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The Electrical System Expansion Planning for the Eastern Electrical Region, Saudi Arabia

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ABSTRACT. This paper presents an optimal electrical system expansion planning for the Electrical Eastern Region (EER), Saudi Arabia. The load demand forecast is presented. The load duration curve has been determined. The existing and committed generation system has been obtained. By using screening curve, the most appropriate candidate units for expansion planning have been chosen. The optimal generation expansion has been established, as well as the loss of load probability.

1. Introduction

Under the Ministry of Industry and Electricity, the Electricity Corporation has the responsibility for coordination and supervision of development of electrical industry throughout the Kingdom of Saudi Arabia. As far as the electricity sector is concerned, the Kingdom of Saudi Arabia is divided into five geographical regions, namely Eastern, Western, Northern, Southern and Central regions. In each region, several electrical companies and government projects are combined in one company called The Saudi Consolidated Electrical Company (SCECO). One of these companies is the SCECO East, which is responsible for the generation, transmission, and distribution of electricity in the Electrical Eastern Region (EER) of the Kingdom[1-2].

From the demand point of view, there are several sectors consuming electricity, such as industrial, residential, commercial and governmental sectors. The industrial sector consumes about 60% of the total generated electricity.

In the Eastern Region, there is an interconnected system as well as an isolated system. The interconnected grid feeds the major load centers, whereas the isolated system represents a small part of the total load. As an example, in 1993 the peak load of the Eastern Region was 5479 MW, while the total net generation was 8713 MW. The power generated by the interconnected system was 7063 MW, and the electricity generated by the Saline Water Conversion Corporation was 1615 MW, while that generated by the isolated system was only 35 MW .

Regarding electric generation capacity expansion planning programs, there are several computer programs as well as packages. These packages are :

1. Wien Automatic System Planning Package (WASP)

The WASP was originally developed in the USA by the Tennessee Valley Authority and Oak Ridge National Laboratory. It is the most frequently used and best proven program for electric capacity expansion analysis in the public domain. The most updated version is known as WASP III[3].

In the production simulation of WASP, a one-year period is divided into at most 12 sub-periods, for each of which probabilistic simulation is applied. Equivalent load duration curves in the probabilistic simulation are expanded using Fourier series. The decision of the optimum expansion plan is made by forward dynamic programming. The investigation specifies the number of units for each candidate solution, and specifications that may constrain the solution. If the solution is limited by any such constraints, the input parameters can be adjusted and the model re-run. The dynamic programming optimization is repeated until the optimum solution is found[4,5].

2. Optimized Generating Planning Program (OGP)

The OGP was developed by the General Electric Company with LOLP as a reliability criterion, using the capacity table method. Production cost was calculated by using predicted average week day and weekend day hourly loads[6].

3. The Electric Generating Expansion Analysis System (EGEAS)

The EGEAS computer model was developed by the Electric Power Research Institute. EGEAS can be run in both the expansion optimization and production simulation models. Uncertainty analysis, based on automatic sensitivity analysis and data collapsing via description of function estimation is also available[7].

4. The National Investment Model (NIM)

The NIM was developed by Electric de France to assist in electric system planning. The basic aim of the NIM is to help in the choice of thermal generating facilities investments and to draw a picture of the possible trend of the national electric generating system in the future.

5. Over-Under Model

The primary objective of the model is to estimate the levelized consumer cost versus the reserve margin requirement. A unique aspect of this model is the consideration of uncertainty for future demand[8].

6. Scope

The scope is a long range capacity planning analysis program using minimal basic language. It is operated interactively by the user. The program presents the capacity and the type of each candidate technology that meets the load demand to the user, who then chooses interactively, which candidate to evaluate further[9].

7. The Autonomous System Planning Package (ASP)

The ASP determines the optimal expansion plan of an autonomous generating system including diesel units, wind generators, and photovoltaic generators. The package finds the optimal system expansion policy for a period of *N* years. The solution algorithms implemented in the package recognize planning and operational constraints and take into consideration the stochastic nature of meteorological conditions, loads, and availability of diesel units[10-12].

The objective of this work is to develop an optimal electrical generation expansion planning for the Electrical Eastern Region in order to generate electricity, which supplies the loads in accordance with the future load demands.

This paper will be organized as follows: The next section will discuss load demand forcast, load duration curve, fuel prices and availability, and the existing and committed power system. Section three will discuss the results; and section four will present the conclusions.

2. Methodology

In order to develop an optimal generation plan, certain factors have to be taken in consideration. First, the fuel prices and its availability. Second, the package which will be used to obtain the anticipated results. Third, the load demand forecast during the study period, the load duration curve for different seasons as well as the load factors. Fourth, the existing and committed units. Finally, the screening curve which will give an idea for appropriate units for generation expansion.

2.1 Fuel Prices and Availability

The fuel availability data is based on the information obtained from Saudi Aramco. Basically natural gas will be available to meet energy requirements for the Eastern Region. However, generating plants should be designed to use crude oil as a backup fuel. The basic fuel prices used for this study are summarized in Table 1.

TABLE 1. Fuel types and prices.

Fuel type	US $ / mmbtu	
	HHV	LHV
Crude oil	3.3	3.5
Heavy fuel oil	2.1	—
Diesel oil	—	5.9
Natural gas	1.0	1.1

2.2 Load Demand Forecast

The SCECO East contributes about forty percent of the national sales, while the number of customers represents about 15% of the total national customers. Since the industrial sector is located in the Eastern Region, including Saudi Aramco, Jubail complex and the petrochemical industries, hence, the main consumer is the industrial sector. The average industrial consumption per customer has recorded high increase during the recent years[13]. The load demand is expected to increase, since a new oil field has been commissioned, more industrial compounds have been established, and the dependence on electrical appliances is ever increasing.

The average annual growth rate is four percent. The load demand forecast for the Eastern Region and the annual peak load are shown in Fig. 1. In addition, it shows that the load demand will increase from 7416 MW in 1997 to 11731 MW in the year 2008.

2.3 Load Duration Curve

It is very important to have a description of how many hours of a given period, loads will have a certain value. One common way is to use the load duration curves. The load duration curve shows the cumulative frequency distribution of the system load. It represents graphically how much energy is supplied to the various levels of the system load. The distribution of the loads as shown by load duration curves gives the planner vital information for determining the proper mix of base, intermediate, and peak capacity. It also helps to determine the cost of the facility to meet load demands[14]. In the Eastern Region, the monthly variations of the peak load can be divided into two periods, summer and winter. During winter, the monthly peak average ranges from 65% to 72% of the annual peak. The load duration curves are shown in Fig. 2 & 3. It was noticed that the monthly load factors are quite high, since the main customers are the industrial sectors, such as Saudi Aramco, Jubail complex, and the petrochemical industries, as they operate day and night. During the summer period the load factor ranges from 80% to 92%, while in winter time the load factor ranges from 85% to 89%. The annual load factor is about 73%[15].

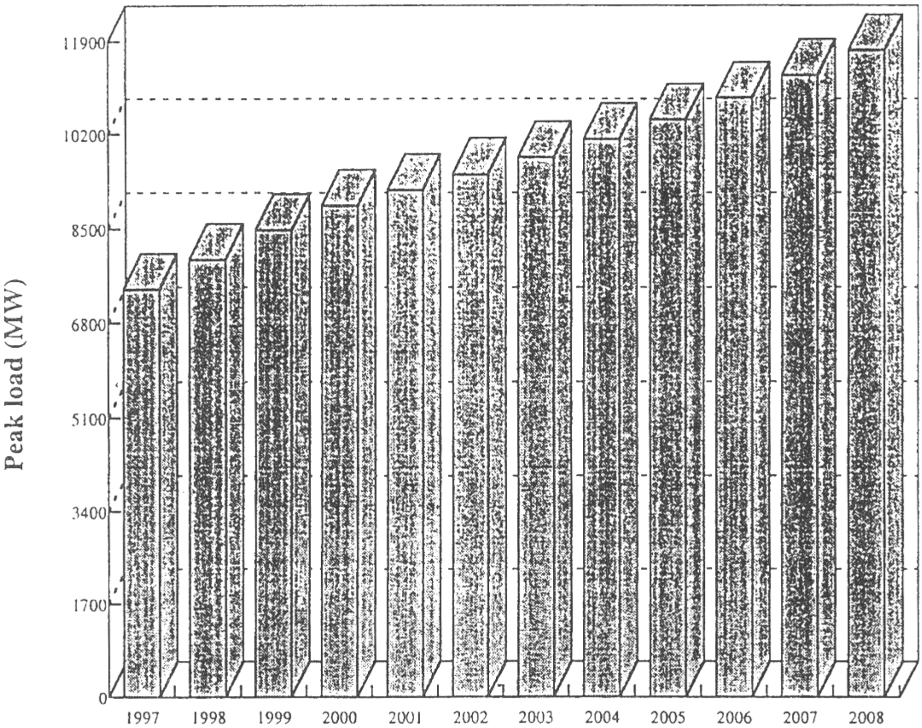

FIG. 1. Load demand forcast.

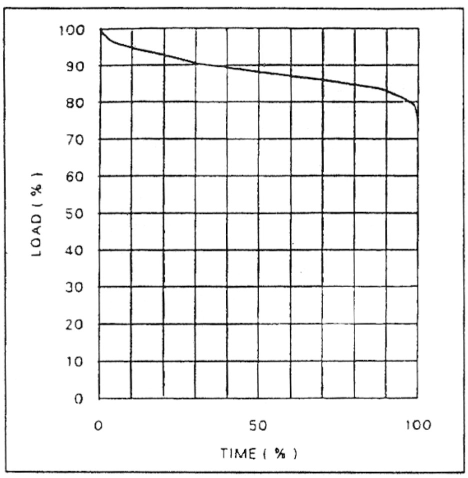

FIG. 2. Winter load duration curve.

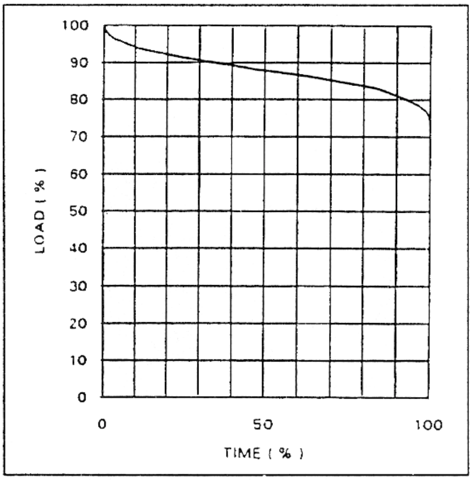

FIG. 3. Summer load duration curve.

2.4. Existing & Committed Power Systems

The existing power generation plants in the Eastern Region consist of two steam turbine power plants, and eight gas turbine power plants, with a total capacity of 7173 MW. The number of units in each steam turbine plant is four units, with a total capacity of 4000 MW. Each gas turbine plant consists of eight units with a total capacity of 3173 MW[16].

Table 2 shows the characteristics of the existing generation units, namely the rating capacity of each unit, the heat rate, the maintenance (days per year), domestic fuel cost, and both fixed and variable operating and maintenance costs.

TABLE 2. Characteristics of the existing system.

Location	# of units	Rating		Heat Rate (kJ/kWh)	EFOR (%)	Maint. (days/yr)	O & M Costs		Year of Commis.
		Net (MW)	Total (MW)				Fixed ($/kW/mth)	Variable ($/MWh)	
BERG	3	65	195	14,761	11.00	28	1.25	1.5	1977
GDAM	2	15	30	18,451	15.00	28	1.25	1.5	1968
	2	15	30	18,451	15.00	28	1.25	1.5	1972
	2	23	46	18,451	15.00	28	1.25	1.5	1974
	2	23	46	18,451	15.00	28	1.25	1.5	1975
	2	24	48	18,451	15.00	28	1.25	1.5	1976
	2	24	48	18,451	15.00	28	1.25	1.5	1977
	1	26	26	16,343	10.00	28	1.25	1.5	1978
	3	44	132	16,343	8.00	28	1.25	1.5	1978

TABLE 2. Contd.

Location	# of units	Rating Net (MW)	Rating Total (MW)	Heat Rate (kJ/kWh)	EFOR (%)	Maint. (days/yr)	O & M Costs Fixed ($/kW/mth)	O & M Costs Variable ($/MWh)	Year of Commis.
GFAR	3	70	210	14,393	11.00	28	1.25	1.5	1979
	1	70	70	14,393	11.00	28	1.25	1.5	1980
	1	70	70	14,393	9.00	28	1.25	1.5	1981
	7	61	427	13,029	8.00	28	1.25	1.5	1984
	1	61	61	13,029	8.00	28	1.25	1.5	1985
SGHZ	2	400	800	11,598	4.00	42	1.88	1.0	1980
	1	400	400	11,598	4.00	42	1.88	1.0	1981
	1	400	400	11,598	4.00	42	1.88	10	1981
GQAY	1	17	17	4,252	10.00	28	1.25	1.5	1977
	2	17	34	4,252	10.00	28	1.25	1.5	1980
	1	17	17	4,252	10.00	28	1.25	1.5	1983
	2	26	52	3,851	10.00	28	1.25	1.5	1985
GQAI	1	28	28	14,397	15.00	28	0.33	5.63	1981
SQUR	2	600	1200	9,665	7.00	42	0.45	1.0	1989
	2	600	1200	9,665	7.00	42	0.45	1.0	1992
GSAF	1	22	22	18,133	8.00	28	0.33	1.5	1974
	1	44	44	16,343	10.00	28	0.33	1.5	1976
GSHD	3	71	213	13,979	11.00	28	0.3	1.5	1978
	1	68	68	13,979	11.00	28	0.3	1.5	1978
	1	71	71	13,979	11.00	28	0.3	1.5	1979
	2	71	142	13,979	11.00	28	0.3	1.5	1980
	1	68	68	13,979	11.00	28	0.3	1.5	1980
	1	71	71	13,979	11.00	28	0.3	1.5	1981
	7	62	434	13,029	8.00	28	0.3	1.5	1982
	1	62	62	13,029	8.00	28	0.3	1.5	1983
GOTH	3	22	66	18,133	10.00	28	0.3	1.5	1973
	1	43	43	16,343	8.00	28	0.3	1.5	1974
	4	43	172	16,343	8.00	28	0.3	1.5	1975
GJUY	1	22	22	18,133	10.00	28	1.25	5.63	1995
	2	44	88	16,343	8.00	28	1.25	5.63	1995

2.5 Screening Curve

The screening curve methods combine simplified representation of generation costs and system load projection. One of the advantages of screening curve is to give an optimum mix of generating technologies. The basic approach is to construct cost curves for each technology and then to match the points of intersection with corresponding load points to determine the most cost effective. The technique plays major trade offs between capital cost, operating costs, and level of use for various types of generating capacity in a system.

3. Results

3.1 Candidate Units for Generation Expansion

Based on the decision made using the screening curve as shown in Fig. 4, the system candidates contain 600 MW and 300 MW steam turbines, and 100 MW and 50 MW gas turbines. Fig. (4) Tables 3 & 4 list the four candidates' characteristics with detailed description about each candidate's capital cost, discount rate, fixed operating cost and variable cost, fuel cost, and annual average heat rate.

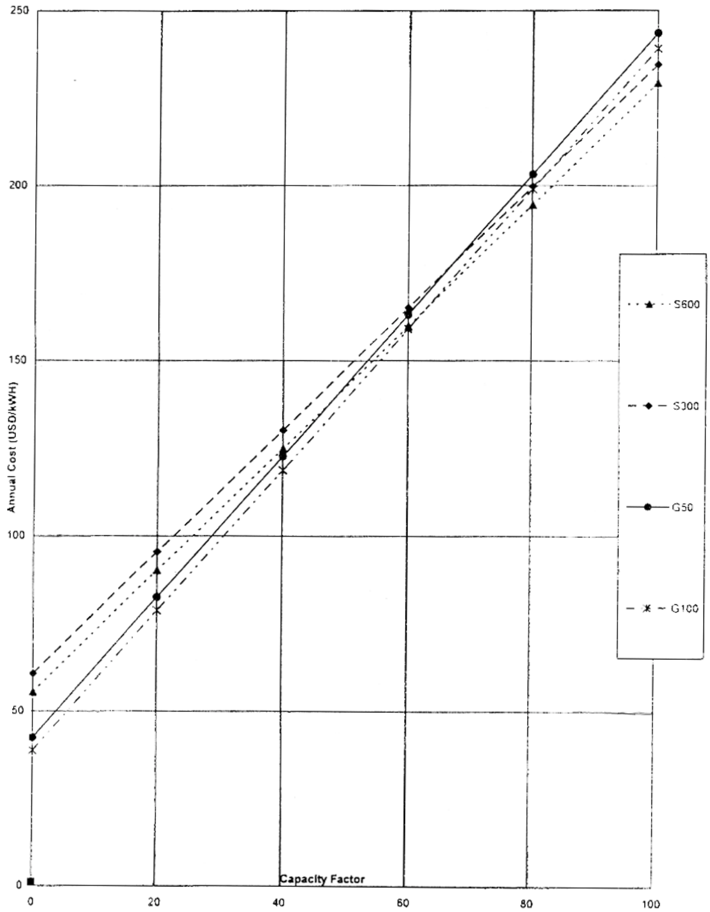

FIG. 4. Annual cost versus capacity factor.

TABLE 3. Characteristics of candidate systems for generation expansion

Unit name	Unit size (MW)	Book life (years)	Capital cost ($ / kW)	Annual esc rate	Fixed 0 & M ($/kW/yr)	Annual esc rate	Variable (mills / kWh)	Annual esc rate	Fuel cost (US$ / 10.6 kcal)	Annual esc rate	Annual average heat rate (kcal / kWh)
S600	600	30	630	0.8	0.75	0	2	0	9	0	2160
S300	300	30	630	0.8	0.75	0	2	0	9	0	2160
G50	50	20	460	0.8	1.25	0	3	0	6.4	0	3481
G100	100	20	420	0.8	1.0	0	3	0	6.4	0	3481

Table 4. Variable and fixed cost for candidate generating units.

Unit name	Unit size	Variable cost mills / kWh	Fixed cost	$ / kW - yr capacity factors (%)				
			0	20	40	60	80	100
S600	600	19.84	55.48	90.24	125.00	159.76	194.52	229.28
S300	300	19.84	60.73	95.49	130.25	165.01	199.77	234.53
G50	50	22.95	42.31	88.55	122.79	163.03	203.27	243.51
G100	100	22.88	38.70	78.78	118.87	158.95	199.03	239.12

3.2 The Optimal Generation Expansion

The economically attractive options were fed into the WASP III dynamic optimization model in order to screen out the numerous generation expansion options. The least cost development scenario is given in Fig. 5.

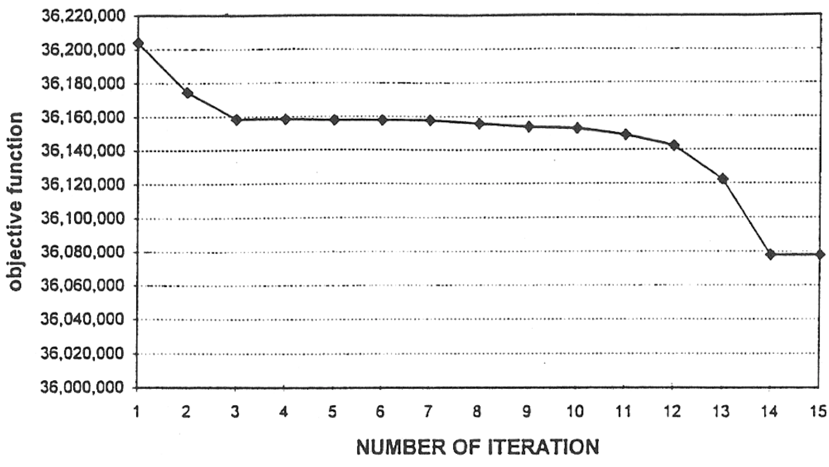

FIG. 5. Objective function versus number of iterations.

Table 5 shows the optimal generation candidates. The total required generation through the coming twelve years is 6600 MW. The solution consists of addition of 6 units of 600 MW steam turbines, 8 units of 300 MW steam turbines, 5 units of 100 MW gas turbines, and 10 units of 50 MW gas turbines.

TABLE 5. The expansion optimal solution.

Year	LOLP %. maint.	Capacity MW	S600 600 MW	G100 100 MW	S300 300 MW	G50 50 MW
1997	0.205	2250	2	8	*	5
1998	0.275	100	*	*	*	2
1999	0.498	0	*	*	*	*
2000	0.318	0	*	*	*	*
2001	0.144	600	1	*	*	*
2002	0.374	0	*	*	*	*
2003	0.183	600	1	*	*	*
2004	0.323	600	1	*	*	*
2005	0.456	300	*	*	1	*
2006	0.247	1050	*	3	2	3
2007	0.179	600	*	*	2	*
2008	0.143	600	1	*	*	*
Total		6700	6	11	5	10

Tables 6-8 present the annual load loss indices (or indexes).

TABLE 6. The annual loss of load probability percentage.

	1997	1998	1999	2000
Peak demand (MW)	7416	7948	8480	8916
Added capacity (MW)	2250	100	0	0
Reserved margin %	20.40	18.60	15.90	17.40
Annual LOLP %	0.205	0.275	0.498	0.318

TABLE 7. The annual loss of load probability percentage.

	2001	2002	2003	2004
Peak demand (MW)	9204	9484	9785	10116
Added capacity (MW)	600	0	600	600
Reserved margin %	20.30	16.70	19.30	17.30
Annual LOLP %	0.144	0.374	0.183	0.323

TABLE 8. The annual loss of load probability percentage.

	2005	2006	2007	2008
Peak demand (MW)	10474	10875	11285	11731
Added capacity (MW)	300	1050	600	600
Reserved margin %	15.80	17.50	18.20	18.80
Annual LOLP %	0.456	0.247	0.179	0.143

4. Conclusion

From this study, it is clear that the electricity generation options available are steam turbines and gas turbines. During the planning period 1997-2008, demand on electricity will increase, and to meet this demand 6 $\times$ 600 MW steam turbines, 5 $\times$ 300 MW, 8 $\times$ 100 gas turbines, and 10 $\times$ 50 MW gas turbines should be added. These generation additions allow the retirement of some of the existing system units during the period up to the year 1998 (Table 9).

TABLE 9. The generation units addition during the planning period 1997-2008.

Year	Required generation
1997	2 $\times$ 600 MW + 8 $\times$ 100 MW + 5 $\times$ 50 MW
1998	2 $\times$ 50 MW
2001	1 $\times$ 600 MW
2003	1 $\times$ 600 MW
2004	1 $\times$ 600 MW
2005	1 $\times$ 300 MW
2006	2 $\times$ 300 MW, 3 $\times$ 100 MW, 3 $\times$ 50 MW
2007	2 $\times$300 MW
2008	1 $\times$ 600 MW

In addition to the generation committed, the following generation is required:

Since, the LOLP in the year 1999 (Table 6) is quite high, hence an additional generator should be included in the expansion planning. In the year 2005 (Table 8), the LOLP is high, and hence an addition to the expansion planning for that year is required[17].

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التخطيط لتوسعة شبكة توليد القوى الكهربائية بالمنطقة الشرقية بالمملكة العربية السعودية

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