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Long-Term Load Forecasting of Southern Governorates of Jordan Distribution Electric System

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Abstract

Load forecasting is vitally important for electric industry in the deregulated economy. This paper aims to face the power crisis and to achieve energy security in Jordan. Our participation is localized in the southern parts of Jordan including, Ma'an, Karak and Aqaba. The available statistical data about the load of southern part of Jordan are supplied by electricity Distribution Company. Mathematical and statistical methods attempted to forecast future demand by determining trends of past results and use the trends to extrapolate the curve demand in the future.

Keywords

Long-Term Load Forecasting, Peak Load, Max Demand and Least Squares

1. Introduction

In the absence of perspective planning, the state faces power crisis. The important factors which lead to power crisis are: 1) low utilization of existing energy sources; 2) low utilization of existing generating capacity; 3) faculty planning and defective execution of projects; 4) inadequate linking of transmission network; 5) absence of efficient and integrated operations of different power stations in a system; 6) political influences in decisions on locations of power stations due to lack of studies and researches.

Jordan suffers from the lack of the electrical energy due to the above mentioned factors especially the low utilization of existing energy sources, absence of long term planning of energy and no attentions or supports are given to the researchers and personnel of power stations.

Perspective planning of the system should be based on proper forecasting of the load of the system, availability of generating stations and their improvements, combination of resources, economic considerations, streng-

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thening and coordinating various existing systems and above all the availability of the adequate finance and management skill for realizing the benefits of the perspective planning.

It is first necessary to find out the load requirements of the area where electricity is to be supplied. This depends on the population of area, density of population, standards of living, industrial development and the cost of energy; when we talk about these factors we talk about people's energy security and country security which must be achieved. In the southern part of Jordan, the load consists mainly of domestic load like, lights, fan heaters, refrigerators, air conditioners, radio, television, electric cookers, electric water heaters and low power motors. Commercial load like lighting for big supermarket and street lighting. Industry load is excluded from this study because the maximum demand of industries in southern part of Jordan was taking into account the period of establishing these factories (and they have own substations and own tariff).

Load forecasting can be broadly divided into three categories: short-term forecasts which are usually from one hour to one week, medium forecasts which are usually from a week to a year, and long-term forecasts which are longer than a year [1]. Traditional studies for long-term load forecasting were based on regression method, which could not provide a true representation of power system behavior in a volatile electricity market. Many studies present traditional methods like neural networks, genetic algorithms, fuzzy rules, which support vector machines, wavelet networks and expert systems [2] [3], while [4]-[6] introduce two approaches based on regression method and artificial neural network (ANN) for long-term load forecast by applying fuzzy sets to ANN for modeling long-term uncertainties and compare the enhanced forecasting results with those of traditional methods. There are also some researchers present artificial neural network (ANN) combined with linear regression [7]. In [8], energy data of several past years were used to train an adaptive network based on fuzzy inference system (ANFIS). Also in [9], a new hybrid forecast engine is proposed; the proposed engine has an iterative training mechanism composed of a novel stochastic search technique and Levenberg-Marquardt (LM) learning algorithm. Another method combined with artificial neural network supports vector machine (SVM). A novel dynamic architecture for artificial neural network (DAN2) method was used in load forecasting; the structure of DAN2 was automatic formed by training [10].

In this paper, by using the max demand data which is recorded from 2005 to 2013 and employing the least squares regression, peak load demand for 2014-2023 is forecasted. The results are validated by using the real data of 2014.

2. Least Squares Method

Generally, load forecasting methods are mainly classified into two categories: classical approaches and non-classical techniques. Classical approaches are based on statistical methods and forecast future value of a variable by using a mathematical combination of the historic information but this way have week prediction result, least squares method is most power full techniques will be used in forecasting, load forecasting is of the most difficult problems in distribution system planning and analysis. However, not only historical load data of a distribution system play a very important role on peak load forecasting, but also the impacts of meteorological and demographic factors must be taken into consideration so least squares method is the best method to solve this kind of problem [11].

Let D = demand of electrical power (kW or MW).

y = the year in which the demand is considered.

y^o = base year.

Then the exponential growth of demand with time would be expressed as: $D = \mathrm{e}^{a+b\left(y-y^o\right)}$

Where: a, b = constants.

In order to evaluate the constants a and b, based on actual demand data over a number of year, put $y - y^o = Y$.

$$\text{then: } D = \mathrm{e}^{a+bY}$$

$$\text{then: } \ln D = a + bY.$$

$$\text{Let } V = \ln D$$

$$\text{then } V = a + bY \tag{1}$$

Equation (1) is an equation relating V and Y in a linear fashion.

Suppose that the demand for consecutive years are given as: $D_1, D_2, D_3, \cdots, D_n$. The plot of $V = f\left(Y\right)$ is shown in **Figure 1**.

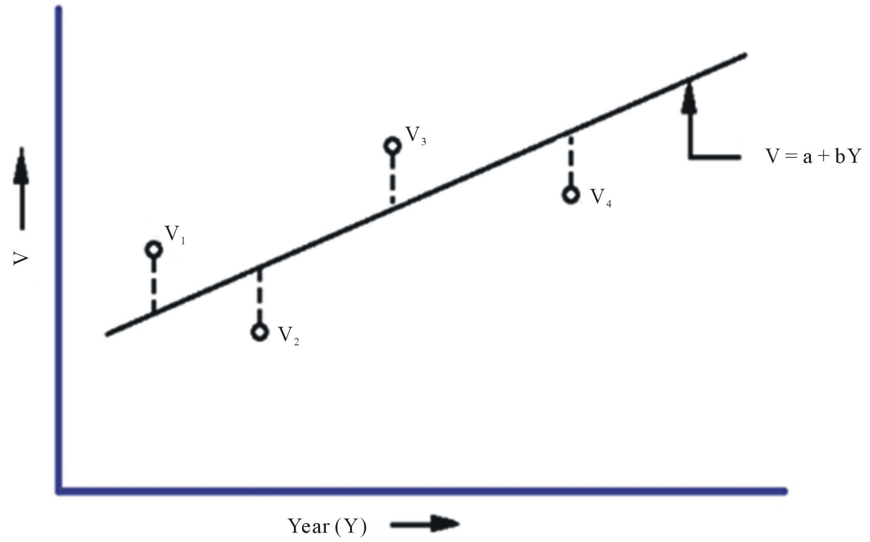

Figure 1. Least squaresthe demand for consecutive years.

Corresponding to various values of Y_i's there are V_i's. All the V_i's are randomly distributed as shown in the last figure. For an exponential growth, $V = a + bY$. In order to correctly assess the demand, the sum of the squares of the errors committed by such approximation should be minimzed [12], *i.e.*

$s = \sum_{i=1}^{n} \left[V_i - \left(a + bY_i \right) \right]^2$ should be minimum. Conditions for s to be minimum are:

$$\frac{\partial s}{\partial a} = 0 \quad \text{and} \quad \frac{\partial s}{\partial b} = 0$$

Then: $\frac{\partial s}{\partial a} = \sum_{i=1}^{n} 2\left[V_i - \left(a + bY_i \right) \right] (-1) = 0$

$$\sum_{i=1}^{n} V_i = na + b \sum_{i=1}^{n} Y_i \tag{2}$$

Also: $\frac{\partial s}{\partial b} = \sum_{i=1}^{n} 2\left[V_i - \left(a + bY_i \right) \right] (-1) Y_i = 0$

$$\sum_{i=1}^{n} V_i Y_i = a \sum_{i=1}^{n} Y_i + b \sum_{i=1}^{n} Y_i^2 \tag{3}$$

Thus, Equations (2) and (3) provide the conditions for the sum of the least squares of the deviation to be minimum.

For simplifying further, let $\sum_{i=1}^{n} Y_i = 0$

From Equation (1), we have:

$$a = \frac{1}{n} \sum_{i=1}^{n} V_i \tag{4}$$

$$\text{And} \quad b = \frac{\sum_{i=1}^{n} Y_i V_i}{\sum_{I=1}^{n} Y_i^2} \tag{5}$$

Thus Equations (4) and (5) would enable us to evaluate the constants a and b so as to minimize the error in load forecasting.

3. Distribution Electric System of Southern Governorates in Jordan

The distribution of electric system of southern governorates in Jordan cover four governorates Ma'an, Aqaba, Tafila and Karak. The total number of constructed substations and their accumulative capacity in the distribution areas lha1 belong to the company until the end of 2013 was (4531) with a capacity of 2542 MVA, at the end of 2013, the total length of medium and low voltage for both overhead and underground networks have been reached (11,650) km [13], **Figure 2** and **Figure 3** represent the main substation in each governorate Karak, Ma'an, Tafila and Aqaba

i. Karak Forecasting

Referring to nine years load data, we found the Max demand of each years as shown in **Table 1** by using this data in **Figure 2**, and applying the least squares to find the Max Demand for next ten years **Table 2** and **Table 3** shown the Max Demand for next ten years.

In the last column of **Table 3**, we found the value of forecasting for next ten years; then we put these values on the axis, then we have to generate the curve in **Figure 4**.

After we found the values of Max demand of next years, we will be able to predict the year for which you want the new plant, in next page **Table 4** show this. Note here is that the pregnancy has exceeded the maximum allowable load before it is predictable.

ii. Tafila Forecasting

In appendix A found the table of last nine years, then we found the max demand of each years and plot in this **Table 5**. Then like us these values in the form of the curve in **Figure 5** and **Figure 6**.

Then we use the least squares to find the Max Demand for next ten years. When use the least squares generate **Table 6** and **Table 7**.

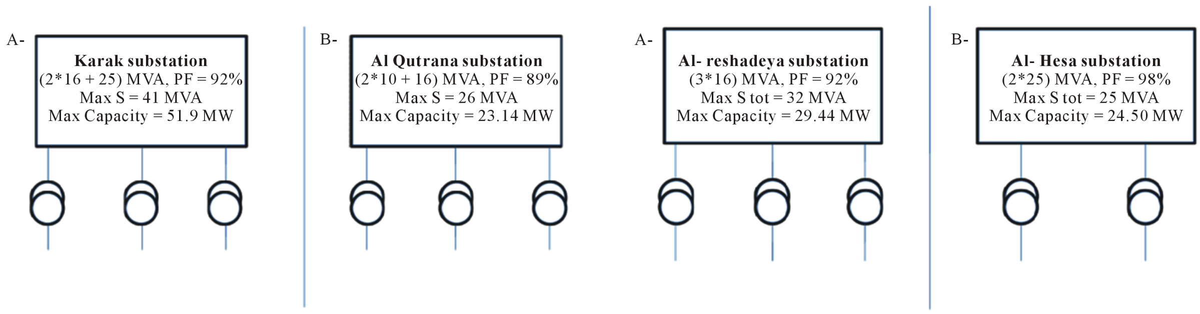

Figure 2. The main substation at Karak and Tafila governorate.

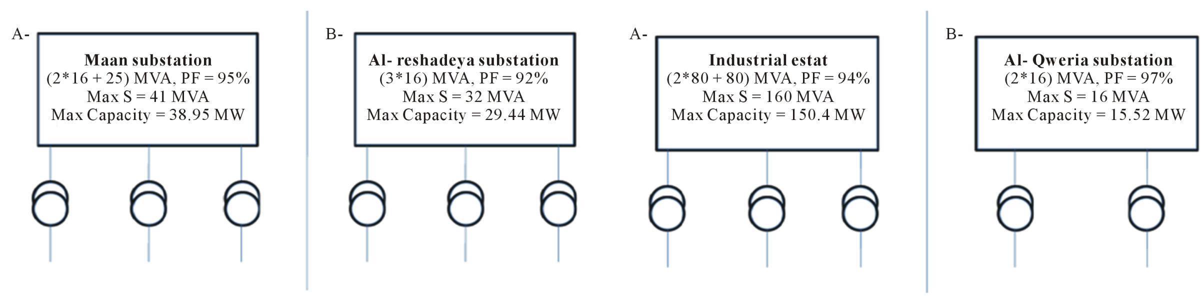

Figure 3. The main substation at Ma'an and Aqaba governorate.

Table 1. Max demand of Karak governorate for nine years.

City		2005	2006	2007	2008	2009	2010	2011	2012	2013
Karak	Karak	25.65	41.38	39.66	43.07	36.20	36.20	45.24	51.88	50.93
	Qutraneh	16.86	17.15	18.34	19.31	22.19	22.19	18.70	19.96	20.18
	karak total	48.32	58.53	58	59.3	71.02	71.02	76.66	84.04	84.38

Table 2. Least squares co-officiant.

Last Years	Max *D*	$D'_i = D/10$	$Vi = \ln D'_i$	Y_i	$V_iY'_i$	Y_i^2
2005	48.32	4.832	1.57526	−4	−6.30104	16
2006	58.53	5.853	1.766954	−3	−5.30086	9
2007	58	5.8	1.757858	−2	−3.51572	4
2008	59.3	5.93	1.780024	−1	−1.78002	1
2009	71.02	7.102	1.960376	0	0	0
2010	71.02	7.102	1.960376	1	1.960376	1
2011	76.66	7.666	2.036795	2	4.07359	4
2012	84.04	8.404	2.128708	3	6.386123	9
2013	84.38	8.438	2.132745	4	8.530981	16

Table 3. Max Demand for next ten years.

Next Years	Sum of V_i	Sum of Y_i	Sum of V_iY_i	*a*	*b*	Max *D*
2014						93.716134
2015						100.26608
2016						107.27381
2017						114.77132
2018	17.0990979	0	4.05342603	1.8999	0.067557	122.79285
2019						131.375
2020						140.55698
2021						150.3807
2022						160.89101
2023						172.1359

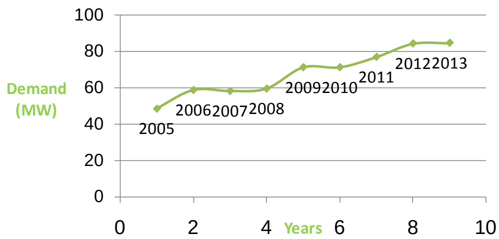

Figure 4. Total max demand for Karak governorate.

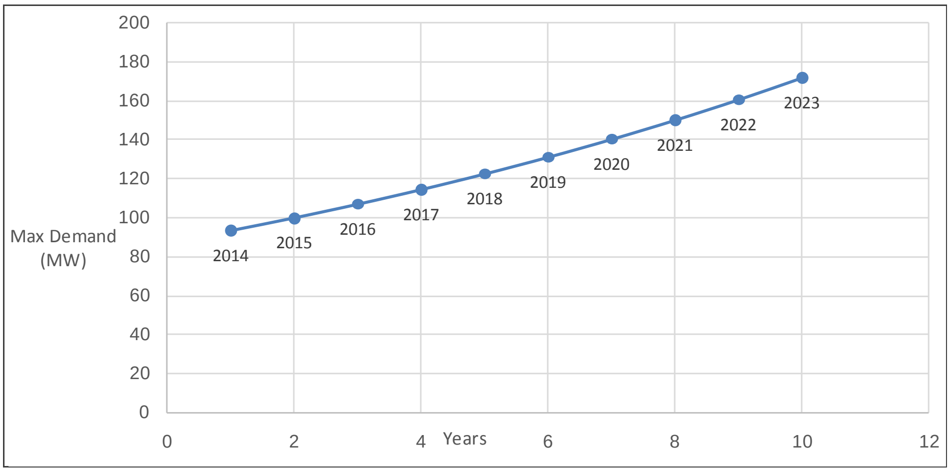

Figure 5. Max demand of next years.

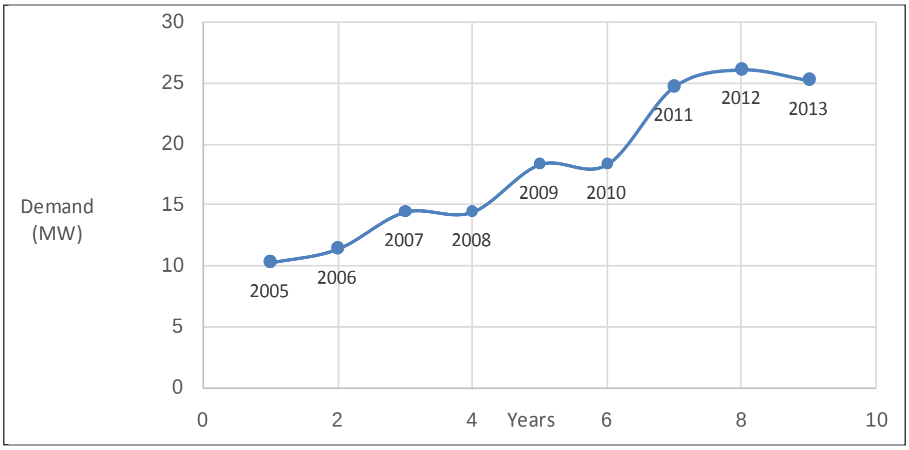

Figure 6. Tafila total max demand.

Table 4. Karak forecasting for 10 years.

Sub	Max $_D$	85% - 90%	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Karak	51.9	44.12 - 46.71	54.10	57.35	60.79	64.44	68.30	72.40	76.75	81.36	86.24	91.419
Qutraneh	23.14	19.67 - 20.83	21.65	22.15	22.65	23.17	23.69	24.24	24.79	25.35	25.93	26.523
karak total	75.04	63.79 - 67.54	93.716	100.27	107.27	114.77	122.79	131.38	140.56	150.38	160.89	172.14

Table 5. Max demand of Tafila governorate for nine years.

City		2005	2006	2007	2008	2009	2010	2011	2012	2013
Tafileh	Hasa	4.80	3.76	6.60	5.90	8.56	8.56	11.57	12.98	12.72
	Rashedieh Tafileh	6.08	7.65	7.84	8.81	9.78	9.78	13.16	13.13	12.53
	Tafileh Total	**10.28**	**11.4**	**14.44**	**14.44**	**18.34**	**18.34**	**24.73**	**26.12**	**25.24**

Table 6. Least squares co-officiant.

Last Years	Max D	$D'_i = D/10$	$V_i = \ln D'_i$	Y_i	$V_i Y'_i$	Y_i^2
2005	10.28	1.028	0.027615	−4	−0.11046	16
2006	11.4	1.14	0.131028	−3	−0.39308	9
2007	14.44	1.444	0.367417	−2	−0.73483	4
2008	14.44	1.444	0.367417	−1	−0.36742	1
2009	18.34	1.834	0.606499	0	0	0
2010	18.34	1.834	0.606499	1	0.606499	1
2011	24.73	2.473	0.905432	2	1.810864	4
2012	26.12	2.612	0.960116	3	2.880349	9
2013	25.24	2.524	0.925845	4	3.70338	16

In the last column of Table 7, we found the value of forecasting for next ten years, then we put these values on the axis, then we have to generate the curve in Figure 7.

After we found the values of Max demand of next years, we will be able to predict the year for which you want the new plant, in next page Table 8 show this.

When we see to the Table 8, in 2017 the value of Demand is between 85% - 90%, in this range we must send to the authority concerned power plants that we want during the next 3 years we want a new Plant.

iii. Ma'an Forecasting.

In appendix A found the table of last nine years, then we found the max demand of each years and plot in this Table 9.

Then like us these values in the form of the curve in Figure 8.

Then we use the least squares to find the Max Demand for next ten years. When use the least squares generate Table 10 and Table 11.

In the last column of Table 11, found the value of forecasting for next ten years, then we put these values on the axis, then we have to generate the curve in Figure 7.

After we found the values of Max demand of next years, we predicted the year for which you want the new plant, in next page Table 12 show this.

When we see to Table 12, in 2017 the value of Demand is between 85% - 90%, in this range we must send to the authority concerned power plants that we want during the next 3 years we want a new Plant, then in end of 2019 the plant is Ready for operate and cover any increase above 100% in that year.

Table 7. Max demand for next ten years.

Next Years	Sum of V_i	Sum of Y_i	Sum of V_iY_i	*a*	*b*	Max *D*
2014						31.914722
2015						36.101063
2016						40.836539
2017						46.19318
2018	4.8978694	0	7.39529519	0.544208	0.123255	52.252466
2019						59.106565
2020						66.859735
2021						75.62991
2022						85.550493
2023						96.772386

Table 8. Tafila Forecasting for 10 years.

Sub	Max Capacity	85% - 90%	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Hasa	24.5	20.83 - 22.05	16.51	19.22	22.37	24.5	24.5	24.5	28.38	32.76	37.72	43.18
Rahadieh-Tafileh	29.44	25.02 - 26.50	15.30	16.81	18.47	21.69	27.75	34.60	38.48	42.87	47.82	53.29
Tafila total	53.94	45.86 - 48.55	31.9	36.09	40.84	46.19	52.25	59.10	66.86	75.63	85.54	96.47

Table 9. Max demand of Ma'an governorate for nine years.

City		2005	2006	2007	2008	2009	2010	2011	2012	2013
Ma'an	Ma'an	21.44	25.07	25.56	28.32	35.94	35.94	37.64	40.62	40.66
	Rashadleh Quadiesieh	5.01	7.2	5.42	5.58	4.1	4.1	5.42	3.62	3.65
	Ma'an Total	**26.45**	**32.09**	**30.98**	**30.98**	**40.04**	**40.04**	**43.05**	**44.42**	**44.31**

Table 10. Least squares co-officiant.

Last Years	Max *D*	$D'_i = D/10$	$V_i = \ln D'_i$	Y_i	$V_i Y'_i$	Y_i^2
2005	26.45	2.645	0.972671	−4	−3.89068	16
2006	32.09	3.209	1.165959	−3	−3.49788	9
2007	30.98	3.098	1.130757	−2	−2.26151	4
2008	30.98	3.098	1.130757	−1	−1.13076	1
2009	40.04	4.004	1.387294	0	0	0
2010	40.04	4.004	1.387294	1	1.387294	1
2011	43.05	4.305	1.459777	2	2.919554	4
2012	44.42	4.442	1.491105	3	4.473314	9
2013	44.31	4.431	1.488625	4	5.954501	16

Table 11. Max Demand for next ten years.

Next Years	Sum of V_i	Sum of Y_i	Sum of V_iY_i	*a*	*b*	Max *D*
2014						50.492014
2015						53.921166
2016						57.583207
2017						61.493955
2018	11.6162154	0	3.94247393	1.290691	0.065708	65.670301
2019						70.130282
2020						74.893161
2021						79.97951
2022						85.411297
2023						91.211982

Table 12. Tafila forecasting for 10 years.

Substation	Max *D*	85% - 95%	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Maan	38.95	33.11 - 35.1	38.95	38.95	38.95	38.95	38.95	38.95	41.34	43.9	46.63	49.55
Rahadieh-Quadiesieh	29.44	25.02 - 26.5	11.58	15.02	18.7	22.62	26.82	31.3	33.96	36.52	39.25	42.17
Total	68.39	58.13 - 61.6	50.53	53.97	57.65	61.57	65.77	70.25	75.03	80.14	85.6	91.43

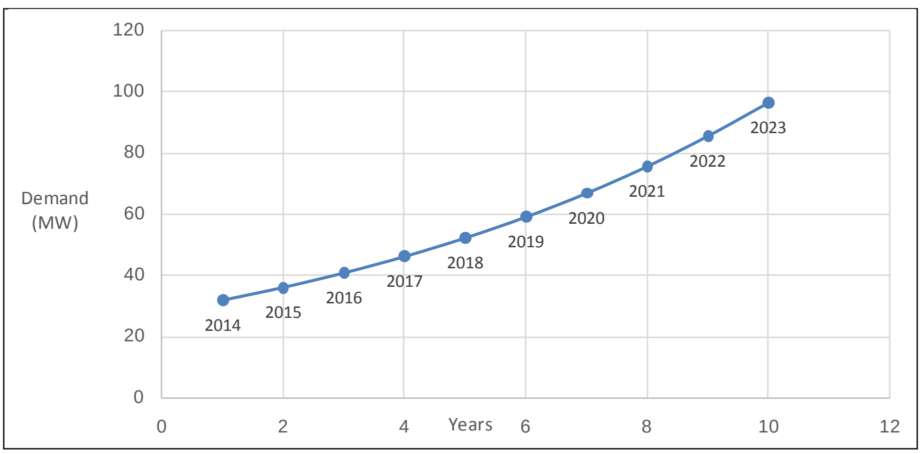

Figure 7. Tafila max demand for next 10 years.

iv. Aqapa Forecasting.

In appendix A found the table of last nine years, then we found the max demand of each years and plot in this **Table 13**.

Then like us these values in the form of the curve in **Figure 9** and **Figure 10**.

Then we use the least squares to find the Max Demand for next ten years. When use the least squares generate **Table 14** and **Table 15**.

In the last column of **Table 15**, we found the value of forecasting for next ten years, then we put these values

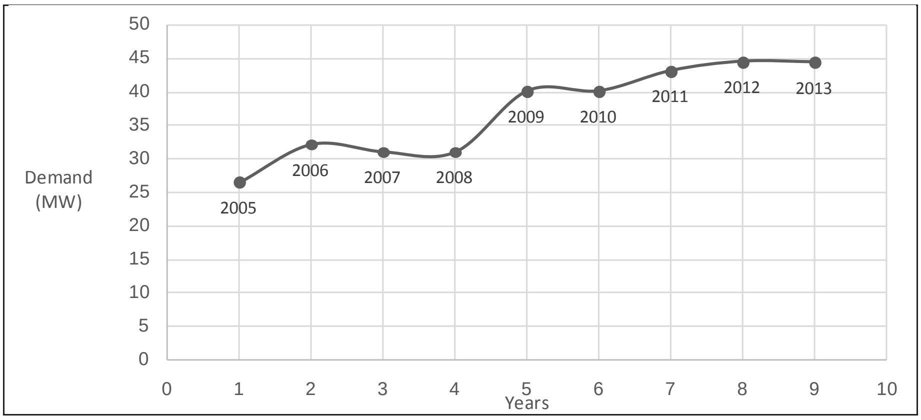

Figure 8. Ma'an total max demand.

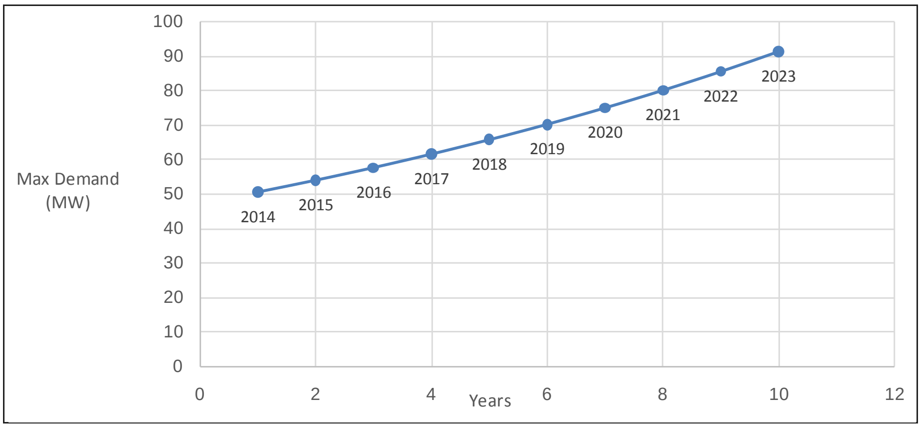

Figure 9. Next ten years forecasting of Ma'an.

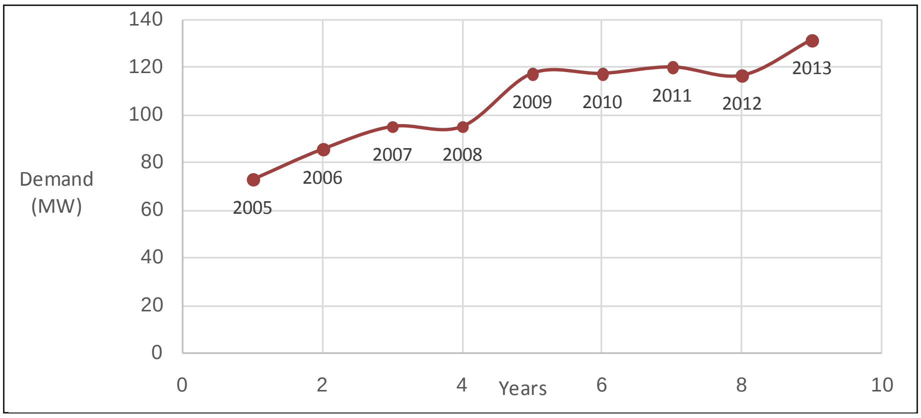

Figure 10. Total max demand.

Table 13. Max demand of Aqaba governorate for nine years.

City		2005	2006	2007	2008	2009	2010	2011	2012	2013
Aqaba	Industrial East	1.08	27.28	30.16	38.32	47.68	47.68	26.64	23.00	27.28
	A2	50.07	35.73	37.08	33.62	30.03	30.03	42.44	33.27	51.65
	Thermal	8.52	9.46	11.79	14.83	22.72	22.72	21.73	23.73	17.71
	Guweira	13.05	13.07	15.25	14.78	15.95	15.95	16.22	15.46	17.48
	Aqaba Total	**72.73**	**85.47**	**95.03**	**95.03**	**117.23**	**117.23**	**119.93**	**116.47**	**131.49**

Table 14. Least squares co-officiant.

Last Years	Max *D*	$D_i' = D/10$	$V_i = \ln D_i'$	Y_i	$V_i Y_i'$	Y_i^2
2005	72.73	7.273	1.984169	−4	−7.93668	16
2006	85.47	8.547	2.14558	−3	−6.43674	9
2007	95.03	9.503	2.251608	−2	−4.50322	4
2008	95.03	9.503	2.251608	−1	−2.25161	1
2009	117.23	11.723	2.461553	0	0	0
2010	117.23	11.723	2.461553	1	2.461553	1
2011	119.93	11.993	2.484323	2	4.968646	4
2012	116.47	11.647	2.455049	3	7.365146	9
2013	131.49	13.149	2.576346	4	10.30538	16

Table 15. Max demand for next ten years.

Next Years	Sum of V_i	Sum of Y_i	Sim of $V_i Y_i$	*a*	*b*	Max *D*
2014						144.73949
2015						154.64678
2016						165.23221
2017						176.5422
2018	21.0717872	0	3.97248867	2.34131	0.066208	188.62635
2019						201.53765
2020						215.33272
2021						230.07205
2022						245.82027
2023						262.64644

on the axis, then we have to generate the curve in **Figure 11**.

After we found the values of Max demand of next years, we predicted the year for which you want the new plant, in next page **Table 16** and **Table 17** show this.

When we see to **Table 16** and **Table 17**, not found any value of Demand is between 85% - 90%, for ten years we not need a new plant for Al-Aqapa city.

4. Conclusion

This paper presents long-term load forecasting of Southern Governorates of Jordan Distribution Electric System

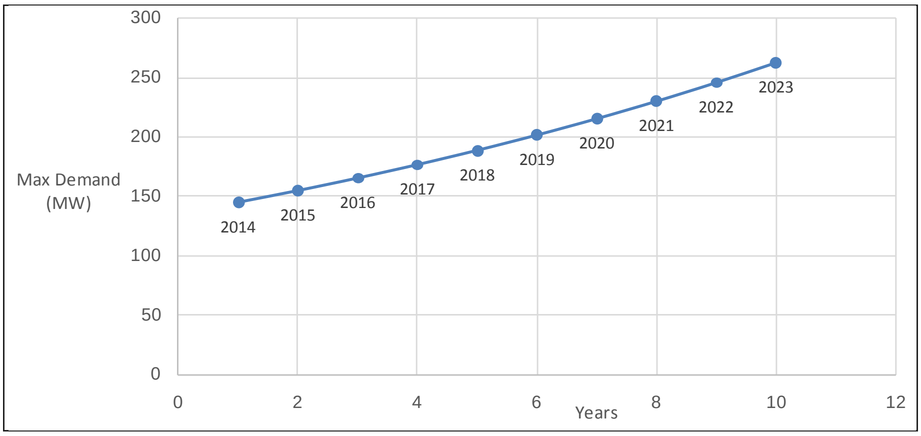

Figure 11. Next ten years forecasting of Aqaba

Table 16. Aqaba forecasting for 10 years.

2023	2022	2021	2020	2019	2018	2017	2016	2015	2014	Max *D*	Sub
106.78	98.83	90.88	82.93	74.98	67.03	59.08	51.13	43.18	35.23	150.4	**Industrial Estat**
93.41	89.23	85.06	80.88	76.71	72.53	68.35	64.18	60	55.38	131.56	**A2**
52.256	48.8	45.35	41.89	38.44	34.98	31.53	28.07	24.64	21.16	73.6	**Thermal**
10.204	8.96	8.68	9.63	11.41	14.09	17.58	21.85	26.83	32.97	15.52	**Guweira**
262.65	245.82	230.07	215.33	201.54	188.63	176.54	165.23	154.65	144.74	371.08	**aqapa Total**

Table 17. Total max demand of southerner governorates of Jordan distribution electric system forecast 2014-2023.

2023	2022	2021	2020	2019	2018	2017	2016	2015	2014	Max of Sub	City
262.65	245.82	230.07	215.33	201.54	188.63	176.54	165.23	154.65	144.74	371.08	**Aqapa**
172.14	160.89	150.38	140.56	131.38	122.79	114.77	107.27	100.27	93.716	75.04	**Karak**
96.77	85.55	75.63	66.86	59.11	52.25	46.19	40.84	36.1	31.92	53.94	**Tafila**
91.43	85.6	80.14	75.03	70.25	65.77	61.57	57.65	53.97	50.53	68.39	**Maan**
622.99	577.86	536.22	497.78	462.28	429.44	399.07	370.99	344.99	320.906	568.45	**Total**

based on least squares method by finding the Max Capacity of all Substations for each city and finding total Max capacity for that substations, and total Max Demand of South area. In 2020, the Max Demand of south between 85% - 90% from Max capacity in this year, to cover the expectoration for upcoming load we recommend to build new plant for the South Jordan to be ready to operate in end of 202. Also the max demand will be at Aqapa 262.65 MW and total max demand at all Southern Governorates will equal 622.99 MW. The forecast in Aqapa calculated based on all proposed upcoming industrial projects. Under this scenario, the forecasted peak load in 10years' time is 262.65 MW.

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