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Maximum Annual Load Estimation and Network Strengthening for the Kingdom of Bahrain

تقدير الأحمال القصوى السنوية وتعزيزها لشبكة مملكة البحرين

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Abstract: Three scenarios have been carried out to calculate the predicted maximum annual load for the Kingdom of Bahrain with the objective of formulating an expansion plan for a future generating system. The results of the three scenarios were obtained and compared using a comprehensive analysis. The maximum annual load was calculated at average rates of 6.79% in the more reasonable scenarios using the MATLAB package following the curve- fitting polynomial technique.
Keywords: *MATLAB, electrical load, Kingdom of Bahrain, curve–fitting*.

المستخلص: تم تنفيذ ثلاثة سيناريوهات لحساب التنبؤ للأحمال الكهربائية السنوية لمملكة البحرين بمهمة صياغة خطة التوسع في نظام التوليد للمستقبل. تم مقارنة نتائج السيناريوهات الثلاثة التي تم الحصول عليها مع تنفيذ تحليلها بشمولية. كما أن الأحمال الكهربائية القصوى قد حسبت على أساس سنوي متوسط بمعدل 6.79% في أكثر السيناريوهات المعقولة باستخدام برنامج الماتلاب.
كلمات مدخلية: *ماتلاب، الحمل الكهربائي، مملكة البحرين، تحديد المنحنى.*

INTRODUCTION

Power generation in the Kingdom of Bahrain is expected to grow in coming years. The bulk of additional supply is expected to be met through expansion of domestic and imported power generation. The government is currently pursuing a combination of public and private options to ensure future generation can be added as required when needed. On-going changes in the electricity utility sector are imposing ever-stricter constraints upon the operators of transmission networks. It appears obvious that the demand for electricity are increasing year by year. Therefore, this incremented increase on demands requires improvements in generation by increasing generating units as well as improving the network. It is clear that the challenge imposed on generation capacity to meet future requirements is carried out.

In the transition phase from the Ministry of Electricity and Water to EWA, sector sustainability was in need of ensuring. By providing liquidity for augmentation and expansion projects as well as for major maintenance work, the proposed projects would contribute to economic sustainability within the sector to achieve and help the government- set economic growth targets, needed in that the power sector to increase its generational capacity, efficiency and coverage. The projects will also increase confidence in financing long-term transmission and distribution assets in the Kingdom of Bahrain. There are a number of projects being carried out for the electricity sector enhancement in the Kingdom of Bahrain important projects presented in this study under contracts signed by the authority.

The first power station in Bahrain was Ras Roman power station (named Manama Station 1) with a maximum capacity of 0.2 MW (BAEWSB, 2005; BAEWAE, 2005; SN, 2004; SN, 2005). Moreover, the average growth during its first three decades was very small and slow in movement. The seventeenth decade has been considered as the decade of the great transmission in the history of Bahrain due to the increase in electricity production during that decade. The first gaseous turbine was installed in 1958 due to increased demand for electricity. In 1965, six gaseous turbines were installed to increase power generation due to increase of demand on the electricity. By the end of year 2004 (SN, 2004; SN, 2005; BAEWSB, 2006; BAEWSB, 2007) demand had reached 1849 MW produced though power stations in Manama, Muharraq, Sitra, Riffa'a, and Hidd. From 1994 to 2004, the Electricity and Water Authority in Bahrain signed a contract with Alba to get a benefit off approximately 240 MW from Alba though two tie-lines of 220kV and 66kV.

Literature Review

Hahn, *et al*. (2009) used various models and methods to predict future load demand. These various models and methods help decision-makers in the electricity sectors in facilities planning n and in optimal day-to-day operation of power plant. Doege, *et al*. (2009) realized power markets have been restructured since 1990s worldwide with electrical power nowadays being traded as a commodity. The liberalization and with it, uncertainty in gas, fuel and electrical power prices, requires effective management of production facilities and their financial contracts.

The description of two models for wind turbine generating systems (WTGSs) was considered (Eminoglu, 2009) and was widely used as distributed generation sources within distribution systems. These models were developed using modifications of the bi-quadratic equation which generally used to calculate node voltages in distribution systems' load flow analysis. The developed models in reference (Eminoglu, 2009) were validated with an experimental setup composed of an induction generator coupled with an induction motor as a prime mover, with calculated values obtained using other models reported in literature. They were also incorporated into distribution systems load flow analyses, and with results compared with results of Simulink models. Simulink models were developed in Matlab using Sim Power Systems Blockset (Lujun, 2011) and (Devesh, *et al*. 2009).

Elaine, *et al*. (2011) described a new generator portfolio planning model. The model combines a deterministic, renewable portfolio planning module with a Monte Carlo simulation of system operation that determines the anticipated least-cost dispatch from each technology, necessary reserve capacity and expected carbon emissions per hour. Results suggest that further reductions in carbon emissions may be achieved using emerging technologies which reliably provide large capacities without necessarily providing positive net annual energy generation. These technologies may include demand response, vehicle-to-grid systems and large-scale energy storage.

The electricity authority signed a consultation services contract with the Electric Supply Board Ireland (ESBI). This contract cost BD 6 million (about 15 million USD). This contract will help develop Bahrain's transmission network of 220kV and 66kV till the year 2011 (ALHalwaji, 2008). The authority has a plan for the years 2006 till 2020 (BAEWAE, 2005; SN, 2004; SN, 2005) to have a new power station with a 3000 MW capacity to meet demand, especially during summer in a range of 7% to 12%. This increment in load during summer is attributed to electrical consumption of commercial projects (private sector) in Bahrain. The cost of such projects is approximately 30 millio USD n. This power station would help satisfy the demand in coming years, i.e meeting the Economics of Scale; a term used to describe the reduction in cost-per-unit as more electrical units are produced. One new power station in Bahrain is El-Ezzel power station (900 MW – 1000 MW) with a cost of BD 189 million (AW Newspaper, 2008)

Problems the Authority Faces

There are number of problems the authority could face, such as (ANP, 2008): The number of domestic customers who pay their bills is88% to 92%, while the commercial customers is 99%. Some customers use bad quality appliances which consum too much power due to power's cheap cost. However, those customers will actually pay more because bad quality appliances consume more power. The available power stations can satisfy electricity need while some distribution networks are aging. This network needs to update or be replaced.

Strengthening the Power Network

One of the largest projects in Bahrain is to increase the strength of the transmission network which is 66 kV high voltage network at a cost of BD 32 million (BAEWAE, 2005; SN, 2004; SN, 2005). This network includes 12 new substations extended to 10 existing substations. 102 km underground cables have also been installed. A 220 kV high voltage transmission network was installed at a cost of 35 million BD in addition to 220 kV three substations (BAEWAE, 2005; SN, 2004; SN, 2005).

Power Stations in the Kingdom of Bahrain

In 1931, Manama (1) station was installed (0.2 MW). From 1931 through the years, the demand has increased due to so many completed projects coming to the Kingdom (BAEWSB, 2006; BAEWSB, 2007). The capacity of power stations in the year 2005 is summarized in (Tables 1, 2, 3 and 4) (BAEWSB, 2006; BAEWSB, 2007). El Ezzel power station was constructed and made operational by the year 2006. Table (5) shows its capacity

Table 1. Capacity of Manama and Muharraqe Power Stations (Year 2005).

Turbine Type	Year of Commissioning	Each Unit Capacity (MW)	No. of Unit(s)	Capacity (MW)
Gas	1975	16	2	32
Gas	1976	15	2	30
Total			4	62

Table 2. Capacity of Sitra Power Station (Year 2005).

Turbine Type	Year of Commissioning	Each Unit Capacity (MW)	No. of Unit(s)	Capacity (MW)
Steam	1975	25	2	50
Steam	1977	25	2	50
Gas	1984	25	1	25
Total			5	125

Table 3. Capacity of Rifaa Power Station (Year 2005).

Turbine Type	Year of Commissioning	Each Unit Capacity (MW)	No. of Unit(s)	Capacity (MW)
Gas	1978	50	2	100
Gas	1979	50	1	50
Gas	1980	50	2	100
Gas	1983	50	2	150
Gas	1984	75	4	300
Total			11	700

Table 4. Capacity of Hidd Power Station (Year 2005).

Turbine Type	Year of Commissioning	Each Unit Capacity (MW)	No. of Unit(s)	Capacity (MW)
Gas	1999	136	2	272
Gas	2002	140	1	140
Gas	2003	140	2	280
Steam	2004	270	1	270
Total			6	962

Table 5. Capacity of El-Ezzel Power Stations (Year 2006).

Turbine Type	Year of Commissioning	Each Unit Capacity (MW)	No. of Unit(s)	Capacity (MW)
Gas	2006	127	4	508
Steam	2006	221	2	442
Total			6	950

METHODOLOGY, RESULTS AND DISCUSSION

In order to satisfy a standard maximum annual load, the curve-fitting technique was applied using the MATLAB package (Appendix A). It should be noted that the model is represented by mathematical equations containing coefficients. These coefficients are obtained using the MATLAB. In this case, the model shows relationship between power (in MW) and time (year). Therefore, it is clear that the power is a function of time. The 27 year annual maximum load and maximum capacity data for Bahrain were used to obtain the capacity model and the annual maximum load model.

The capacity model was obtained using two conditions. The first condition was without removing the similar annual capacity values- Figure (1), which anticipated the capacity might remain fixed for a number of years. The model can be expressed as:

$P(x) = 117.7x^8 - 51.5x^7 - 523.2x^6 + 279.6x^5 + 644.7x^4 - 284.4x^3 - 50.6x^2 + 381.1x + 1100.4$, where the function P(x) is Power in MW as a function of year.

The second condition removes the identical values Figure (2), which is more reasonable. Since the curve passes through the middle point. The model will then be =

$P(x) = 68.26963357407x^5 + 53.24284454339x^4 - 75.92947566430x^3 + 88.64107358845x^2 + 387.92874492301x + 1169.08349135408$, where function P(x) is Power in MW as a function of year.

The maximum load model is obtained and modeled in the following expression: $P(x) = 16.021496169784x^4 + 58.617772416671x^3 + 95.894754300138x^2 + 382.239943575733x + 967.819350083527$, where function P(x) is Power in MW as a function of year. This model can be drawn as shown in Figure (3) showing the annual maximum load.

Following up peak-load values for present day, the most reasonable and expected value for 2009 (year of research) is 5.5% increment. The average % Increment of maximum load for the 27 years is 6.79 %. This is shown in (Figure 4). Based on results obtained from the present study with projected load by Bahrain's Electricity and Water Authority (EWA), Table (6) is produced and sketched as shown in(Figure 5). Three scenarios were applied to reflect possible future estimated maximum annual load.

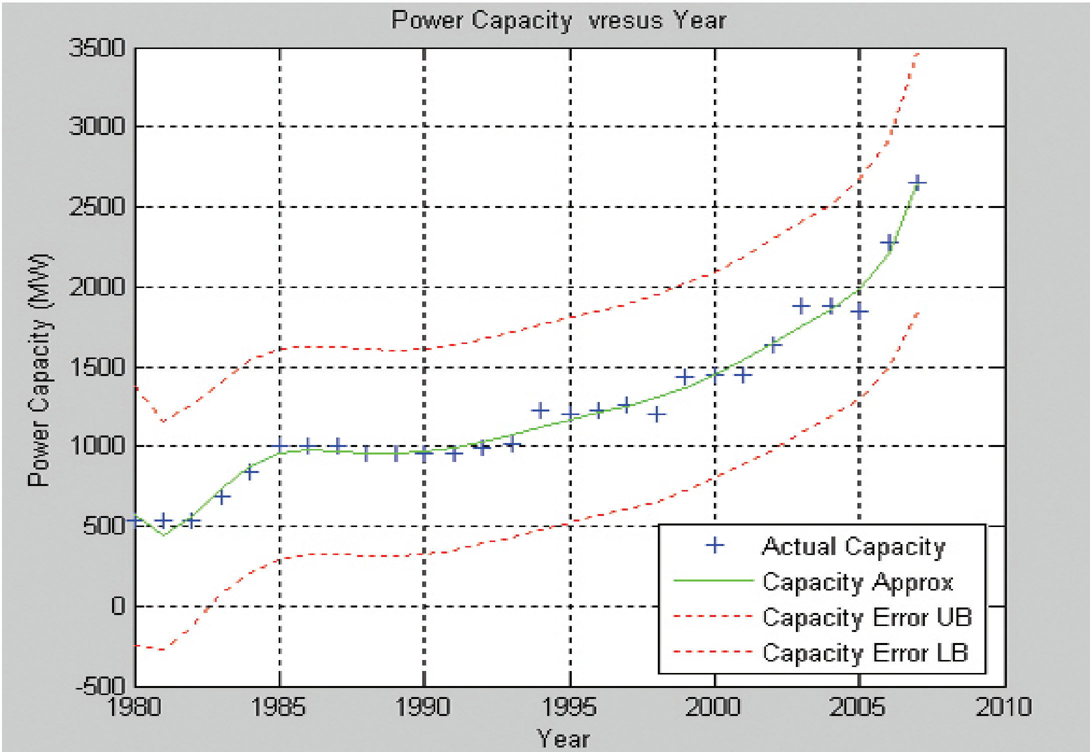

Fig. 1. Annual capacity values for Kingdom of Bahrain through the Years 1980-2007 (all points included).

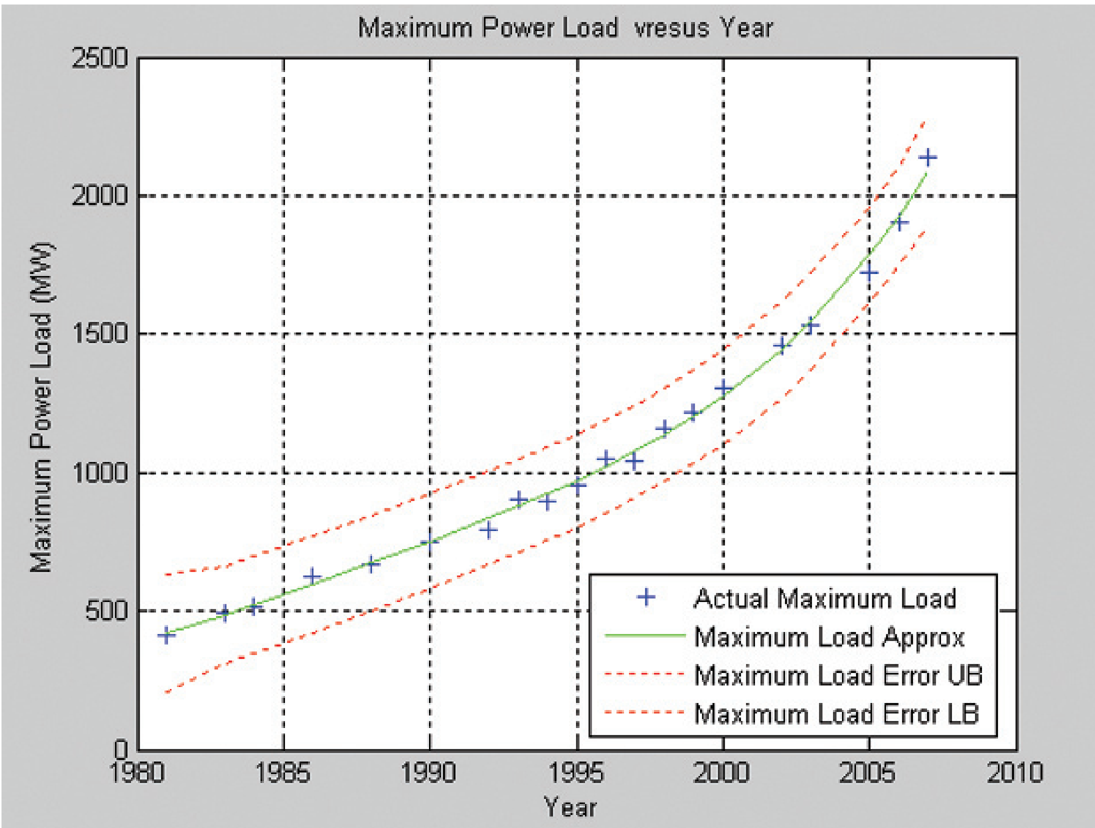

Fig. 2. Annual capacity values for Kingdom of Bahrain through the Years 1980-2007 (excluding the similarity).

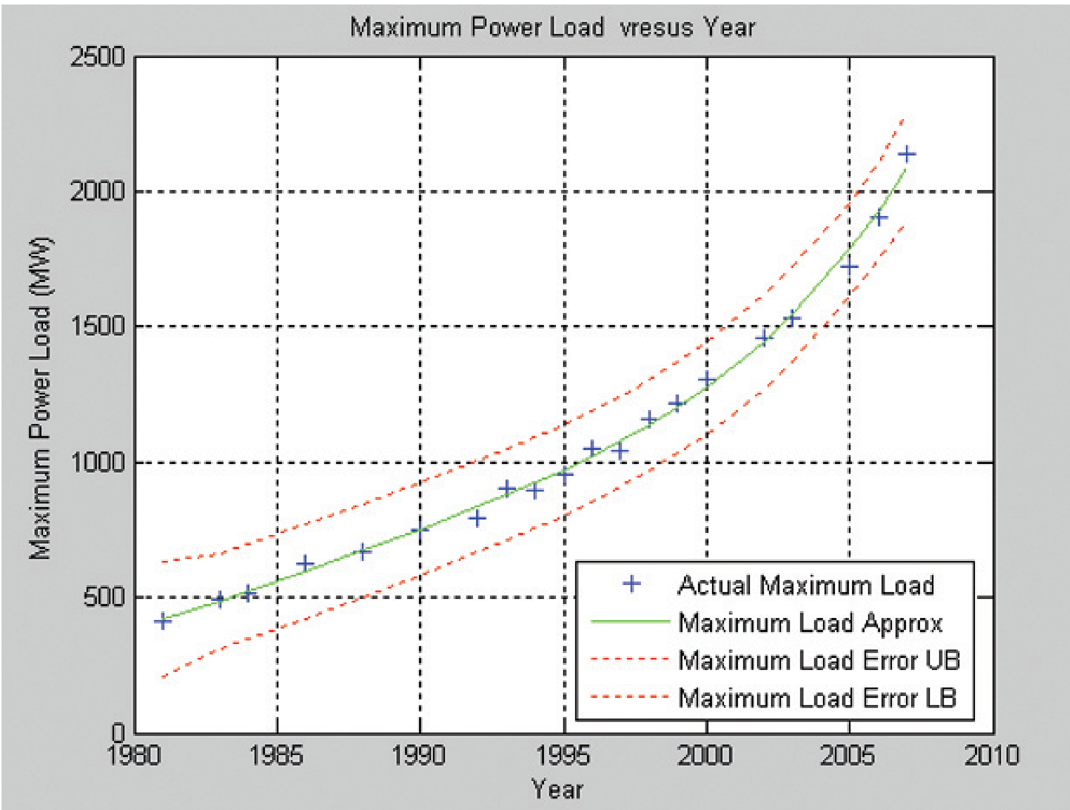

Fig. 3. Annual maximum load values for Kingdom of Bahrain through the years 1980-2007.

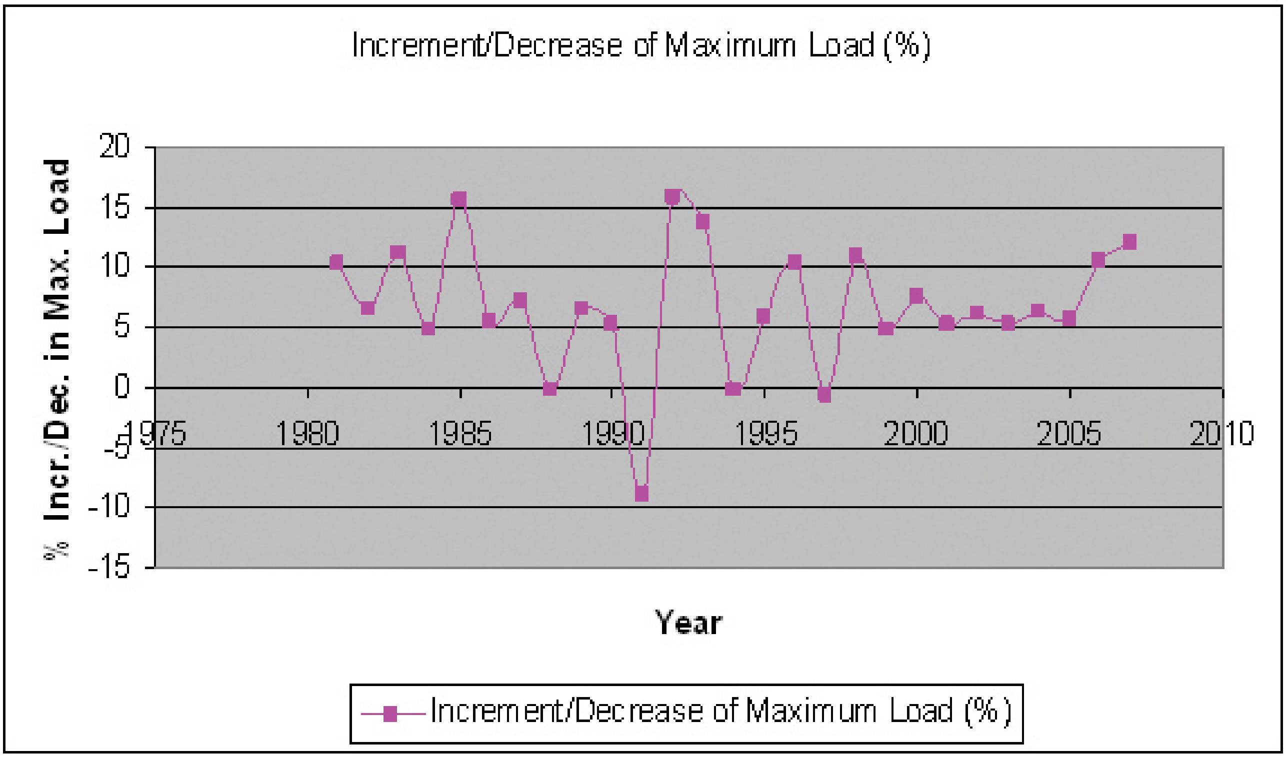

Fig. 4. Increment/decrease of maximum load in percentage.

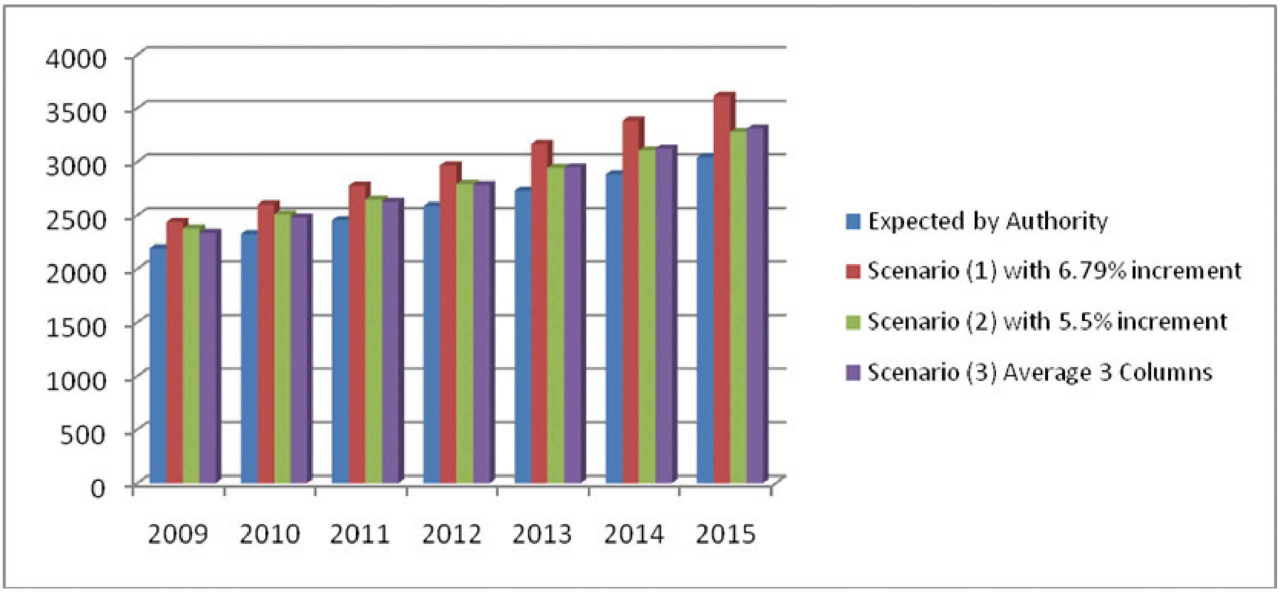

Fig. 5. Three scenarios reflecting possible future maximum annual load maximum estimated load (MW) vs Year.

Table 6. Load demand expectation for 2009-2015 (projected by the Authority with three scenarios).

Year	Expected by Authority	Scenario (1) with 6.79% increment	Scenario (2) with 5.5% increment	Scenario (3) Average 3 Columns
2009	2194	2436	2377	2336
2010	2325	2601	2508	2478
2011	2453	2778	2646	2626
2012	2588	2967	2792	2782
2013	2731	3168	2945	2948
2014	2881	3383	3107	3124
2015	3039	3613	3278	3310

Three scenarios are considered in the presented paper, illustrated in (Table 6). The first is obtained by the developed model in the present study while the second is the most reasonable increment considered by the authority. Finally, the third is the average load for the values.

CONCLUSION

For the EWA to improve the electricity network in the Kingdom of Bahrain, customers and the EWA need to consider the following points to reduce demand load and avoid problems mentioned earlier:

- Thermal insulation for buildings.
- Power and Energy audits.
- Rules, standards, and labeling for all appliances.

These practices will help to reduce power demand and may be called main strategic points. Using the curve-fitting technique through MATLAB package with the 27 year annual data of both collected annual maximum capacity of the system and the maximum annual load, capacity and annual maximum load for the Kingdom of Bahrain were obtained and easily modeled to find the estimated values.

The present study shows the load to be increasing by an average of 6.79% overthe previous maximum annual load with the 27 years data. This rich data helped to obtain reasonable modelswith which to estimate annual maximum load within the data period and after. The two obtained models were sufficient to initiating capacity and annual maximum loads for the Kingdom of Bahrain.

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REFERENCES

Al-Ayam Newspaper (ANP) (2008) *Reducing the Electricity cut off, Al-Ayam Newspaper 6998*. Kingdom of Bahrain.

Al Halwaji, S (2008) *10 power s/s and 30 Transformers for Summer 2008 completes*. Al-Wasat Newspaper, Issue No. 2062: 4.

Al-Wasat Newspaper (AW Newspaper) (2008) *Hidd Power Station*. Al-Wasat News Paper 2057, Kingdom of Bahrain.

Bahrain Authority of Electricity and Water (BAEWAE) (2005) *The Electricity Sector in Kingdom of Bahrain*. The Arab Electricity 11, Jordan.

Bahrain Authority of Electricity and Water (BAEWSB) (2005) *Statistical Book*. Kingdom of Bahrain.

Bahrain Authority of Electricity and Water (BAEWSB) (2006) *Statistical Book*. Kingdom of Bahrain.

Bahrain Authority of Electricity and Water (BAEWSB) (2007) *Statistical Book*. Kingdom of Bahrain.

Bahrain Authority of Electricity and Water (2005) *Electricity and Water Authority Web-Site*. Kingdom of Bahrain.

Doege, J, Fehr, M, Hinz, J, Luthi, H and **Wilhelm, M** (2009) Risk management in power markets: the hedging value of production flexibility. European *Journal of Operational Research* **199:** 2474-2483.

Devesh, T, Bikramjit, B, and **Koushik B** (2009) Simulation of thermal and electric field evolution during spark plasma sintering. *Ceramics International* **35:** 699-708.

Elaine, K, Hart, M, and **Jacobson, Z** (2011) A Monte Carlo approach to generator portfolio planning and carbon emissions assessments of systems with large penetrations of variable renewables. *Renewable Energy* **36:** 2278-2286.

Eminoglu, U (2009) Modeling and application of wind turbine generating system (WTGS) to distribution systems. *Renewable Energy* **34:** 2474-2483.

Hahn, H, Meyer-Nieberg, S, and **Pickl, S** (2009) Electric load forecasting methods: Tools for decision making. *European Journal of Operational Research* **199:** 902-907.

Lujun, Z (2011) An energy-saving oil drilling rig for recovering potential energy and decreasing motor power. *Energy Conversion and Management* **52:** 359-365.

Statistical Newsletter (SN) (2004) *Arab Union of Producers, Transporters and Distributors of Electricity*. Jordan.

Statistical Newsletter (SN) (2005) *Arab Union of Producers, Transporters and Distributors of Electricity*. Jordan.

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Appendix, Matlab-Simulink Program

```
disp(['THIS PROGRAM IS USED TO PLOT
']);
disp(['                                              ']);
disp(['                                              ']);
disp(['                                              ']);
disp(['                                              ']);
disp(['**************************************************************************
****************************************']);
porder=input(' INSERT THE ORDER OF THE POLYNOMIAL ORDER=');
Est_year1=input(' INSERT THE YEAR (FOR FINDING THE CAPCITY AND MAXIMUM LOAD
AT THIS YEAR) YEAR=');
year=1980:1:2007;
years=transpose(year);
Capacity=[533;533;533;686;839;999;999;999;961;961;956;956;995;1020;1226;1201;1226;1261;12
02;1439;1449;1449;1629;1879;1879;1849;2272;2650];
sdate = (years - mean(years))./std(years);
year1=1980:1:Est_year1;
years1=transpose(year1);
Est_year=(Est_year1-mean(years1))./std(years1);
[p_porder,S_porder] = polyfit(sdate,Capacity,porder);
Capacity_Coef=p_porder
[Capacity_porder,del_porder] = polyval(p_porder,sdate,S_porder);
%subplot(2,1,1);
plot(years,Capacity,'+',years,Capacity_porder,'g-',years,Capacity_porder+porder*del_porder,'r:',...
years,Capacity_porder-porder*del_porder,'r:'), grid on
title('Power Capacity  vresus Year  ')
ylabel(' Power Capacity (MW) ')
xlabel('Year ')
legend('Actual Capacity ','Capacity Approx ','Capacity Error UB ','Capacity Error LB',4)
Estim_Capacity=0;
for j=0:1:porder;
Estim_Capacity=Estim_Capacity+p_porder(1,j+1)*Est_year^(porder-j);
j=j+1;
end
format('short')
Estim_Capacity
format('long')
figure
Maxload=[375;414;441;490;514;594;627;672;670;714;752;685;793;901;899;952;1050;1044;1159;
1216;1307;1376;1459;1535;1632;1725;1906;2136];
sdate = (years - mean(years))./std(years);
[p_porder,S_porder] = polyfit(sdate,Maxload,porder);
Maxload_Coef=p_porder
[Maxload_porder,del_porder] = polyval(p_porder, sdate,S_porder);
%subplot(2,1,2);
plot(years,Maxload,'+',years,Maxload_porder,'g-',years,Maxload_porder+porder*del_porder,'r:',...
  years,Maxload_porder-porder*del_porder,'r:'), grid on
```

```
title('Maximum Power Load  vresus Year  ')
ylabel(' Maximum Power Load (MW) ')
xlabel('Year ')
legend('Actual Maximum Load ','Maximum Load Approx ','Maximum Load Error UB ','Maximum
Load Error LB',4)
Estim_Maxload=0;
for j=0:1:porder;
Estim_Maxload=Estim_Maxload+p_porder(1,j+1)*Est_year^(porder-j);
j=j+1;
end
format('short')
Estim_Maxload
```