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MOST PROMINENT ASPECTS ASSOCIATED WITH POWER SYSTEM PLANNING PROCESS

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Abstract –The problem of power system planning, due to its complexity and dimensionality aspects, is one of the most challenging aspects facing the electric power industry in developing as well as developed countries. The proposed work will attempt to describe how these aspects are analyzed and assessed based on two major considerations, namely, reliability and cost. A case study considers two separate systems in a fast-developing country, each of which must be reinforced to meet the future predicted loads. The benefits of reinforcing separately or reinforcing by interconnecting the two systems are demonstrated. Uncertainties having a significant impact upon the decision-making process in the planning process are also addressed.

1. INTRODUCTION

Power systems planning is essentially a projection of how the system should grow over a specific period of time, given certain assumptions and judgment about the future loads and the size of investment in generating capacity additions and transmission facilities expansion and reinforcements.

Any plan can become technically and economically obsolete. New inventions in electrical utilization equipment or unforeseen industrial, commercial or residential projects can change the load forecast. Breakthroughs in new generation and transmission technologies, unexpected inflation in equipment or labor costs or change of national income can all mean system plans may take another direction.

Power system planning has become more difficult, but more important to provide the necessary information to enable a decision to be made today about many years in the future. In almost all cases, planning must be done in the face of many uncertainties, for example: future load patterns, population increase and the economic growth which characterize the developing countries, as well as technical, economic and environmental constraints [1-3].

The main issue regarding power system planning, particularly, in developing countries is to establish basic principles and guidelines to serve as a framework within which the process of planningmay proceed. This framework should be flexible, not rigid with the broad objectives of finding a plan (or plans) which guaranties a desired degree of a continuous, reliable and least cost service. Good service or, in other words, acceptable reliability level of power system usually requires the additions of more generating capacity to meet the expected increase in future electrical demands. However, in many developing countries with vast, separately populated areas reliability-cost tradeoffs exist between satisfying the fast load growth by investment in additional generating capacity for isolated systems or building transmission networks to interconnect these systems and transfer power between their load centers in case of emergencies and power shortages.Therefore, reliability and cost constraints are major considerations in power system planning process[4-11].

2. POWER SYSTEM RELIABILITY EVALUATION

Reliability is one of the most important criteria which must be taken into consideration during all phases of power system planning, design and operation. Reliability criterion is required to establish target reliability levels and to consistently analyze and compare the future reliability levels with feasible alternative expansion plans. This need has resulted in the development of comprehensive reliability evaluation and modeling techniques [12-14].

2.1 Loss of Load Expectation (LOLE)

One capacity related reliability index, known as the loss of load expectation (LOLE) method, is presently considered as the most common adopted probabilistic index in system generation expansion planning process. Referring to Figure 1, this method utilizes all its captioned data to evaluate the expected number of days per year on which the available generating capacity is not sufficient to meet all the period load levels and can be computed by the following equation:

$$LOLE = \sum_{i=1}^{n} t_i \cdot p(O_i) \; (days/year) \qquad (outage > Reserve) \tag{1}$$

Where

t_i : The time duration of that severs outage O_i *that caused load loss (load not served)*

$p(O_i)$: *probability of loss of load due to the* i^{th} *severe outage of size* O_i.

n: *total number of severe outages ocurred during that period considered*

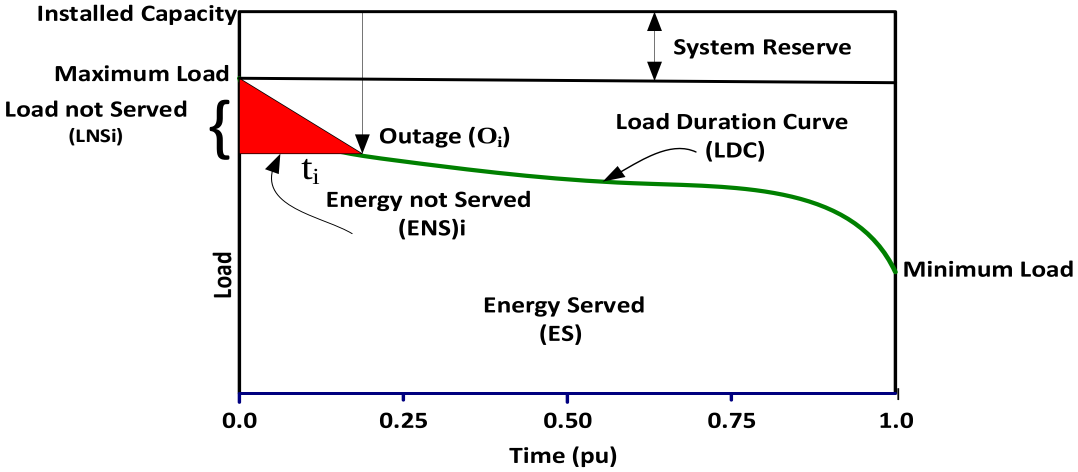

Fig. 1 Load Duration Curve displaying various load-related variables

2.2 Expected Load Not Served (ϵLNS)

In power system reliability evaluation, sometimes another reliability index beside the ***LOLE*** is needed to know the magnitude of loads that have been lost due to severe outages (i.e. when the existing loads exceed the available system capacity). So, this index is known as the Expected Load Not Served (ϵLNS) and can be evaluated as follows:

$$\epsilon LNS = \sum_{i=1}^{n} (LNS)_i \cdot p(O_i) \qquad MW/y \; (outage > Reserve) \tag{2}$$

2.3 Expected Energy Not Served (*ϵENS*)

Since the energy not served $(ENS)_i$ Caused by power outages reflects great damages and heavy losses to the entire consumers' classes, so, another essential and most needed reliability index known as the Expected Energy Not Served (**ϵENS**) can be deduced as follows:

$$\epsilon ENS = \sum_{i=1}^{n} (ENS)_i \cdot p(O_i) \qquad MWh/y \ (outage > Reserve) \tag{3}$$

Where

$(ENS)_i = [(LNS)_i \cdot t_i]$:*The energy not served due to severe* i^{th} *outage of size Oin time t*

3. POWER SYSTEM COSTS EVALUATION

There are several costs associated with power systems installation and operation [15,16,17]. These costs include:

3.1 Fixed Cost

The fixed cost represents the cash flow at any stage of the planning horizon resulting from the costs of installing new generating units during the planning period. It depends on the current financial status of the utility, the type and size of generating units and the cost of time on money invested during the planning period. The total fixed costs (FC_T) for unit(s) being installed can be computed as:

$$FC_T = \sum_t \sum_k (CAP_k \cdot CC_k \cdot NU_k)^t \tag{4}$$

Where

CAP_k: *unit capacity added to the system of type k.*

CC_k : *capital cost of unit of type k* (\$/kW).

NU_k: *number of unit(s) added to the system of type k at each interval of time t.*

t: *interval period of time considered in the planning horiozon.*

T: *total number of years in the planning horizon.*

3.3 Variable Cost

The variable cost, (*VC*), represents the cost of energy served by the system. It is affected by the load variation, the type and size of generating units and the number of hours of operation. Also, these costs are related to the cost of operation and maintenance (fuel, interim spare parts, repair, staffing, wages and miscellaneous expenses) and can be evaluated as:

$$VC_T = \sum_t \sum_k (\epsilon ES_k \cdot ESC_k \cdot NU_k)^t \tag{5}$$

Where

ϵES_k:*expected energy served by a unit of type k*

ESC_k: *energy served cost of a unit of type k* (\$ / kWh)

The total system costs (SC_T) for the entire expansion plan can be estimated by summing all the above individual costs at every stage of the planning period as being expressed in the following equation:

$$SC_T = FC_T + VC_T \tag{6}$$

3.4 Outages Cost

In power system cost-benefit analysis, the outages cost (OC) forms a major part in the total system cost [18,19,20]. These costs are associated with that energy demanded, but cannot be served by the system due to severe outages, and is known as the expected energy not served, (ϵENS). Outages cost is usually borne by the utility and its customers. The utility outages cost includes loss of revenue, loss of goodwill, loss of future sales and increased maintenance and repair expenditure. However, the utility losses are seen to be insignificant compared with the losses incurred by the customers when power interruptions and energy cease are apt to occur. Customers perceive the power outages and energy shortages differently. A residential consumer may suffer a great deal of anxiety and inconvenience if an outage occurs during a hot summer day or deprives him from domestic activities and causes food spoilage. For a commercial user, he will also suffer a great hardship and loss of being forced to close until power is restored. Also, an outage may cause a great damage to an industrial customer if it occurs disrupting and disabling the production processes.

One method of evaluating the $\epsilon ENS$is described in [13]. Therefore, for estimating the outages cost, OC, is to multiply the value of that $\epsilon ENS$by an appropriate Outage Cost Rate (OCR), as follows:

$$\mathrm{OC_T} = \sum_{\mathrm{t}} (\epsilon \mathrm{ENS} \cdot \mathrm{OCR})^{\mathrm{t}} \tag{7}$$

OCR: $US\$/kWh$. and $\epsilon\mathrm{ENS}$:kWh lost.

The overall cost of supplying the electric energy to the consumers is the sum of system cost that will generally increase as consumers are provided with higher reliability and customer outages cost that will, however, decrease as system reliability increases or vice versa. This overall system cost (OSC) can be expressed as in the following equation:

$$OSC_T = \mathrm{SC_T} + \mathrm{OC_T} \tag{8}$$

The most prominent aspect of outage cost estimation, as manifested in the above equation, is to assess the worth of power system reliability by comparing this cost (OC)with the size of system investment (SC) in order to arrive at the least overall system cost that will establish the most appropriate system reliability level that ensures energy continuous flowas well as the least cost of its production.

4. MODULES DEVELOPED FOR THE RELIABILITY AND COST EVALUATION UTILIZED IN THIS STUDY

To perform the assessments and analyses of this study, a computer program comprising the planning modeling process has been developed at the King Saud University and shown in Figure2,

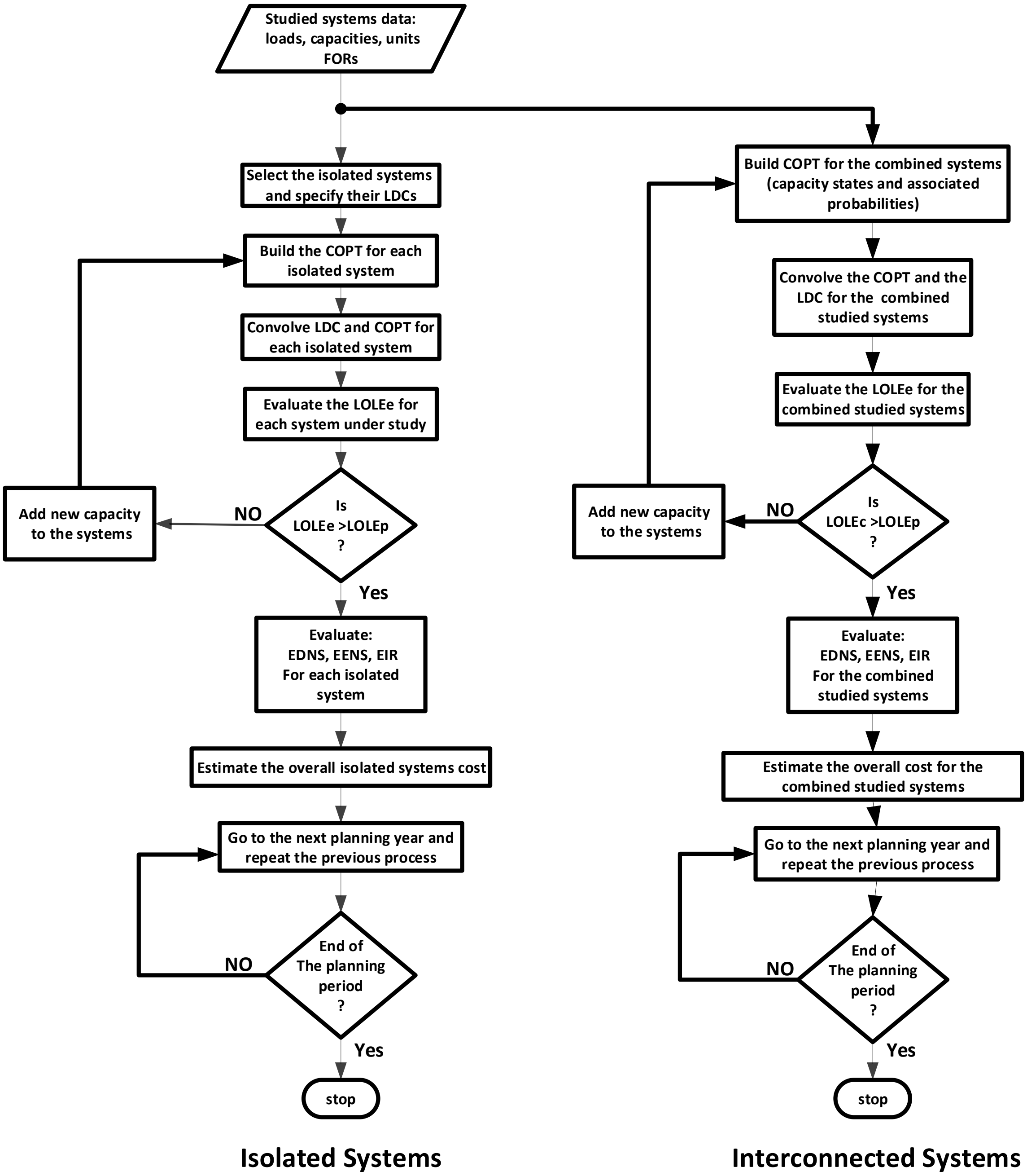

Fig 2. Flowchart for the proposed planning approach

5. CASE STUDY

The previous mentioned approach has been applied to an existing case in a fast developing country. This case study is based on two practical systems (A and B) supposed to be serving a major populated community with potential future load growth. The study considers that uncertainty is a vital aspect of power systems planning in developing countries. Thus, the analysis procedure generally involves identifying the potential uncertain events and assigning a probability to the event.

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The impacts may then be probability-weighted, and a composite system impact value can be computed. this process may be repeated by examining alternative or contingency plans.

5.1 Isolated and Interconnected power systems

In neighboring countries, Normally, power systems have interconnections with each other. The interconnection reduces the amount of reserve capacity needed to be installed as compared with that which would be required without the interconnection. The amount of such reduction depends on the amount of assistance that a system can get, the transfer capability of the tie-line and the availability of excess capacity reserve in the assisting systems.

One objective reported in this paper is to evaluate the reliability benefits associated with the interconnection of systems. Therefore, the study is focused on reliability evaluation of two systems, both as isolated systems and as interconnected systems. Analysis of this type explores the benefits that may accrue from interconnecting systems rather being isolated as well as deciding viable generation expansion plans.

A 5-year expansion plan for systems A and B (data for both systems were obtained from their sources in the northern region of the Kingdom of Saudi Arabia) assuming a reliability criterion of 0.2 days/year (0.1-0.6 frequently quoted as appropriate values) were determined. The analysis represents the expansion plans for both systems as being isolated and interconnected. An outcome of these expansion plans is shown in Figure 3.

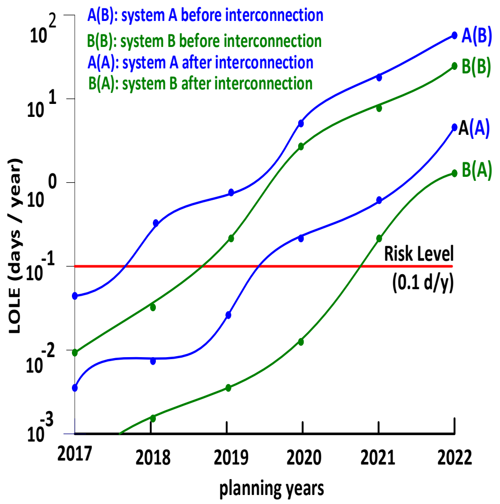

Fig.3 Variations of LOLE before and after interconnection

If the two systems are reinforced whenever the reliability index falls below the prescribed level (i.e.$LOLE = 0.2\ d/y$) at any year of the planning horizon, the results shown in Table 1, exhibit that the number of units and the PV cost are reduced if the two system are interconnected rather being isolated.

Table 1.PV costs (**MUS$**)for isolated and interconnected systems

sys	Isolated			Interconnected		
	No.of units	Cost (MUS$)	ENS (MWh)	No.of units	Cost (MUS$)	ENS (MWh)
A	3	10.42	6.652	2	8.35	2.054
B	2	14.22	5.852	1	6.15	3.045

Therefore, it can be concluded from the above analysis that both systems will benefit from the interconnection. The reliability of both systems can be improved and consequently cost of service is reduced through interconnection and reserve sharing. However, this is not the overall saving because the systems must be linked together in order to create an integrated system. The next stage must, therefore, assess the economic worth that may result from either interconnection or increasing generating capacity individually and independently.

5.2 Loads Growth Uncertainty

Increasing future Loads growth is one of the main forecast parameters that is subject to uncertainty [20].Load growth is influenced by many factors including the national economy, income per capita, power management, prices, policies and conservation. Therefore, changes in these factors may imply that the actual margins may turn out to be higher or lower than planned scenario and is likely to affect the system reliability criteria and consequently to influence capacity planning decisions. The uncertainty in load forecasting can be included in the risk analysis by dividing the load forecast probability distribution into class intervals. The area of each class interval represents the probability of the load being the class interval mean. The risk is computed for each load represented by the class interval and weighted by the probability that this load exists. The sum of these products represents the risk for the forecast load. To investigate the impact of load forecast uncertainty on the planning outcome of System A, the forecasted peak load was assumed to be 350 MW, with uncertainty normally distributed using a seven step approximation [7]. The discredited peak load levels with a standard deviation of 6% load are shown in Table 2.

Table 2. Data for load forecast uncertainty [13]

Standard deviation from the mean	Load levels (MW)	probability
-3	287	0.006
-2	308	0.061
-1	329	0.242
0	350	0.382
1	371	0.242
2	392	0.061
3	413	0.006

The results of this study, as shown in Fig. 4,b reveal that costs for system A (fixed and variable costs) increase with load. The reason is that costs increase with load owing to more additional units being operated and forlonger periods

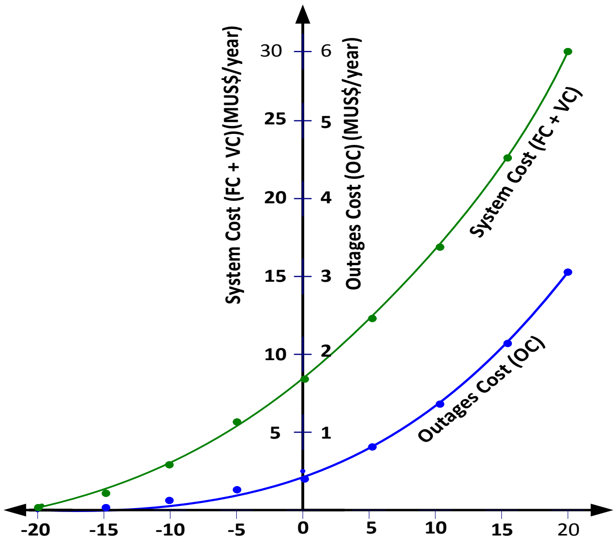

Fig. 4 Effects of load uncertainty on system cost and of system power outages energy not served (ENS)

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The total cost of power supply to consumers is critically dependent on the cost assigned to the ENS. Theeffect of the ENS variation with load uncertainty is tested and the results areshown also on Fig. 3which reveal that the ENS increases with increasing loads which implies reduction in the prescribed reliability level and hence requires more investment and operation costs.

5.3. Uncertainty in Unit Installation Time

In developing countries, deferring (postponing) unit installation time, due to unexpected economic conditions is probable and must be considered in the planning process. A summary of 5-year expansion plan results, which indicates the effect one-year delay in installation time on system A expansion plans is shown in Table 3.

Table 3 system costs (MSR) timely (deferred) installation Time

Year	Unit added	SC(MUS$)	OC(MUS$)
1	0(0)	00(00)	3.2(2.1)
32	0(0)	00(00)	4.4(3.4)
3	1(0)	33(00)	3.5(4.8)
4	0(1)	00(39)	6.3(4.3)
5	1(0)	21(00)	5.9(6.4)
Total		64(39)	23.3(251.0)

From the above table it is seen that if the installation date of a unit which should be installed in a specific future year is deferred (between the brackets) until the next year, the PV system cost decreases because of payment postponement but the PV outage cost increases due to the deterioration of system reliability level. It is seen that capacity deferments have a considerable effect on reliability (see Figure 5).

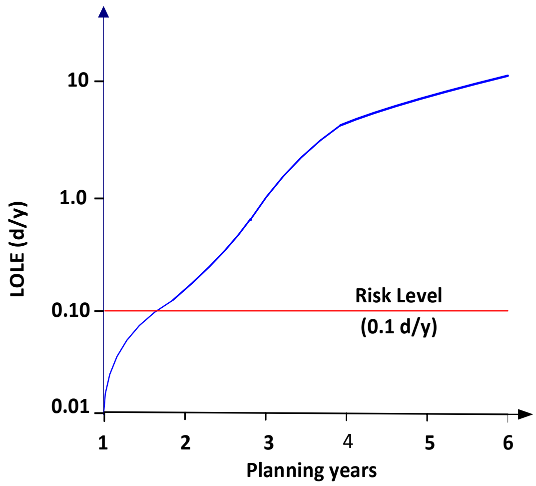

Fig. 5 Effect of deferred unit addition upon system reliability level

This increase in system risk explains the rise in outage costs resulting from postponing unit installation. If more uncertainties in installation time are assumed, results depicted by Figure 6 show that, as unit deferring is increased, the outages cost increase rapidly but that the system cost steadily decreases. On the contrary, the timely installation has less effect on the outage costs than in the deferred case. Consequently, incentives should exist to justify decisions upon deferring or complying with the scheduled time of unit addition. One reason could be that it would be a catastrophic if unit installation is postponed for longer periods as shown in Figure 5.

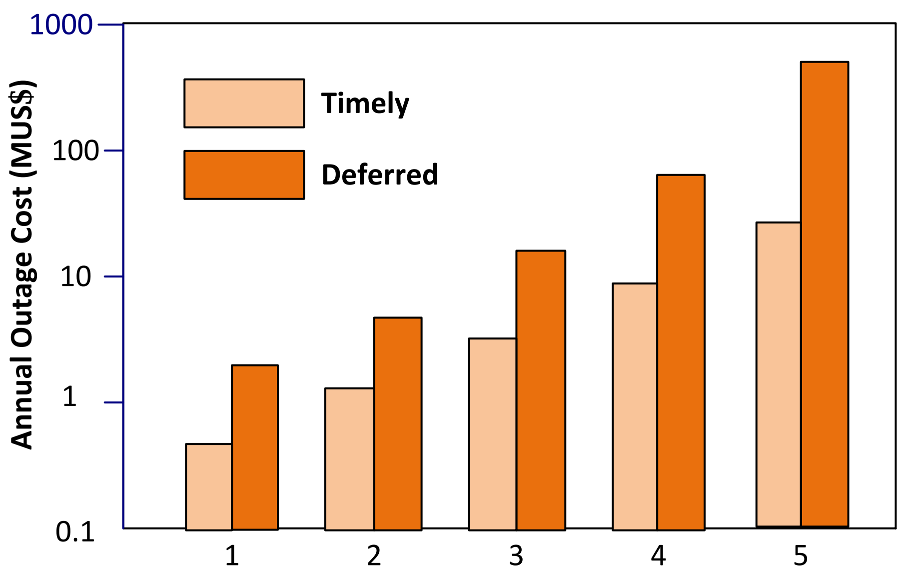

Fig.6 Impact of Timely/deferred unit installation on outage cost

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6. OPTIMAL RELIABILITY LEVEL

In power system planning, evaluation of optimal reliability levels is a major step in power system planning process to ensure continuous and quality service provided with reasonable cost. The system planners perform sensitivity analysis based on economic variations, installation and transmission costs. Therefore, LOLE reliability index has been applied for system (A) electric system and the using the economic concepts and the reliability criterion shown in the Appendices. In the analysis, new generating units of 68 MW (identical to the present installed units in system A) have been added to the system when reliability levels deteriorate below the prescribed level. To arrive at the most appropriate range of reliability levels, system cost (SC) has been weighted with the outages cost (OC). System cost includes unit installation cost as well as the fuel and maintenance cost. Outages cost represents the cost of losses suffered by the society (all classes of customers) due to insufficient capacity and consequently, energy curtailment. The total system cost (TSC) depicts the overall cost endured by the customers in return of power supply and its availability.

In an attempt to arrive at the most optimal reliability level that ensure the least system cost, the above mentioned costs have been investigated employing system (A). The results of the investigations are illustrated by Figure 7, where it manifests that system cost (SC) increases as reliability level increases but the outage cost (OC) decreases as a result of reliability improvement due to more system investment and adequate generating capacity additions. The most optimal reliability level, as depicted by the figure, to be set at 0.175 days/year. However, in some cases adding new capacity may not signify the ideal solution to meet increasing future loads and maintain better reliability levels. Therefore, it is better to enhance operating unit's performance through regular preventive maintenance. Also, it is an imperative to establish a good co-operation between the supply side (electric company) and the demand side (the consumers) through well-coordinated load management strategies, improving system load factor and power factorcorrection. Hence, system will be capable of meeting loads efficiently and reliably particularly, in power system interconnection.

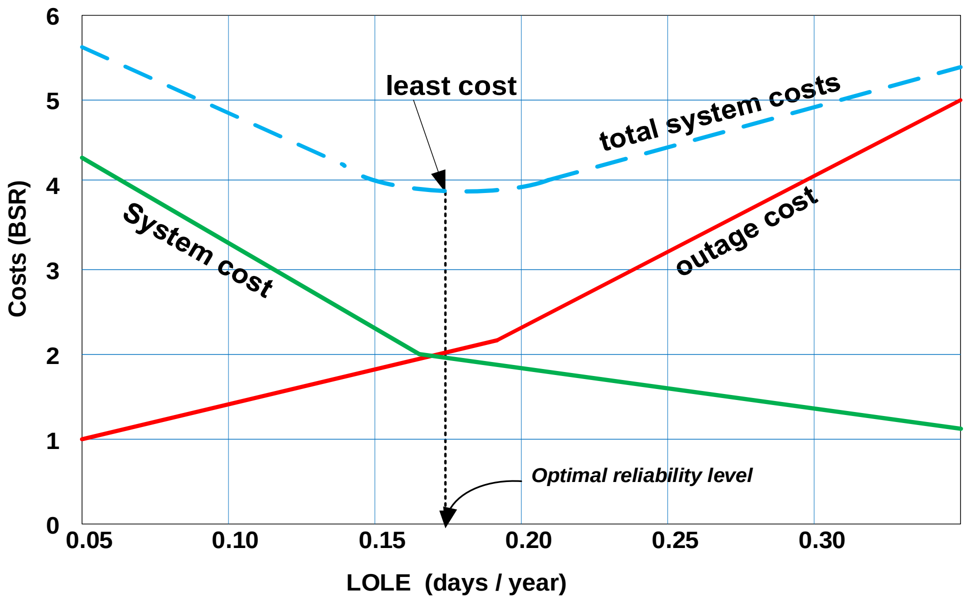

Fig. 7 Variation of reliability levels with total system costs

7. CONCLUSIONS

In this paper, significant issues that may arise in power system planning in developing countries have been considered and analyzed. Two major constraints associated with power planning process, namely, reliability and cost have been modulated and applied to particular systems expansion planning in a developing country. The result demonstrates the benefits and merits associated with both reliability and cost of interconnecting isolated systems into an integrated system. The uncertainly in future loads growth and unit installation time can be costly and undesirable. Therefore, their effects should be anticipated and studied in order to mitigate their effects so that possible deterioration in system reliability level as well as unnecessary additional expenditure can be averted.

Hence, in all countries, especially the developing ones, data collection is not an easy task and it is often difficult to establish probabilistic data for a system which did not have regular and organized collection of data for the use in probabilistic techniques. It is, therefore, important to establish systematic data collections describing all behavior aspects of power system which can then be used in reliability and economic evaluation for future planning and studies which are critically needed for power system planning process.

REFERENCES

[1] R. Sullivan, "Power System Planning", McGraw Hill, 1977, pp. 97-150.

[2] A. Weber et al., "Long-term Power System Planning in the Context of Changing Policy Objectives", Workgroup for Infrastructure Policy (WIP), University of Technology, Berlin, June 2013.

[3] H. G. Stoll, "Least-Cost Electric Utility Planning", John Wiley & Sons, New York, pp. 321-405.

[4] G. Schramm, "Electric Power in Developing Countries: Status, Problems, Prospects", Annual Review of Power, vol. 15, pp. 307- -333, 1990.

[5] T. J. Wilbanks, "Implementing Environmentally Sound Power Sector Strategies in Developing Countries", Annual Review of Power, Vol. 15, pp. 255-276, 1990

[6] P. Meier, "Power Sector Innovation in Developing Countries: Implementing Investment Planning under Capital and Environmental Constraints", Annual Review of Power, Vol. 15, pp. 277-306, 1990.

[7] S. M. Sadeghzadeh; M. Ansarian, "Techno-economic power system planning in developing countries", 7th IET International Conference on Advances in Power System Control, Operation and Management (APSCOM), 30 Oct. -2 Nov. 2006, Hong Kong, China, page 216.

[8] A. J. Covarrubias, "Expert systems and power system planning in developing countries", IEEE Conference Proceedings, Southeastcon '88, 11-13 April 1988, pp. 551-555.

[9] H. Rudnick; R. Quinteros, "Power system planning in the South America electric market restructuring", VI Symposium of Specialists in Electric Operational and Expansion Planning - VI SEPOPE, May 24-29,1998, Bahia, Brazil.

[10] A. P. Agalgaonkar; S. V. Kulkarni, "Evaluation of Configuration Plans for DGs in Developing Countries Using Advanced Planning Techniques", IEEE Transaction on power systems, VOL. 21, NO. 2, May 2006, pp. 973 – 981.

[11] H. El-Zayyat et al., "Power System Planning in Developing Countries, the case of Jordan", Mansoura Engineering Journal (MEJ),Vol. 16, No, 2, 1991.

[12] J. Endrenyi, "Reliability Modeling in Electric Power Systems", Wiley Interscience Publications, New York, 1978.

[13] R. Billinton, and R.N. Allan, "Reliability Evaluation of Power Systems", Pitman Books, London, 1984.

[14] R. Billinton, and R.N. Allan, "Reliability Assessment of Large Electric Power Systems", Kluwer Academic Publishers, Boston, 1988.

[15] P. Wang,R. Billinton, and L. Goel, "Unreliability Cost Assessment of an Electric Power System Using Reliability Network Equivalent Approaches", IEEE Transactions on Power Systems, Vol. 17. No. 3 August 2002. pp. 549-556.

[16] M. Munasinghe, "The Economics of Power System Reliability and Planning", the World Bank Publications, 1979, pp. 45-85.

[17] J. Lassila, S. Honkapuro, and J. Partanen, "Economic Analysis of Cost Parameters and Their Implications on Investment Decisions", IEEE Proceedings, 2005, pp. 1-8.

[18] R. Billinton, W. Wangdee, "Customer Outage Cost Evaluation of an Actual Failure Event", Proceedings of the 2000 IEEE Canadian Conference on Electrical and Computer, pp. 94-99.

[19] C. Ketkaew et al, "Outage Cost Assessment of Industrial Customers for maintenance Planning". 2008 IEEE Electrical Power and Energy Conference, pp. 1-7.

[20] L. Garver, "Reserve Planning Using Outage Probabilities and Load Uncertainties", IEEE-Transactions on Power Apparatus and Systems, Vol.PAS-89, April 1970, pp. 514-521.