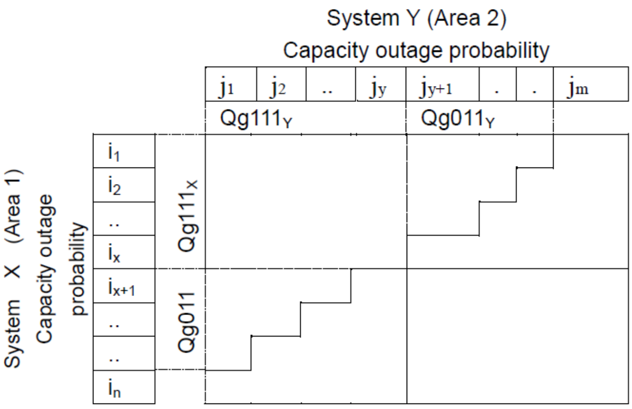

Fig. 2. Two-area capacity states connected with tie line

Let in = total number of units in the system X (area 1), where the units i1 → ix, represents the utilized units (Qg111x) in system X and the units ix+1→ in, represents the available capacity of reserve units (the surplus (Qg011x)), which can be assisting to the other area (area 2). Similarly, we shall use jm= number of units in the system Y (area 2), where the units j1 → jx, represents the utilized units (Qg111y) in system Y and the units iy+1→ im, represents the available capacity of reserve units (the surplus (Qg011y)), which can be assisting to the other area (area 1).When the power flow, that each area will supply extra capacity power to the other area only insofar as it doesn't cause loss of load for itself. In this paper, will take into account the failure of the tie line which is connected between in two-area.

Large-Scale Implementation

Although both issues of reliability and quality represent considerable challenges to researchers in the area, and while the first issue could finally be resolved using advanced large-scale network analysis with efficient sparse-matrix algorithms, the second issue had to be dealt with in a more careful manner. The formulation of the overall composite reliability and quality problems in terms of the trio-interactions between generation, transmission and demand. An appropriate computerized scheme is needed in order to properly evaluate various reliability and quality indices according to their stated definitions. The master linear program presented before forms the bases for analyzing and evaluating the quality indices. For example, the Load Supply Reliability can be evaluated as follows:

(1) $LNS_l = Load\ Not - Served\ at\ Bus\ (l)\ = (\bar{P_l}\ - P_l^{(1)})$

(2) $$LNS = Total\ System\ Load\ Not - Served = \sum_{l=1}^{n_L}(\bar{P_l}\ - P_l^{(1)})$$

where the bus loads at the solution of the master linear program are termed as $P_l^{(l)}$ and P_l denotes the solution load value at
bus (*l*).

On the other hand, For example, generation quality indices, the Utilized Generation Capacity index is given by

Qg111= Utilized Capacity ≡ {needed, exists, can reach}

(3) $$\sum_{l=1}^{n_L}\left(P_l^{(1)}\right)$$

Similarly, the Bottled Generation Capacity index is given by

Q_g110 = Bottled Capacity ≡ *{needed, exists, cannot reach}*

(4) $$Min\ \{[\sum_{l=1}^{n_L}\bar{P}_l - \sum_{g=1}^{n_G}P_g^{(1)}],[\sum_{g=1}^{n_G}Max\ \{0,(\bar{P}_g - P_g^{(1)})\}]\}$$

Also, the Surplus Generation Capacity (Qg011) is calculated as

Qg011 = Surplus Capacity ≡ {not needed, exists, can reach}

(5) $$Q_g011 = Min\{[Max\ \{0,(\sum_{g=1}^{n_G}\bar{P_g} - \sum_{l=1}^{n_L}\bar{P_l})\}],[Max\{0,(\sum_{g=1}^{n_G}P_g - \sum_{l=1}^{n_L}\bar{P_l})\}]\}$$

where the generation output values Pg are calculated at the solution of the linear program with open limits on the loads. An optimization software package (CPLEX) has been used to solve the Master Linear Program.

Applications to interconnected Systems

In the applications presented in this paper, two systems, namely the Hail and Qassim systems in the Saudi Electrical Company. Table 2 summarizes some of the reliability and system quality performance measures applied to the power system for two operating scenarios. The first scenario represents loss of transmission lines from Qassim and Riyadh systems for extended duration, while the second scenario represents connected of transmission lines from Qassim and Riyadh systems. The results obtained for the first operating scenario (isolated scenario) reveal that the LNS(o) in the Hail and the Qassim networks is 168.9 and 1685.65 MW, respectively. Although Capacity Reserve Margin (CRM) in Riyadh system is able to supply both networks to compensate the load not served, but the loss in the transmission lines caused the LNS. On the other hand, no Load Not-Served (LNS(i)) exists in the Hail-Qassim networks for the second operating scenario (interconnected scenario), indicating that these systems has sufficient backup generation with adequate transmission facilities from Riyadh system.

Table 3. Reliability and system quality performance assessment measures for two operating scenarios

Power Network	First operating scenario (loss of transmission lines from Qassim and Riyadh systems for extended duration)		
	System Load Not-Served (LNS)	Utilized Generation Capacity (Qg111)	Bottled Generation Capacity (Qg110)
Hail	168.9 MW	481.1 MW	112.5 MW
Qassim	1685.6525MW	1993.75 MW	14.29
Power Network	Second operating scenario (connected of transmission lines from Qassim and Riyadh systems)		
	System Load Not-Served (LNS)	Utilized Generation Capacity (Qg111)	Bottled Generation Capacity (Qg110)
Hail	0 MW	655 MW	0 MW
Qassim	0 MW	3679 MW	0 MW

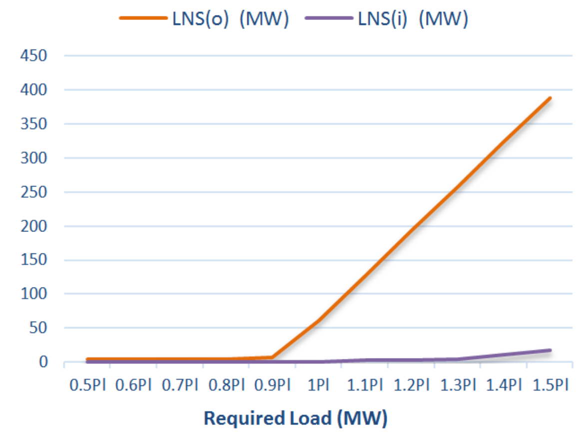

Fig. 3. Variation of Load Not Served (LNS) with the of variation of required load levels of the Hail isolated and Interconnected network

The results of Figure 3 show that there is no Load Not-Served (LNS_O) in the isolated scenario for all required load levels up to 90 % of the nominal load (655 MW), where it starts to increase continuously to reach 383 MW at a required load level of 980 MW, this situation indicates that the unsupplied load is now due to transmission limitations rather than generation availability. In the interconnected scenario, on the other hand, The results reveal that the Load Not-Served (LNSi) stays at zero value for all required load levels up to 130 % of the nominal load, where it starts to increase continuously to reach about 17.1 MW at 150 % of the nominal load. The Utilized Generation Capacity index ($Qg111_O$) for the isolated network scenario of Hail system (Figure 4) increases continuously with the available generation capacity levels until it saturates at about of 100% of available generation (645 MW) . On the other hand, the Utilized Generation Capacity ($Qg111_i$) stays at 655 MW (nominal load) for all available generation capacity levels. Based on the results, when all required load levels in Hail system are considered with their respective probabilities of occurrence, and taking into account the availability rates of generation and transmission capacities, the overall expected value of the Load Not Served (LNS) is 4.01 MW, which is less than 1% of the required load in Hail network. On the other hand, overall expected value of the Bottled Generation Capacity (Qg110) was found to be 3.86 (MW), which again is less than 1% of the total Hail generation. The results for the Hail zone in the interconnected scenario showed that even at 50% available generation capacity, the Load Not Served (LNSi) in Hail would only be 5.3 MW, which indicates strong interconnection support from Qassim. For the same reason, the Utilized Generation Capacity (Qg111i) at the 50% available generation capacity in Hail is 650 MW, which already covers 99 % of the total zone required load.

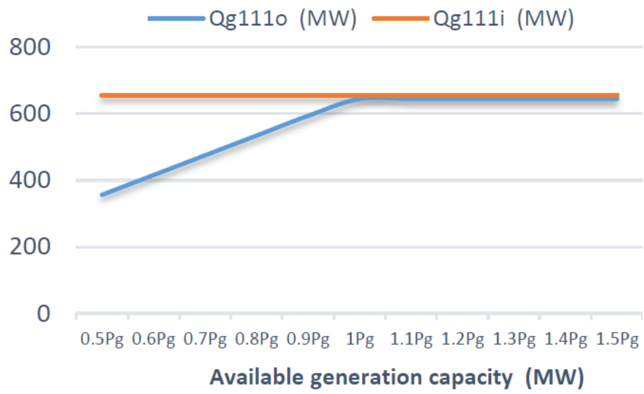

Fig. 4. Variation of Utilized Generation Capacity (Qg111) with variation of available generator capacity levels of the Hail isolated and Interconnected network

Figures 5 show 3-dimensional graph depicting the variation of the Load Not-Served (LNSO) with both required load and available generation capacity levels of the Qassim isolated network. It is noted from the results of Figure 5 that the Load Not-Served (LNSO) starts at low value for all available generation capacity levels between 100% and 150% of nominal as long as required load level is 50% of nominal, this situation, however, changes for all available generation capacity levels between 50% and 100% of nominal and the all required load levels between 60% and 150% of nominal, where more required load levels would increase the amount of the Load Not-Served (LNSO), this situation indicate that the unsupplied load is now due to generation unavailability and transmission limitations.

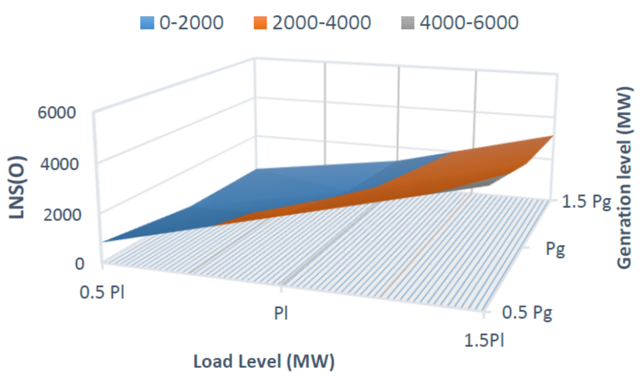

Fig. 5. Variation of Load Not-Served (LNS_O) with both load and available generation capacity levels of the Qassim isolated network

The results for the interconnected network scenario of Hail network (Figure 6, 3-dimensional graph) show that the highest region of the Bottled Generation Capacity (Qg110i) occurs when the available generation capacity levels between 100% and 150% of nominal and the required load levels between 110% and 150% of nominal (would jump from 0 MW in the isolated mode to 40.94 MW), this situation is due to the limited capacity of transmission lines. On the other hand, the Bottled Generation Capacity (Qg110i) on the other regions would actually disappears (is almost zero value).

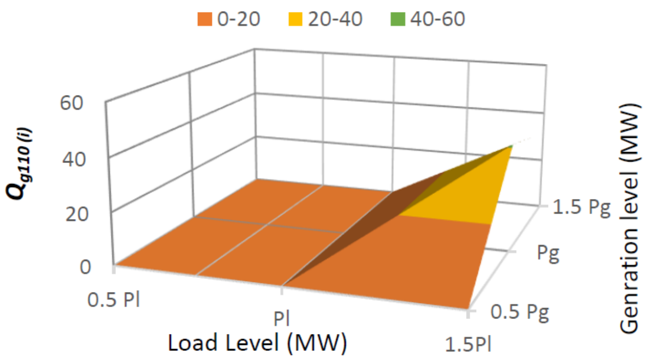

Fig. 6. Variation of Bottled Generation Capacity ($Qg110_i$) with both load and available generation capacity levels of the Hail interconnected network

Conclusion

The results for the interconnected network scenario of Hail network (Figure 6, 3-dimensional graph) show that the highest region of the Bottled Generation Capacity (Qg110i) occurs when the available generation capacity levels between 100% and 150% of nominal and the required load levels between 110% and 150% of nominal (would jump from 0 MW in the isolated mode to 40.94 MW), this situation is due to the limited capacity of transmission lines. On the other hand, the Bottled Generation Capacity (Qg110i) on the other regions would actually disappears (is almost zero value).

Acknowledgment

The authors would like to thank the Deanship of the Scientific Research of University of Ha'il, Saudi Arabia for funding and supporting this research project (RG-191245).

Authors: *Dr. Badr Mesned Alshammari (corresponding), Electrical Engineering Department, University of Hail, KSA. e-mail: bms.alshammari@uoh.edu.sa; Dr. Tawfik Guesmi, Electrical Engineering Department, University of Hail, KSA. e-mail: t.guesmi@uoh.edu.sa; Prof. Mohammed Eleiwa, Electrical Engineering Department, University of Hail, KSA. e-mail: ma.eleiwa@uoh.edu.sa; Dr. Rabeh Abbassi, Electrical Engineering Department, University of Hail, KSA. e-mail: r.abbassi@uoh.edu.sa; Dr. Mohammed Alghassab, Electrical Engineering Department, Shaqra University , KSA, E-mail: Malghassab@su.edu.sa.*

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