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Estimating the weights of latticed power transmission towers using Genetic programming

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A R T I C L E I N F O

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A B S T R A C T

The recent booming in the power network industry inspired a lot of researchers to develop models to estimate the optimum cost of transmission towers. Unlike previous researches which depended on design the tower from scratch, this research depends on collecting actual database from several projects around the globe and applying the well-known Genetic Programming (GP) technique to develop a model to predict the tower weight. The accuracy of the developed formula was about 84%. The developed model could be used in early tender stage or to check design economy

1. Introduction

Electrical power networks depend on transmission towers to support the power conductors. These towers cost about (one third to one half) of the transmission line cost (F.Kiessling et al, 2003). Accordingly, many studied were carried out to optimize the cost of transmission towers. Both of (Shea et al, 2006) and (Huiyong et al, 2011) used topology optimization technique to minimize the towers weights. (Couceiro et al, 2016) presented a study to optimize the design of transmission towers using Simulated Annealing technique. (Huiyonget al, 2009), (Abdullah et al, 2012), (Sanah et al, 2016), (Premalatha et al, 2017) and (Bharat et al, 2018) developed different genetic algorithm (GA) models to optimize the design of the transmission towers. On the other hand, (Li et al, 2015), (Siamak et al, 2012) and (Nagavinothini et al, 2015) implemented three different Artificial Intelligent (AI) which are Ant Colony Optimization (ACO), Firefly Algorithm (FFO) and Particle Swarm Optimization (PSO) to optimum design of transmission towers in order.

GA are AI optimizing technique that mimicking the evolution procedure of living creatures. It starts with generating a random set of solutions, and then the fitness of each solution is evaluated, the most fitting solutions are selected, and the rest are deleted. Those selected solutions are used to produce the next generation of solutions and the cycle continues until the desire accuracy achieved. This technique was used in as base to develop more AI techniques such as Genetic Programming GP and Evolutionary polynomial Regression EPR. GP is a technique uses GA to optimize the fitness of mathematical formula to certain dataset. The output of this technique is a closed form equation which could be utilized manually (Ebid, 2020). This technique successfully was used in optimizing the design of steel girders (Ebid, 2021) and (El-Aghoury, 2022).

Despite of the large number of previous researchers concerned in estimating the optimum weight of power transmission towers, but all of them depended on design the towers from the scratch. The novelty of this research is that it is based on actual database collected from several power transmission lines projects around the globe. This makes it more practical and closer to industry.

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2. COLLECTED DATA

164 records were collected from eight projects in Egypt, Yemen, Ethiopia, Libya, Saudi Arabia and Iraq. Each record contains the line voltage (V in KV), number of conductors including earth wires (N), tower deviation angle (A in degrees), extension height below basic tower (Ext in m) and tower weight (W in tons) as illustrated in Fig 1. The collected database was divided into training dataset (124 records) and validation dataset (40 records). Table 1, 2 summarizes their statistical characteristics and the Pearson correlation matrix. Finally, Fig 2 shows the histograms for both inputs and outputs. The collected dataset is attached in the appendix.

Table 1- Statistical analysis of collected database

	V (KV)	N	Ao	Ext (m)	W (ton)
Min.	66.0	8.0	0.0	0.0	3.3
Max.	500.0	26.0	90.0	35.0	163.8
Avg.	383.8	18.5	40.2	7.2	49.6
SD	168.7	7.0	34.0	6.0	35.8
VAR	0.44	0.38	0.84	0.83	0.72

Table 2- Pearson correlation matrix

	V	N	A	Ext	W
V	1.00				
N	0.03	1.00			
A	0.05	-0.01	1.00		
Ext	0.20	0.14	-0.01	1.00	
W	0.57	0.44	0.56	0.38	1.00

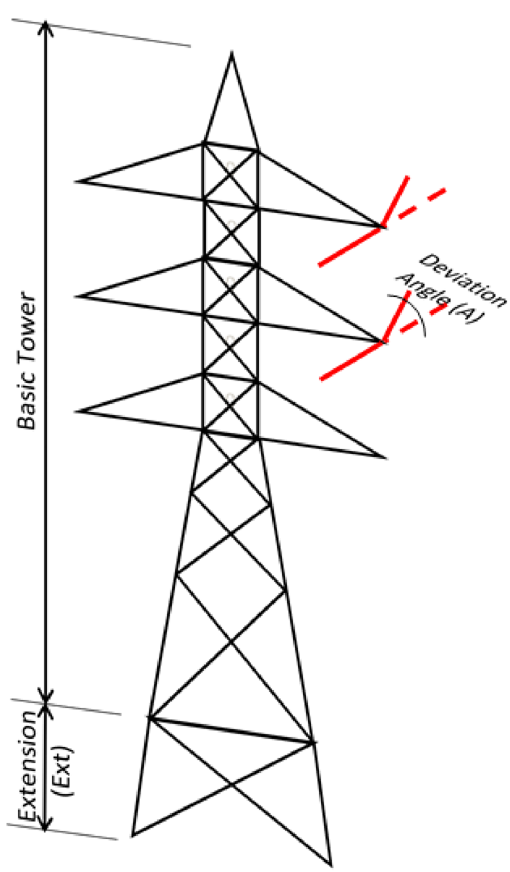

Fig. 1- Illustration of the geometrical inputs (A & Ext)

3. ESTIMATING THE TOWER WEIGHT USING (GP) TECHNIQUE

A four levels of complexity GP model was developed using population size of 100,000 gens, surviving ratio of 25% and 100 generations. Eq. (1) shows the developed formulas for (W). The achieved fitness was measured in terms of Sum of Squared Error (SSE), (Error %) and (R2) as (10976, 16.5% and 0.947) respectively. Fig. 3 illustrates its fitness.

$$W = \frac{V*(N*A+V)+800*N*Ext+50000}{12500} \tag{1}$$

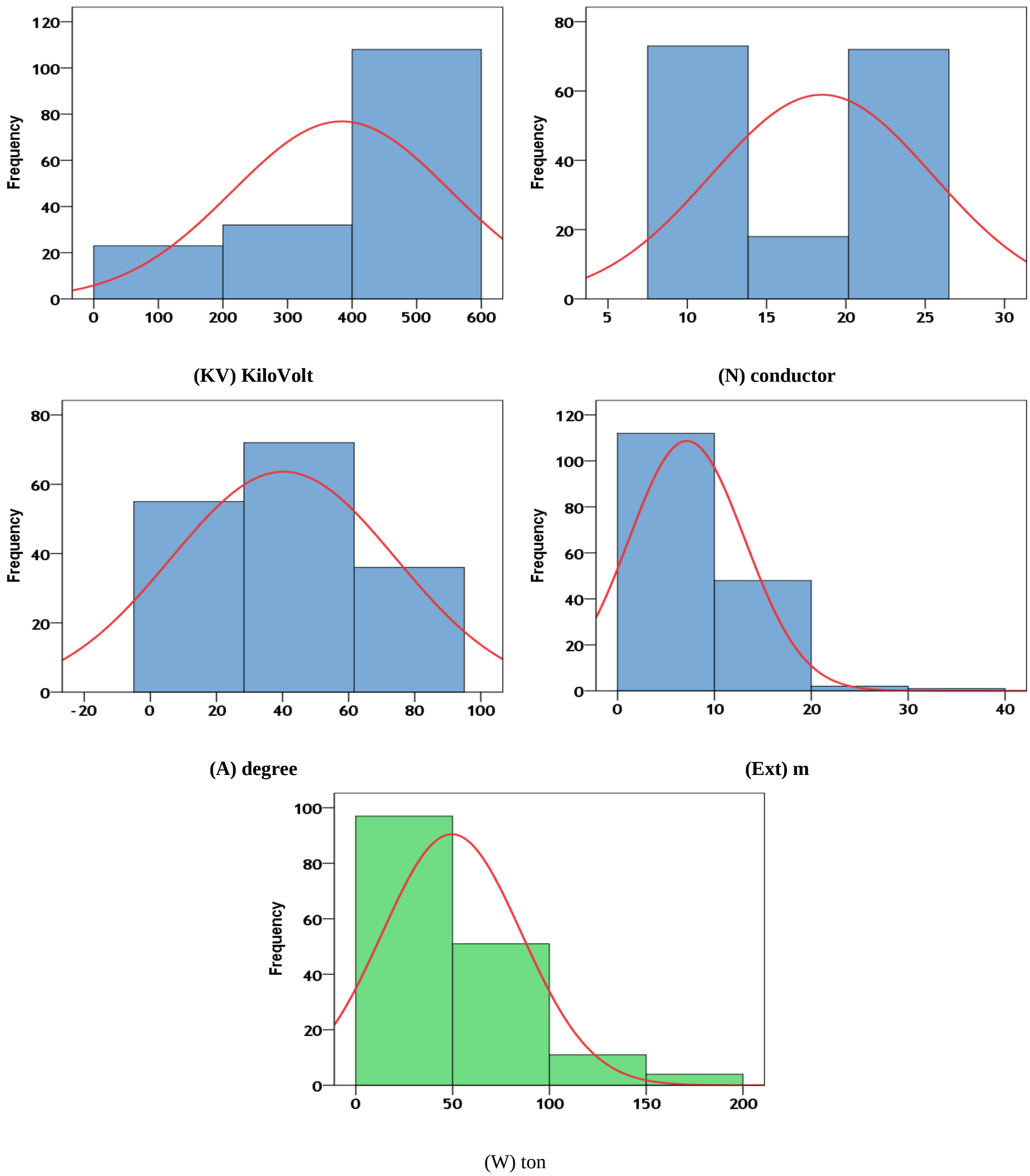

Fig. 2- Distribution histograms for inputs (in blue) and outputs (in green)

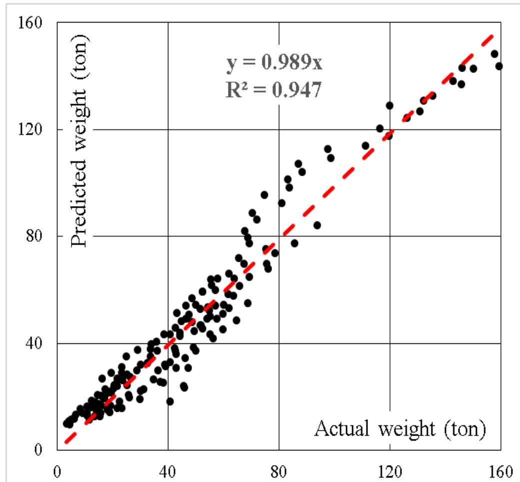

Fig. 3- Relation between predicted and actual (W) values using the developed models

4. DISCUSSION AND CONCLUSIONS

This study presented a (GP) model to estimate power transmission tower weight (W) using its angle of deviation (A), number of supported conductors (N), tower extension (Ext) and power line voltage (V). From the developed formula, the following points could be concluded:

- Tower weight (W) increases with increasing (A), (N), (Ext) and (V) which is reasonable
- The prediction accuracy of the developed formula is ±16.5%
- As a regression technique, the generated equation is valid for the considered range of variables values, beyond that; the accuracy must be verified.
- The developed formula indicated that within the considered range of parameters, the minimum tower weight is 4.0±16.5% which is 3.34 ton.
- As indicated from Eq. 1, (V) & (N) have stronger impact on (W) than (A) & (Ext).
- Based on the achieved accuracy, the developed formula could be used for preliminary estimations in tender stage and to check the economy of the tower design.

Appendix A. The collected dataset

KV K volt	**N** Cond.	**A** degree	**Ext** m	**W** ton
500	25	0	0	38.060
500	25	0	3	39.060
500	25	0	6	42.570
500	25	0	9	44.040
500	25	0	12	48.520
500	25	0	15	51.420
500	25	10	0	45.750
500	25	30	0	52.330
500	25	30	3	54.790
500	25	30	6	61.660
500	25	30	9	63.830
500	25	30	12	67.290
500	25	30	15	75.160
500	25	60	0	68.780
500	25	60	3	71.990
500	25	60	6	80.950
500	25	60	9	83.780
500	25	60	12	88.290
500	25	60	15	98.560
500	25	90	0	111.160
500	25	90	3	116.360
500	25	90	6	130.830
500	25	90	9	135.400
500	25	90	12	142.700

KV K volt	**N** Cond.	**A** degree	**Ext** m	**W** ton
500	13	30	3	46.197
500	13	30	6	49.103
500	13	30	9	56.239
500	13	30	12	59.586
500	13	30	15	64.703
500	13	60	0	55.137
500	13	60	3	57.059
500	13	60	6	63.455
500	13	60	9	65.549
500	13	60	12	69.217
500	13	60	15	76.007
500	13	90	0	75.583
500	13	90	3	78.464
500	13	90	6	85.647
500	13	90	12	93.719
500	26	0	0	37.199
500	26	0	3	38.775
500	26	0	6	42.287
500	26	0	9	44.132
500	26	0	12	46.213
500	26	0	15	49.922
500	26	0	18	52.273
500	26	0	21	55.295
500	26	10	0	45.452

KV K volt	N Cond.	A degree	Ext m	W ton
500	25	90	15	159.290
500	8	0	0	15.900
500	8	0	3	16.900
500	8	0	6	18.400
500	8	0	9	20.500
500	8	0	12	21.600
500	8	0	15	23.100
500	8	10	0	23.300
500	8	30	0	25.200
500	8	30	3	26.300
500	8	30	6	28.600
500	8	30	9	32.500
500	8	30	12	33.500
500	8	30	15	35.900
500	8	60	0	33.500
500	8	60	3	35.700
500	8	60	6	38.300
500	8	60	9	42.500
500	8	60	12	44.700
500	8	60	15	47.400
500	8	90	0	43.100
500	8	90	3	46.200
500	8	90	6	48.400
500	8	90	9	52.400
500	8	90	12	55.600
500	8	90	15	57.700
66	13	0	0	3.250
66	13	0	5	4.000
66	13	0	10	4.950
66	13	0	15	6.100
66	13	10	0	4.420
66	13	30	0	4.650
66	13	30	5	6.110
66	13	60	0	6.680
66	13	60	5	9.100
66	13	90	0	8.100
66	13	90	5	10.700
66	26	0	0	11.450
66	26	0	5	13.450
66	26	0	10	15.600
66	26	0	15	18.100
66	26	30	0	15.200
66	26	30	5	18.700
66	26	30	10	21.500
66	26	60	0	19.000
66	26	60	5	22.300
66	26	60	10	26.000
66	26	90	0	25.600
66	26	90	5	30.000
500	13	0	0	29.631
500	13	0	3	31.146
500	13	0	6	34.522
500	13	0	9	36.379
500	13	0	12	40.562
500	13	0	15	42.729
500	13	10	0	40.744
500	13	30	0	42.793

KV K volt	N Cond.	A degree	Ext m	W ton
500	26	10	3	47.275
500	26	10	6	49.838
500	26	10	9	55.096
500	26	10	12	57.533
500	26	10	15	60.034
500	26	30	0	51.837
500	26	30	3	54.293
500	26	30	6	56.934
500	26	30	9	61.947
500	26	30	12	65.373
500	26	30	15	69.126
500	26	60	0	67.642
500	26	60	3	70.368
500	26	60	6	74.631
500	26	60	9	83.021
500	26	60	12	86.933
500	26	60	15	97.512
500	26	60	25	119.897
500	26	60	35	145.980
500	26	90	0	119.520
500	26	90	3	126.228
500	26	90	6	132.162
500	26	90	9	145.661
500	26	90	12	150.201
500	26	90	15	157.734
500	26	90	18	163.774
220	13	0	0	10.620
220	13	0	4	12.100
220	13	0	8	13.700
220	13	0	13	15.950
220	13	10	0	10.770
220	13	30	0	12.280
220	13	30	4	14.550
220	13	30	8	17.120
220	13	60	0	16.190
220	13	60	4	19.300
220	13	60	8	23.210
220	13	90	0	24.860
220	13	90	4	28.990
220	13	90	8	33.820
220	19	0	0	14.046
220	19	0	3	15.263
220	19	0	6	16.839
220	19	0	9	17.735
220	19	0	12	20.115
220	19	0	15	21.153
220	19	30	0	19.380
220	19	30	3	21.470
220	19	30	6	23.559
220	19	30	9	25.167
220	19	30	15	30.016
220	19	60	15	40.679
220	19	90	0	49.342
220	19	90	3	51.553
220	19	90	6	54.006
220	19	90	9	59.638
220	19	90	12	61.970
220	19	90	15	68.790

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