A Dynamic Approach to Linear Statistical Electrical Energy losses Analyses

(*Comparative Case Study*)

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Abstract: - System dynamics have been used for the planning of different sectors in the electric power industry. In the last decade, the number of new suppliers/ consumers entered into the electric power system is rapidly increasing; they are respectively the renewable energy and electric cars. This necessitates a mechanism to estimate the demand for electricity in the near future as per as to evaluate and forecast the situation in the power system. The amounts of generation, transmission, and distribution have been modelled in the form of regression equations depicting the system. The developed methodology is based on system dynamics and a new concept of trend index is introduced. The data of the Jordanian electric power system for the period (2001-2016) has been investigated and analyzed. The analyzed period is divided into two equal periods, the first (2001-2008); is to perform a comparative study of the status and the performance of the power system. However, the second period (2009-2016); is used to investigate the trends of the electrical power system. Numerical examples illustrating the effectiveness of the proposed method are presented. Discussion, conclusions and recommendations on the accuracy of the achieved results are also introduced.

Key-Words: - Dynamic Analysis, Trend Index, Energy Losses Analysis, Electrical Losses in Jordanian Power System.

1 Introduction

The maximum benefit from the electric power system is obtained when all generations, transmissions and distributions are operating at their maximum efficiency. The flow of the electrical current in the power system equipment causing some of power and energy losses in the form of technical losses which considered as the major part of whole system losses. The other part is the economic losses which is called also the commercial losses and defined as a portion of electrical energy not billed precisely or entirely not billed [1], they are due to errors in metering devices, billing errors and illegal consumption of electricity.

For Jordanian electrical power system, the electrical energy losses amount in the last 10 years was varied between (13%-19%), including the amount of the commercial losses which were varied between (1% - 2.5%), [2]. In the last few years, the reduction in the commercial losses amount was due to the efforts taken by electricity authorities against the misuse of electrical energy in form of legally and financially as penalties.

There are a lot of researches assets to determine the amount of electrical energy losses in power system; these include analytical, statistical, heuristic, dynamic methods, etc. The difference between these methods is the amount of the input data required, accuracy, simplicity and computational time to achieve the results.

In the recent years, the use of the statistical methods in power system analysis is repeatedly in use, [3, 4, and 5]. They can solve complicated problems in principle; therefore, it shall be taken into consideration at the first step while planning, evaluating the demand for electricity, forecasting, pricing (electricity tariff updating) and etc.

The method introduced in this paper has advantages over than the one presented in [6], that, it investigates the power system variable (i.e., the energy losses of generation, transmission and distribution) for the last 16 years (2001-2016). This period has been divided into two equals periods, compared and analyzed. In addition, the concept of trend index is provided in this work.

In engineering analyses, it was found that a period of 10 years or more [7] is a sufficient to obtain satisfactory and acceptable results. The data for analyses were obtained the from [8].

The methodology of the proposed method is presented in section 2. In section 3, the regression model is explained. In section 4, numerical examples are presented to illustrate the application of the proposed method. Conclusions and recommendations are summarized in section 5.

2 Methodology and Materials

A system dynamics approach was developed at Sloan School of Management at MIT in 1956 by the system dynamics group under the direction of Professor Jay W. Forrester (a computer engineer and systems scientist). It is a computer-oriented approach use the interrelation between the variables in a complex setting [9], where, the developed method is initially used in business for decision-making [10].

But hereafter, the dynamics approach has been applied in many more specialized researches and interdisciplinary areas, such as in aircraft industry "aviation passenger transportation" [11.12], railway "cargo carrying capacity" [13], forecasting of "solid waste generation" [14], planning of "water resources" [15] and in the electric power industry [16, 17, 18, 19]. The dynamic system is a straightforward modeling procedure and might be defined as stocks and flows connected through equations that forming a system.

In this paper, the data of the electrical power system has been mathematically modeled in the form of equations depicting and representing the relationship between the variables. For this purpose, the regression lines are used to predict the correlation between system variables.

This approach in differing with the previous one presented in [6], that, it is more expanded, prolonged data were analyzed and considered the effect of the slope factor. Moreover, the presented approach is conducting a comparative study for the periods of (2001-2008) and (2009- 2016). Also, it conducts the trend analyses for the second period as a stand-alone.

For the beneficiary, the base of the proposed method mentioned in [6] is represented hereby as in Fig.1. Where, the data of any two variables are linearized and presented in the form of linear equations by (y_1) and (y_2) respectively; they are the dot-dash line (y_1) and solid line (y_2). Now, for instance, if the rate of change (interrelationship) between the lines (y_1) and (y_2) has to be constant, then, the dashed line ($y_{2cal.}$) is representing the constant rate of change between the lines (y_1) and ($y_{2cal.}$), in other word (y_2) shall be equal ($y_{2cal.}$).

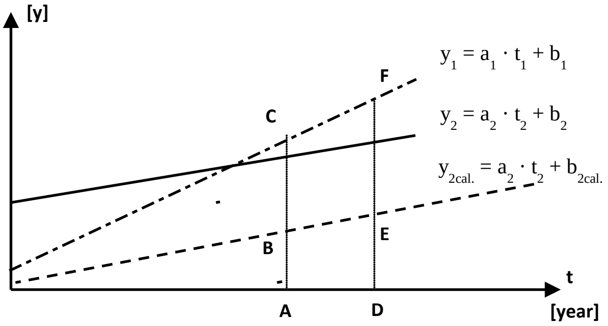

Fig.1: The rate of change between regression lines

Where:

y	–	The linear regression equation ($y = a \cdot t + b$).
a	–	The slope of the line (y) which accompanies an increase of one unit of time (t).
$a_{2cal.}$	–	The slope of the regression line (y_{2cal}), calculated from the given values of the parameters a_1, b_1 and b_2 of the regression lines (y_1) and (y_2).
t	–	Time, it is equal 1 for the first year of the analyzed period and so up to n-years.
b	–	The (y) intercept (the value of (y) for t = 0).
$b_{2cal..}$	–	The intercept of the regression line (y_{2cal}), calculated from the given values of the parameters a_1, a_2 and b_1 of the regression lines (y_1) and (y_2)
y_{2cal}.	–	The standardized (calculated or structured) line with a constant level of change to the base line (i.e.: $y_{2cal} = a_{2cal.} \cdot t + b_2$ or $y_{2cal} = a_2 \cdot t + b_{2cal.}$).

To express the nature of the introduced method; let us assume two regression lines with different slopes (a) and different intercepts (b), presented by (y_1) and (y_2) respectively. The relationship between these two regression lines will depend on the value of parameters of these regression lines (i.e. a_1, a_2, b_1 and b_2). The analyses of these regression lines will lead to different cases of the rate of change and as follows:

2.1 Case - 1

The rate of change between two regression lines (y_1) and ($y_{2.\ Cal}$) is constant if the relationship between their slopes (i.e. a_1 and $a_{2.cal}$) and intercepts (i.e. b_1 and $b_{2cal.}$) are constant as in Fig. 1. Where the following relation can be derived;

$$\frac{AB}{AC} = \frac{DE}{DF} \quad (1)$$

The relationship between the regression lines (y_1) and ($y_{2cal.}$) could be presented as in (2).

$$\frac{y_{2cal\ .(t=1)}}{y_{1(t=1)}} = \frac{y_{2cal\ .(t=2)}}{y_{1(t=2)}} = \cdots = \frac{y_{2cal\ .(t=n)}}{y_{1(t=n)}} = \text{const.} \quad (2)$$

The above relation is realized when the relation between their slopes and intercepts are as follows:

$$\frac{a_1}{a_{2cal}} = \frac{b_1}{b_{2cal}} \quad (3)$$

The regression line (y_2) for (t=1, 2… n) will have a constant rate of change to line (y_1) if the value of the;

$$a_2 = a_{2cal.} \quad (4.1)$$

Or

$$b_2 = b_{2cal} \quad (4.2)$$

Where, the values of (a_{2cal} and b_{2cal}.) for any two regression lines can be calculated based on (3), and as follows;

$$a_{2cal.} = \frac{b_2 \cdot a_1}{b_1} \quad (5.1)$$

Or

$$b_{2cal.} = \frac{b_1 \cdot a_2}{a_1} \quad (5.2)$$

This means, the rate of change between the regression lines (y_2) and (y_1) will be constant, if (y_2) will equal to (y_{2cal}.). In other words, (y_2) is standardized to be equal to (y_{2cal}.). Hence, the values of the slope (a_2) and/or intercept (b_2) are regulated to be equal to the values of ($a_{2cal.}$) and ($b_{2cal.}$) as presented in (5.1) and (5.2) and as shown in Fig.1.

2.2 Case - 2

If the regression line (y_1) has a steeper slope (increasing w.r.t. "t" axis) and lower intercept than the regression line (y_2). Here, (b_2) is more than (b_1) and (a_2) is less than (a_1) as shown in Fig. 1, (i.e. $a_2<a_1$ and $b_2>b_1$), then considering (5.1) and (5.2) obtaining;

$$a_{2cal.} > a_2 \quad (6.1)$$

$$b_{2cal.} < b_2 \quad (6.2)$$

In this case, the equations (1) to (4) are not realized. The rate of change between the regression lines (y_1) and (y_2) will be constant, only if the slope (a_2) or the intercept (b_2) of the regression line (y_2) will be equal to (5.1) or (5.2) respectively, and then (1), (2) and (3) will be realized, only when the relation of the rate of change will be based on (6.3), yields;

$$y_{2(a2=a2cal)} = a_{2cal.} \cdot t + b_2 \quad (6.3)$$

Or

$$y_{2(b2=b2cal)} = a_2 \cdot t + b_{2cal.} \quad (6.4)$$

This means that, the rate of change of the regression line (y_2) is higher than (y_1) as shown in Fig.1.

2.3 Case - 3

This case is exactly opposite (mirror) to (case 2) above. If the regression line (y_1) has a slight slope and more intercept than the regression line (y_1), (i.e. $a_2>a_1$ and $b_2<b_1$), then obtain;

$$a_{2cal.} < a_2 \quad (7.1)$$

$$b_{2cal.} > b_2 \quad (7.2)$$

This means the rate of change of the regression line (y_2) is lower than (y_1).

2.4 Case - 4

If the regression line (y_1) has a steeper slope and intercept than the regression line (y_2) or vice versa. The level of change of the regression line (y_2) to (y_1) will depend on the parameters of (y_1) and (y_2). This leads to have a set of comparisons (i.e.: $a_1>a_2$ and $b_1 >b_2$ or $a_1< a_2$ and $b_1 < b_2$ or etc.), then the followings, might be obtained;

$$a_{2cal.} > a_2 \quad (8.1)$$

$$b_{2cal.} < b_2 \quad (8.2)$$

Or

$$a_{2cal} < a_2 \quad (8.3)$$

$$b_{2cal.} > b_2 \quad (8.4)$$

In this case, the calculated value of the slope ($a_{2cal.}$) and intercept ($b_{2ca.l.}$) could have value more, less than (a_2) and (b_2) respectively. (This could be a special case of case 2 and case 3). This means the rate of change of the regression line (y_2) might have a slight/steeper slope and lower/higher intercept than the regression line (y_1).

3 Model of Regression Equation

For electrical power systems analyses, it was found that the linear regression model is enough for line fitting and can give a satisfactory result. The confident of the fitted lines are determined by the goodness of fit (R^2). Where, (R^2) is defined as a measure to identify the goodness of fit of the regression model with respect to the real data. The value of (R^2) is varying between (0 - 1). The more (R^2) is close to (1), the more reliable and confident the achieved result [2,6].

The least squares method is used to offer the possible fit. Thus, in this paper, the linear regression as in the form of (9) will be used for further analyses.

$$y = a \cdot t + b \quad (9)$$

4 Numerical Examples and Data Analysis

The effectiveness of the proposed method along with the selected regression model has been applied to data acquired from the annual report of (NEPCO), [8].

The analyzed period (2001-2016) is divided into two equal periods (2001- 2008) and (2009-2016). The analyses are conducted into two forms; comparative and trend analyses.

4.1 Comparative Study of Energy Losses

The analyses are conducted to the major components of the electrical power system; generation, transmission, and distribution. Moreover, the efficiency of the whole system will be investigated, and as follows:

4.1.1 Generation

The balance of generated and sent out energy over the period of (2001-2008) and (2009-2016) are as shown in Table 1, the difference between these values are the energy losses values, (i.e. A1-B1 in Table.1).

Table 1. Generated energy and sent out energy [GWh].

Year	Generated* Energy	Sent Out Energy	Losses = A1-B1	Losses%
Sn.	A1	B1	C1	D1
2001	7349	6856	493	6.71
2002	7828	7308	520	6.64
2003	7679	7175	504	6.56
2004	8657	8073	584	6.75
2005	9332	8756	576	6.17
2006	10835	10309	526	4.85
2007	12760	12134	626	4.91
2008	13483	12878	605	4.49
2009	13988	13452	536	3.83
2010	14462	13876	586	4.05
2011	14369	13753	616	4.29
2012	16333	15713	620	3.80
2013	16957	16341	616	3.63
2014	17863	17231	632	3.54
2015	18516	17945	571	3.08
2016	18924	18415	509	2.69

* -includes the losses in the electricity generation company

The effect of applying the linear regression model of (9) to the data in Table 1, are as presented in Table 2.

Table 2. Regression lines of the data from Table 1.

1.	Generation	Analyzed Period			
		2001-2008	R^2	2009-2016	R^2
A1	Generated Energy	$y = 925.49 \cdot t + 5575.7$	0.916	$y = 784.87 \cdot t + 12895$	0.959
B1	Sent out energy	$y = 909.15 \cdot t + 5094.9$	0.914	$y = 787.49 \cdot t + 12297$	0.9583
C1	Losses = A1-B1	$y = 16.333 \cdot t + 480.75$	0.647	$y = -2.6274 \cdot t + 597.56$	0.0211
D1	Losses [%]	$y = -0.356 \cdot t + 7.4868$	0.818	$y = -0.1815 \cdot t + 4.4307$	0.739

The system status and the rate of change of the two periods of time (2008-2016) and (2009-2016), can be evaluated by investigating the relationship between the regression lines of the variables and as follows:

4.1.1.1 Generated Energy

Based on Table 2, the regression lines of the generated energy (Column 1 – A1) for the analyzed period of (2001-2008) and (2009-2016), yields;

A_1 = Generated Energy for the analyzed period of (2001-2018) is;

$$y_1 = a_1 \cdot t + b_1 = 925.49 \cdot t + 5575.7$$

And

A_1= Generated Energy for the analyzed period of (2009-2016) is;

$$y_2 = a_2 \cdot t + b_2 = 784.87 \cdot t + 12895$$

The rate of change between these analyzed periods is made by examining the parameters of these regression lines, based on (5.1) and (5.2), obtaining;

$$a_{2cal.} = \frac{b_2}{b_1} \cdot a_1$$

$$a_{2cal.} = \frac{12897}{5575.7} \cdot 925.49 = 2140.8 > a_2 = 784.87$$

And

$$b_{2cal.} = \frac{a_2}{a_1} \cdot b_1$$

$$b_{2cal.} = \frac{784.75}{952.49} \cdot 5575.7 = 4728 < b_2 = 12859$$

This case is similar to case 2 in section 2, (Where: $a_{2cal.} > a_2$ and $b_{2cal.} < b_2$).

This means that, the rate of change of the generated energy for the period of (2009-2016) which, referenced here by (y_2) is lower than the rate of change its value for the period of (2001-2008), which, referenced here by (y_1).

This can be interpreted that, the amount of generating energy for the period (2009- 2016) is less than the amount of generating energy for the period of (2001-2008).

Therefore, the following conclusion could have placed; to add more generation to the existing system which requires more investment and planning. Also, this depends on the available capacity of the operating reserve to encounter the demand on power in case of power deficiency.

The same conclusion is obtained from Table 1, hence the amount of generating energy for the period of (2001-2008) is equal (13483-7349=6134 [GWh]) and this is more than the generated energy for the period of (2009-2016) which is equal (18924-13988= 4936 [GWh]).

The goodness of fitting of the achieved result is more than (90%) as (R^2) varies between (0.916-0.959).

4.1.1.2 Sent Out Energy

Based on Table 2. The regression lines of the sent out energy (Column 1 – B1) for the analyzed period of (2001-2008) and (2009-2016), is;

B1= Sent out energy for the analyzed period of (2001-2008) is;

$y_1 = a_1 \cdot t + b_1 = 909.15 \cdot t + 5094.9$

And

B1= Sent out energy for the analyzed period of (2009-2016) is;

$y_2 = a_2 \cdot t + b_2 = 787.49 \cdot t + 12297$

The rate of change of the above lines is made by examining the parameters of these regression lines, based on (5.1) and (5.2), obtaining;

$$a_{2cal.} = \frac{122.97}{5575.7} \cdot 909.15 = 2194.3 > a_2 = 787.49$$

And

$$b_{2cal.} = \frac{787.49}{909.15} \cdot 5575.7 = 4431.1 < b_2 = 12297$$

This case is similar to case 2 in section 2, (Where: $a_{2cal.} > a_2$ and $b_{2cal} < b_2$).

The rate of change of the sent out energy (y_2) for the period of (2009-2016) is lower than the rate of change of sending out energy (y_1) for the period of (2001-2008).

This can be interpreted that, the amount of sent out energy for the period (2009- 2016) is more than the amount of sent out energy for the period of (2001-2008). Also, the sent out energy is proportional to the amount of generated energy.

The same result, can be obtained from Table 1, hence, the sum of sending out energy for the period of (2001-2008) is equal (12878 – 6856 = 6022 [GWh]) and this is more than sent out energy for the period of (2009-2016) which is equal (18415-13452= 4963 [GWh].

The goodness of fitting of the achieved result is more than (90%) as (R^2) varies between (0.914-0.958).

4.1.1.3 Generation Losses

Based on Table 2. From the regression lines of the generation losses (Column 1 – C1) for the analyzed period of (2001-2008) and (2009-2016), yield;

C_1 = Generation losses for the analyzed period of (2001-2018) is;

$y_1 = a_1 \cdot t + b_1 = 16.333 \cdot t + 480.75$

And

C_1= Generation losses for the analyzed period of (2009-2016) is;

$y_2 = a_2 \cdot t + b_2 = -2.6274 \cdot t + 597.56$

The rate of change of the above lines is made by examining the parameters of these regression lines, based on (5.1) and (5.2), obtaining;

$$a_{2cal.} = \frac{597.56}{480.75} \cdot 16.333 = 20.34 > a_2 = -2.6274$$

And

$$b_{2cal.} = \frac{-2.6274}{16.333} \cdot 480.75 = -77.3 < b_2 = 597.56$$

This case is similar to case 2 in section 2, (Where: $a_{2cal.} > a_2$ and $b_{2cal.} < b_2$). The rate of change of the generation losses (y_2) for the period of (2009-2016) is lower than the rate of change of generation losses (y_1) for the period of (2001-2008).

The same result, can be obtained from Table 1, hence the sum of energy losses for the period of (2001-2008) is equal to 4434 [GWh], and this is equal to 5.69% of the total generated energy, this value is less than the energy losses for the period of (2009-2016) which is equal to 4686 [GWh], and this is equal to 3.566 % of the total generated energy.

This can be interpreted that, the increment in system loading will cause that, the relative relations of the no-load losses to the whole system losses will decrease and as consequences, the total relative loses value is the system is decreasing (system efficiency enhanced). Also, it was due to the efforts were taken by the power authorities in the last few years to reduce the amount of the misuse (thefts) of electricity.

Here, the goodness of fit for the achieved result is very low and vary between (R^2= 0.647- 0.0211). This means that, if the value of (R^2) is low or very low a special care shall be taken to the concluded results.

4.1.1.4 Percentage Energy Losses [%]

Based on Table 2. From the regression lines of the generation losses (Column 1 – D1) for the analyzed period of (2001-2008) and (2009-2016), yield;

D_1 = Percentage generation losses for the analyzed period of (2001-2018) is;

$y_1 = a_1 \cdot t + b_1 = -0.356 \cdot t + 7.4868$

And

D_1 = Percentage generation losses for the analyzed period of (2009-2016) is:

$y_2 = a_2 \cdot t + b_2 = -0.1815 \cdot t + 4.4307$

Investigating the parameters of these lines, as in (5.1) and (5.2) and as follows;

$$a_{2cal.} = \frac{4.43}{7.49} \cdot -0.356 = -0.211 < a_2 = -0.1815$$

And

$$b_{2cal.} = \frac{-0.1815}{-0.355} \cdot 7.4864 = 3.82 > b_2 = 4.43$$

This case is similar to case 3 in section 2, (Where: $a_{2cal.} < a_2$ and $b_{2cal.} > b_2$).

This means that, the rate of change of the percentage generation losses (y_2) for the period of (2009-2016) is higher than the rate of change of generation losses (y_1) for the period of (2001-2008).

This can be interpreted as follows, this was due to the results of the efforts taken the electricity authorities to reduce the amount of misuse of electricity “thefts” during the analyzed period (2009-2016) with the comparison to the period (201-2008). The slopes of lines are negative (the sign is “-”), this means that,this type of losses is having a trend to decrease.

The goodness of fitting of the achieved result is more than (90%) as (R^2) varies between (0.739-0.818).

4.2 Trend of Generated Energy Analyses

The methodology presented in section 2, is implemented for data obtained from [8] to analyze and evaluate the trend of the variables. Based on (4) and (5), the relation between the slopes and intercepts of the linearized equations can be classified into three types and as follows: the first the variables have a tendency to move toward better (+), the second variables have a tendency to deteriorate in the worst (-) and the third the variables have a tendency to remain constant (const.)

Where:
(+) or (↑) - The variable has a tendency to increase.
(-) or (↓) - The variable has a tendency to decrease.
(const.) - The variable has a tendency to remain constant.

4.2.1 Trend Index

The trend index is a sign showing the direction of the variable to increase, decrease or remain constant. The calculation of the trend index is based on the difference between the values of parameters of the regression lines and the calculated values of the linearized regression equations.

As an example, calculate the trend index for the generated energy (i.e. Table.2, Column 1 - A1), this can be achieved as follows:

- Table 2, indicates the values of the parameters (a, b) of line equation (generated energy, Column 1- A1). The result is as indicated in the below Table 3.
- Calculate values of ($a_{2cal.}$) and ($b_{2cal.}$) based on (5.1) and (5.2), the result is as in the below Table 3.
- Calculate the difference between line parameters (a, b) and the calculated values of the parameters ($a_{2cal.}$) and ($b_{2cal.}$). The result of (a_2- $a_{2cal.}$) and (b_2-$b_{2cal.}$) are as stated in Table 3
- Check the sign of the trend indexes and determine the trend of the variable.

Table 3 Trend Index Determination (example)

Generated Energy	**Analyzed Period**		
Item (A1)	**2001-2008**	**2009-2016**	
a	925.49	784.87	
b	5575.70	12895	
Calculated Values			
$a_{2cal.}$	2140.4	**Trend Sign**	
$b_{2cal.}$	4728.5		
a_2 - $a_{2cal.}$	-1355.5	$a_2 < a_{2cal.}$	(-) or (↓)
b_2- $b_{2cal.}$	8166.5	$b_2 > b_{2.cal}$	(+) or (↑)

4.2.1.1 Generated Energy – Trend Index

The trend indexes for the remaining items of Table 4 are calculated in the same way as shown in above Table 3. The result of analyses for the two periods of (2001-2008) and (2009-2016) are shown in Table 4.

Table 4. Trend Summary of the Generation Analyses

Item .1	**Generation**	**Trend Index**	
		$\mathbf{a_2 > a_{2cal.}}$	$\mathbf{b_2 > b_{2cal.}}$
A1	Generated Energy	(↓)	(↑)
B1	Sent out energy	(↓)	(↑)
C1	Losses =A1-B1	(↓)	(↑)
D1	Losses [%]	(↑)	(↑)
C1/A (2001-2008)	Generation losses	(↑)	(↑)
C1/A1 (2009-2016)	Generation losses	(↓)	(↓)

4.2.1.2 Transmission - Trend Index

The values of the transmission losses are as presented in Table 5, below;

Table 5. Transmitted energy and transmission losses [GWh].

Year	**Purchased Energy**	**Sold Energy / Bulk**	**Losses = A2-B2**	**Losses[%]**
Sn.	A2	B2	C2	D2
2001	6897	6642	255	3.70
2002	7436	7129	307	4.13
2003	7967	7664	303	3.80
2004	8767	8448	319	3.64
2005	9555	9219	336	3.52
2006	10643	10307	336	3.16
2007	12191	11866	325	2.67
2008	13440	13085	355	2.64
2009	13848	13503	345	2.49
2010	14562	14259	303	2.08
2011	15477	15132	345	2.23
2012	16470	16123	347	2.11
2013	16719	16372	347	2.08
2014	17691	17370	321	1.81
2015	18541	18213	328	1.77
2016	18764	18447	317	1.69

) 1* Does not include industrial company's network.
)2* Data from the source was not ready yet, during the preparation of this paper.

However, the regression lines of the above are as presented in the below Table. No. 6 below.

Table 6, Regression models for the data from Table 5.

Item 2	**Transmission Losses***	**Analyzed Period**			
		2001-2008	$\mathbf{R^2}$	**2009-2016**	$\mathbf{R^2}$
A2	Purchased Energy	$y = 933.24 \cdot t + 5412.4$	0.9652	$y = 728.55 \cdot t + 13231$	0.987
B2	Sold Energy	$y = 922.45 \cdot t + 5144$	0.963	$y = 730.25 \cdot t + 12891$	0.987
C2	Losses = A2 -B2	$y = 10.786 \cdot t + 268.46$	0.7665	$y = 10.786 \cdot t + 268.46$	0.766
D2	Losses [%]	$y = -0.1996 \cdot t + 4.3042$	0.826	$y = -0.1006 \cdot t + 2.4846$	0.860

The rate of change between any two variables in Table 6, can be investigated by evaluating the relations between their regression lines. As an example to evaluate the rate of change between the purchased energy and the transmission losses, this can be done by evaluating the relationship between the two regression lines A2= *f* (C2) for the two periods of (2001-2008) and (2009-2016). The analyses are conducted straight forward in the same way as done for the (Generation Losses 4.1.1). The result of analyses are as presented in Table 7 .

Table **7** Trend Summary Transmitted Analyses

Item .2	**Transmission Losses**	**Trend Index**	
		a2 > a2.cal	**b2 > b2.cal**
A2	Purchased Energy	(↓)	(↑)
B2	Sold Energy	(↓)	(↑)
C2	Losses =A2-B2	(↓)	(↑)
D2	Losses [%]	(↑)	(↑)

4.2.1.3 Distrusted Energy Analyses –Trend Index

The data concerning the purchased energy and the sold energy (retail) are as in the below in Table 8 and Table 9.

Table 8. Purchased Energy and distribution losses [GWh]

Year	Purchased Energy	Sold Energ Retail	Losses = A3-B3	Purchased Energy
Sn.	A3	B3	C3	D3
2001	6026	5366	660	10.95
2002	6405	5701	704	10.99
2003	6923	6113	810	11.70
2004	7656	6827	829	10.83
2005	8416	7431	985	11.70
2006	9426	8280	1152	12.22
2007	10777	9270	1516	10.05
2008	11785	10218	1567	13.30
2009	12490	10837	1653	13.23
2010	13454	11837	1617	12.02
2011	14261	12509	1752	12.29
2012	15113	13146	1967	13.02
2013	15445	13429	2016	13.05
2014	16305	14057	2248	13.79
2015	17282	14856	2426	14.04
2016	17663	15385	2278	12.90

However, their regression line models are as in Table 9.

Table 9, Regression models for the data from Table 8

3	Distribution Losses	Analyzed Period			
		2001-2008	R^2	2009-2016	R^2
A3	Purchased Energy	y = 838.6 ·t + 4653.1	0.97	y = 735.89 ·t + 11940	0.99
B3	Sold Energy /Retail	y = 701.36 ·t + 4244.6	0.97	y = 617.36 ·t + 10479	0.99
C3	Losses	y = 137.99 ·t + 406.93	0.92	y = 118.54 ·t + 1461.2	0.91
D3	A3-B3	y = 0.1688 ·t + 10.708	0.17	y = 0.1467 ·t + 12.383	0.28

As an example, to evaluate the rate of change between the purchased energy (Column 1- A3) and the distribution losses (Column 1- C3), this can be made by evaluating the relationship between their two regression lines A3= *f* (C3). The analysis is made in the same way as made for the (Generation Losses 4.1.1).

The trend index results of distributed energy losses for the periods of (2001-2008) and (2009-2016) are as presented in Table 10.

Table 10. Trend Summary of distributed Analyses

Item .3	Distribution Losses	Trend	
		a2 > a2.cal	b2 > b2.cal
A3	Purchased Energy	(↓)	(↑)
B3	Sold Energy /Retail	(↓)	(↑)
C3	Losses = A3-B3	(↓)	(↑)
D3	Losses [%]	(↓)	(↑)

4.2.1.4 Total System Energy Losses Analyses

The data of the (sent out energy and imported energy), (consumed and exported energy) and total energy losses along with their regression models are as shown in Table 11 and Table 12.

Table 11. Total Energy System Losses [GWh]

Year	Sent Out and Imported Energy	Consumed and exported Energy	Losses = A4- B4	Losses [%]
Sn.	A4	B4	C4	D3
2001	7616	6217	1399	18.37
2002	8150	6629	1521	18.66
2003	8651	7021	1630	18.84
2004	9483	7792	1691	17.83
2005	10315	8417	1898	18.40
2006	11349	9341	2008	17.69
2007	12968	10501	2467	19.02
2008	14385	11832	2553	17.75
2009	14655	12095	2560	17.47
2010	15447	12900	2547	16.49
2011	16385	13621	2764	16.87
2012	16497	14155	2342	14.20
2013	16722	14356	2366	14.15
2014	17666	15121	2545	14.41
2015	18548	15787	2761	14.89
2016	18749	16168	2581	13.77

And the regression equations are as follows:

Table 12 Regression models for the data from Table11.

3	Total Energy System Losses	Analyzed Period			
		2001-2008	R^2	2009-2016	R^2
A4	Sent Out and Imported Energy	y = 957.13 ·t + 6057.5	0.960	y = 574.18 ·t + 14250	0.968
B4	Consumed and exported Energy	y = 788.69 ·t + 4919.6	0.96	y = 567.23x ·t + 11723	0.988
C4	Losses = A3-B3	y=168.44 ·t + 1137.9	0.938	y=6.9524 ·t + 2527	0.012
D4	A4-B4	y= -0.0646 ·t + 18.612	0.094	y = -0.4925 ·t + 17.495	0.705

As an example, to evaluate the rate of change between the sent out and imported energy (A4) and the total system energy losses, this can be made by the evaluation the relationship between their two regression lines A4= *f* (C4). The analyses are conducted in the same way as made for the (Generation Losses 4.1.1). The result of total system energy losses analyses for the two periods of (2001-

2008) and (2009-2016) are as summarized in Table 13.

Table 13. Trend Summary of distributed Analyses

Item .4	Total Energy System Losses	Trend	
		$a_2 > a_{2.cal.}$	$b_2 > b_{2.cal.}$
A4	Sent Out and Imported Energy	(↓)	(↑)
B4	Consumed and exported Energy	(↓)	(↑)
C4	Losses = A3-B3	(↓)	(↑)
D4	Losses [%]	(↓)	(↓)

5 Conclusions and Recommendations

The approach presented in this paper has explored the significance of modeling the variables in the electrical power system. The analyses show that, it is not an easy matter to set a model representing all variables of the electrical power system with no mistakes in the interpretation of the achieved results. Thus, it will be very helpful to analyze and discuss the obtained results considering your own experience and take the advice from the experienced people from electricity authority. Once the right model is established, then it will very easy to apply this model as a framework for further analyses.

The data for the last 16 years for the major components of the Jordanian electrical power system; generation, transmission, and distributions along with the total system efficiency have been thoroughly investigated and evaluated. The obtained results show that the adopted linear regression model is fairly close to the real expected results, except for the generation losses; hence the goodness of fitting of the real data to the regression line is very low, (R^2= 0.647- 0.0211). This makes that, the obtained result might be miss interpreted; therefore, special care shall be taken while formulating and concluded the results.

The obtained results for the two comparison periods (2009-2016) and (2009-2016) shows that the demand for electricity for the second period was lower than in the first period. Also, the total system losses for the second period is decreased with compression in the first period, this was due to efforts were taken by the electricity authorities to reduce the misuse of electrical energy, but there is still a need to reduce these losses and to bring it to the acceptable level, this means, there is still a need to reduce the energy losses in transmission and distribution sectors in particular.

The idea of a novel concept, “Trend Index” introduced in this paper has a huge impact while planning, forecasting and evaluating the need for investment in electric power sector. Examples illustrating the effectiveness of the proposed method are presented in Section 4.

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