A Realistic Aggregate Load Representation for A Distribution Substation in Baghdad Network

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ABSTRACT

Electrical distribution system loads are permanently not fixed and alter in value and nature with time. Therefore, accurate consumer load data and models are required for performing system planning, system operation, and analysis studies. Moreover, realistic consumer load data are vital for load management, services, and billing purposes. In this work, a realistic aggregate electric load model is developed and proposed for a sample operative substation in Baghdad distribution network. The model involves aggregation of hundreds of thousands of individual components devices such as motors, appliances, and lighting fixtures. Sana'a substation in Al-kadhimiya area supplies mainly residential grade loads. Measurement-based techniques are to be used in estimating the substation load model parameters. The proposed model accounts for the effect of the feeders, the LV- transformers and the compensation devices present in the system. The model validation is evident from calculated results comparison to realistic measured data.

Keywords: Power System Load Representation, Aggregate Load Model, Genetic Algorithm Optimization. Distribution system studies.

تمثيل واقعي متكامل لحمل محطة توزيع ثانوية في شبكة بغداد

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الخلاصة

تعتبر احمال منظومات التوزيع الكهربائية غير ثابتة وهي متغيرة القيمة والطبيعة مع الزمن ، لهذا فان تنفيذ دراسات التخطيط والتشغيل والتحكم يتطلب بيانات واشكال موثوقة لأحمال المستهلكين . إضافة لذلك ان البيانات الواقعية للأحمال هي مطلب اساسي لإدارة الاحمال ونظام التسعيرة الكهربائية . في هذا العمل تم تطوير نموذج حمل كهربائي شامل وواقعي لنموذج من محطة عاملة في شبكة توزيع كهرباء بغداد ، يتضمن هذا النموذج دمج وشمول تمثيل مئات الالاف من المكونات مثل المحركات والاجهزة المنزلية وتراكيب الانارة . تجهز محطة توزيع صنعاء الثانوية في منطقة الكاظمية احمال من النوع المنزلي بشكل اساسي ، تم جمع البيانات فيها من مقاييس المتغيرات وتم اعتمادها في استخلاص معاملات نموذج الحمل . اخذ بنظر الاعتبار في نموذج الحمل المعروض مجمل مكونات مغذيات التوزيع من خطوط ومحولات ضغط واطي واجهزة تعويض الفولتية . تم التحقق من نموذج الحمل المستنتج بمقارنه نتائج المحاكاة مع معطيات القياس

.**الكلمات الرئيسية :** تمثيل الاحمال لأنظمة القدرة ، نموذج الحمل المتكامل ، الامثلية باستخدام الخوارزمية الجينية . دراسات شبكات التوزيع.

1. INTRODUCTION

Most of the network components in the power system can be modeled accurately, that is realized by providing the adequate information of each component to develop and identify compatible model parameters regarding it's static and dynamic behaviors. Power system electric loads, on the other hand, are difficult to model as they are complex, time-varying, a mix of different types, uncontrollable moreover it is not feasible to model every power consumer connected to the system. Therefore, for such a difficulty aggregation is the solution, and hence aggregate load models are vital and essential in power system studies, **Collin, et al. 2011**, **Zhang et al. 2009,** and **Wei et al. 2005.**

In conventional power system analysis, loads information never exceeds a constant active (P) and reactive (Q) power consumption at a bus of interest. Below that bus, regarding voltage levels, loads are never lumped, i.e., dispersed with different lots of connecting and controlling distribution system components. These components include lines, cables, transformers, volt/var regulators …etc, it is significant to include such components in the load model representation in order to evaluate the system response as accurately as possible.

Several approaches have been developed to construct accurate load models **EL-849, 1979**. EPRI project RP849, **Gentile, et al., 1981,** in early-eighties introduced an industry-based software for load modeling and evaluation. In the mid-eighties, EPRI project RP849-7 in collaboration with GE company produced an improved LOADSYN software for elaborate load model simulation, **Price, et al., 1987**.

In this work, a Genetic Algorithm (GA) based approach is employed to minimize modeling difficulties and to develop an accurate aggregate load model at a residential substation in Baghdad distribution network. The GA is capable of explaining numerous complex optimization problems successfully with fast convergence scale, unlike traditional algorithms. The proposed model is verified using realistic operating data measurements, feeder's load behavior is monitored and measured at Sana'a 33/11 kV substation using modern data acquisition devices and the aggregation is realized considering all network component.

2. LOAD REPRESENTATION

In 1995, IEEE researchers, **IEEE Taskforce, 1995,** published one of the very well established topics of load modeling. They concluded to recommend standard static load models in power flow and dynamic simulation programs for non-load sensitive modeling situations. This model does not throw its shadow on the accurate representation of loads since it ignores inductive motor consequences at locations where results are sensitive to the load-sensitive components. Comprehensive power system loads nevertheless being very difficult to model in real life, due to a number of constituents concerned like different nature and dynamics, time-frame and location, in addition to the dependency on external factors such as weather, .. etc, in other words, the load is uncertain component to model.

Two basic strategies are generally followed to obtain the load model characteristics. These are, measurement-based and component-based, **Zhang, et al., 2009,** and **Wei, et al., 2005**.

In the measurement-based strategy, direct measurements are occupied to determine the voltage and frequency sensitivities of the active and reactive consumption. Then, by fitting the data to the anticipated model, the coefficients of the model are then identified. In contrast, component-based modeling strategy is based on the static and dynamic behavior of all connected load properties, in other words, the load composition, the load mix, and characteristics. A further complication is added to the strategy when the load composition is divided and defined in percentages of each so as to name the load shares as, heating, motor, air-conditioning,...etc. Due to these facts, a component-based method is not a realistic choice for large utilities. To better describe the actual load characteristics, for the load model to be as accurate as it can be, combining both mentioned strategies is the optimal approach.

In this work, the measurement-based approach is utilized to develop a residential realistic load model for a distribution substation. A feeder active power, reactive power, voltage, power factor, and frequency measurements were gathered on an hourly basis over several days period. The polynomial static load model coefficients are then optimally identified using genetic algorithm approach. The 33/11 kV Sana'a substation load coefficients for the fourteen feeders are verified and presented in the "test system and result" part of this work.

2.1 Load Type and Standard Models

A bus-aggregated load comprises different load types. These are included in the load class mix but, in different composition percentages for the residential, commercial and industrial classes. The primary load categories are:

1) Induction motors, typically, motors consume up to 80% of the total delivered system energy and they are common to all load classes.
2) Lighting, these comprise a wide variety of lighting fixtures and types. The energy consumption varies between classes, roughly (10 to 30) percent of the total load.
3) Thermal (heating), thermal loads contribute a large percent of the total residential (in cold weather) and industrial classes. In fair-weather countries, thermal loads account for a low percentage of the total residential demand.

A static load model is to be developed for the sample distribution substation considered here, which supply consumers of the three categories mentioned above.

Basically, static load model is usually expressed either in a "polynomial" or in an "exponential" form concerning power consumption and voltage relationship, Moreover, for more accurate representation, it is required to involve a frequency dependent term, **Price, et al., 1987**, **IEEE Taskforce, 1995**, **CIGRE TaskForce, 1990**, and **Lin, et al., 1993** . The polynomial static load model, alternatively called ZIP-model is formulated as in **Eq.(1)** and **Eq.(2)** for the active and reactive power components respectively incorporating a frequency dependent parameters.

$$\frac{P}{P_o} = \left(a_1\left(\frac{V}{V_o}\right)^2 + a_2\left(\frac{V}{V_o}\right) + a_3\right)\left(1 + C_p\Delta f\right) \qquad (1)$$

And,

$$\frac{Q}{Q_o} = \left(b_1\left(\frac{V}{V_o}\right)^2 + b_2\left(\frac{V}{V_o}\right) + b_3\right)\left(1 + C_q\Delta f\right) \qquad (2)$$

$$\Delta f = f - f_o \qquad (3)$$

Where, P , Q , f and V are the present values for active power , reactive power , frequency and, voltage consequently. P_o , Q_o , f_o and V_o represents a base-case or pre-disturbance or change system values. The coefficients a_i and b_i at which $(i = 1,2,3)$ are the load model coefficients, C_p and C_q are the load model frequency dependent parameters. while Δf is the frequency deviation. On the other hand, the exponential static load model for the active and reactive power components may be expressed as :

$$\frac{P}{P_o} = (V/V_o)^{\propto_p}\left(1 + C_p \Delta f\right) \tag{4}$$

And,

$$\frac{Q}{Q_o} = (V/V_o)^{\propto_q}\left(1 + C_q \Delta f\right) \tag{5}$$

Where, $\propto_p$ and $\propto_q$ represent respectively the active and reactive powers sensitivities to voltage, **IEEE Task force , 1995** .

2.2 Model Coefficients and Parameters Estimation

Model parameters estimation is performed using a type of least squares or likelihood estimation to fit the curve in order to active and reactive load consumption to be measured, **Sadeghi,** and **Sarvi, 2009**. Recently, more advanced coefficient estimation methods were introduced, including Genetic Algorithm (GA) in addition to Artificial Neural Network (ANN) and Particle Swarm Optimization (PSO). Such methods are appropriate for problems where the investigation horizon is quite large with several unknown parameters model. A genetic algorithm approach is dedicated to this work to estimate the optimized load model coefficients, **Goldberg, 1989**.

Generally, the GA is an intelligent global optimization technique capable of effectively inspecting a group of inexplicit parameters minimizing a fitness (or cost) function in Matlab, **MathWorks, 2016**. In the work in hand, the fitness is the difference between the load measured active and reactive powers to the respective modeled ones.

The fitness function optimal minimization by GA can be designated mathematically according to :

$$minimize\ f(x)\ such\ that \begin{cases} g(x) \le 0 \\ h(x) = 0 \\ l_b \le x \le u_b \end{cases} \tag{6}$$

Where $g(x)$, and $h(x)$ are the inequality and equality constraints, l_b and u_b are the lower and upper bounds of the search space respectively. The GA stochastically swaps the search space to find a global minimum.

In the search space (the data measured horizon), **Eq.(1)** & **Eq.(2)** & **Eq.(3)** can be formulated for each data point (n-points in the search space), given as follow:

$$E_{rp_i} = \left(\frac{P}{P_o} - [a_1 \left(\frac{V}{V_o}\right)^2 + a_2 \left(\frac{V}{V_o}\right) + a_3] \times \left(1 + C_p \Delta f\right) \right)_i \tag{7}$$

And similarly,

$$E_{rq_i} = \left(\frac{Q}{Q_o} - [b_1 \left(\frac{V}{V_o}\right)^2 + b_2 \left(\frac{V}{V_o}\right) + b_3] \times \left(1 + C_q \Delta f\right) \right)_i \tag{8}$$

Where $i = 1,2, \ldots .n$

Then, the corresponding fitness function for the load active power is:

$$ERRP = \sum_{i=1}^{n} E_{rp_i} \tag{9}$$

And similarly that for the load reactive power is;

$$ERRQ = \sum_{i=1}^{n} E_{rq_i} \tag{10}$$

Finally, the optimization problem can be set as:

$$minimize \ \ (ERRP \ and \ ERRQ) \tag{11}$$

Subjected to the following constraints ;

$$Constraints \equiv \begin{cases} a_1 + a_2 + a_3 = 1 \\ b_1 + b_2 + b_3 = 1 \\ -const_p \le C_p \le const_p \\ -const_q \le C_q \le const_q \end{cases} \tag{12}$$

If it is required to quantify the voltage deviation only on the load model, C_p and C_q parameters may be assumed zero resulting in a frequency independent simplified model. A concise flow-chart resembling the whole model parameters estimation is shown in **Fig.1**.

3. AGGREGATION STRATEGY

For each substation radial feeder, aggregation is performed starting where the last node located at the outmost distribution transformer, completed at substation busbar. In this work, aggregation strategy is developed in four phases :

1) Phase One: in this stage, the aggregation is performed at the subsequent of each distribution transformer, i.e at the 0.4 kV secondary distribution system concerning distributors, service mains, switches status in addition to the residential load model outcomes.

2) Phase Two: aggregation is completed for the 1/3 of the primary distribution system feeder i.e 11kV network feeder, this is achieved considering overhead transmission lines, cables, distribution transformers, static VAR compensators in addition to the status of protective switches providing one fictitious load busbars. The phase horizon is limited to 1/3 in order to improve the strategy execution time besides minimizing the error deviation.
3) Phase Three: the phase two prospect is repeated for the remaining 2/3 of the feeder in two steps resulting in an aggregate distribution feeder model for each bus section of the substation. Each one of the 14 feeders will be symbolized by a single feeder load model concerning all primary and secondary distribution system network components besides the ZIP load model in addition to induction motors effects. This
4) Phase Four: combining both substation power transformer models will accomplish the aggregation process providing single sectionalized busbars with open circuit bus section since this distribution substation is of single-sectionalized arrangement.
5)

4. TEST SYSTEM AND RESULTS

4.1 Test Substation

The sample 33/11 kV substations from Baghdad distribution system is considered for this load model study. A substation named Sana’a is located in Al-kadhimiya district with two 33kV incoming and fourteen 11kV outgoing feeders is of the scope of this work. All of the fourteen feeders are loaded, the station single line diagram is as shown in **Fig.2** in which only Feeder-14 (FD14) is drawn fully detailed to show its composition, the other thirteen remaining feeders are of similar nature. The substation principally supplies residential areas with minor loads of industrial and commercial natures. **Table 1** shows a sample of the hourly data gathered for feeder FD14 for almost three days (57h). Such data recordings were retrieved and used throughout this work to develop an aggregate load model at the substation busbar.

4.2 Performing Aggregation Strategies

For each distribution transformer, secondary distribution system aggregation is performed involving phase 1 of aggregation strategy, phase 2 starts at the end of FD14 concerning 1/3 the length and including eight transformers result in single fictitious busbar with load model and network component model as series impedance, line capacitance is neglected since its effect is quite small in distribution systems and short networks, this is shown in **Fig.3**. Aggregation continues upward to the beginning of the feeder executing phase 3 of the strategy developing a single feeder load model as shown in **Fig.4**, phase 3 is repeated until all the 14 feeders are models for both busbar sections. Finally, both substation power transformers are represented and aggregated with each section feeders models (7 feeders for each busbar section) and a final distribution substation aggregation approach is designated as shown in **Fig.5**.

As aggregation completed the model coefficients and parameters are investigated using GA, **Table 2** shows the GA factors used in this work to initialize the algorithm concerning active and reactive power fitness functions as previously termed in **Eq.(9)** and **Eq.(10)**. **Fig.6** shows the GA convergence process, which occurred in 48 generations of the data processed for Sana’a substation. The GA optimization program is MATLAB based on 10 segment chromosome length consuming decimal coding.**Table 3** and **Table 4** shows the calculated coefficients, a_i , b_i in addition to C_p and C_q parameters for the fourteen feeders with and without frequency dependency respectively.

4.3 Results Verification

4.3.1 Fitness convergence:

The convergence is accomplished with relatively fast execution time occurring at 50 generations for both active and reactive fitness functions **Eq.(9)** and **Eq.(10)** as plotted in **Fig.6**.

4.3.2 Load model coefficients:

The aggregate load model coefficients and parameters are verified using bus section line voltage comparison, the actual readings the proposed aggregate model results are compared considering individual feeders and then considering entirely substation feeders at each bus section as described in previously discussed Phase 3 and 4, this is shown by **Fig.7** and **Fig.8**.

4.3.3 Voltage deviation:

The deviation in error in the line voltage is distinguished and investigated, the maximum designated recorded error is 3.5% occurring at FD5 as shown in **Fig.9** , in the other hand when aggregating all section feeders to a single model the error becomes unimportant (0.38 %) regarding 11kV voltage level , this error rate between modeled and actual reading is significantly small and this is an evidence that the load modeling approach and aggregation strategy is an accurate representation of residential loads in Baghdad network.

5. CONCLUSIONS

The load model is an essential study for distribution systems since accurate results are of the main requirements for planning and operation analyses.

A realistic measurement based residential load model is developed in this work. The model is of the polynomial type whose parameters were optimized positively using a genetic algorithm based software. The actual feeder’s supply and measurements presented in this work proved sufficient to produce best-fit load model parameters.

The genetic algorithm optimization technique is adopted successfully using MATLAB providing accurate results and fast execution time, the fitness function for the load active and reactive powers is always converged with less than 50 generations consuming 10 segment decimal coding chromosomes. both GA and realistic measurements score accurate load model parameters as well as realistic load model presentation to distribution networks.

The realistic load model and aggregation process proposed in this work is dedicated to being used in Baghdad distribution network planning studies jointly with network operation/control simulators providing more truthful and reliable results that will reflect positively on problem-solving, decision making and future upgrading in the distribution network.

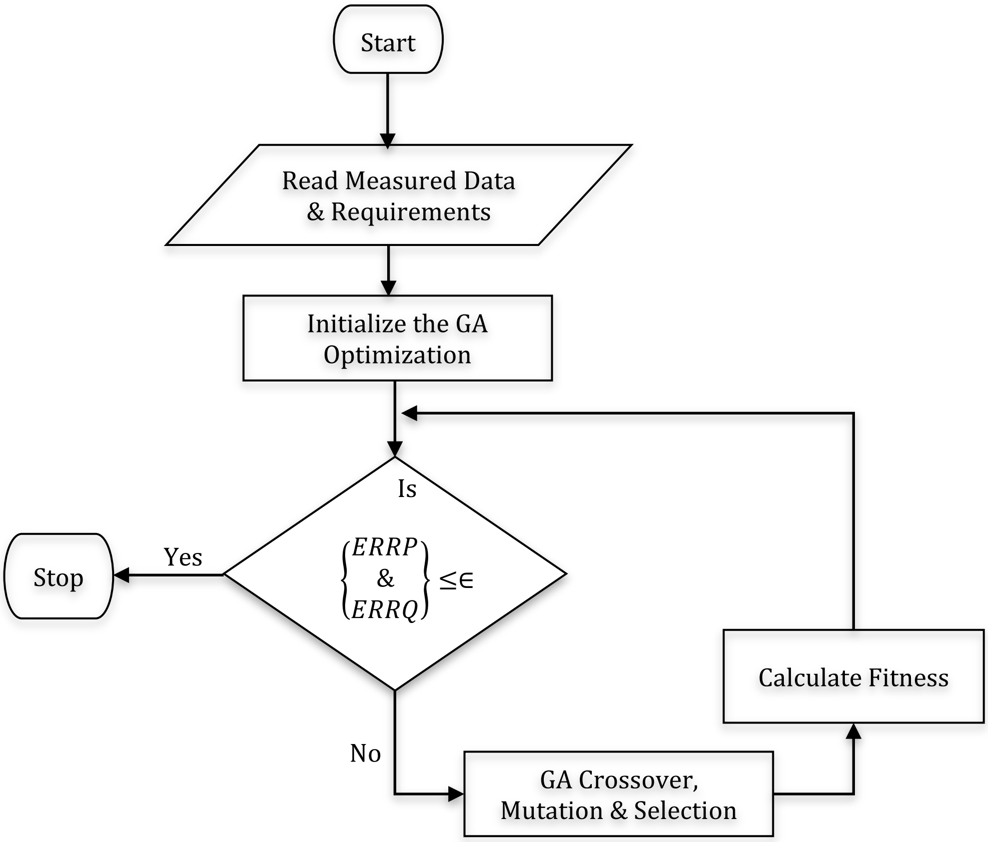

Figure 1. Load representation flow chart.

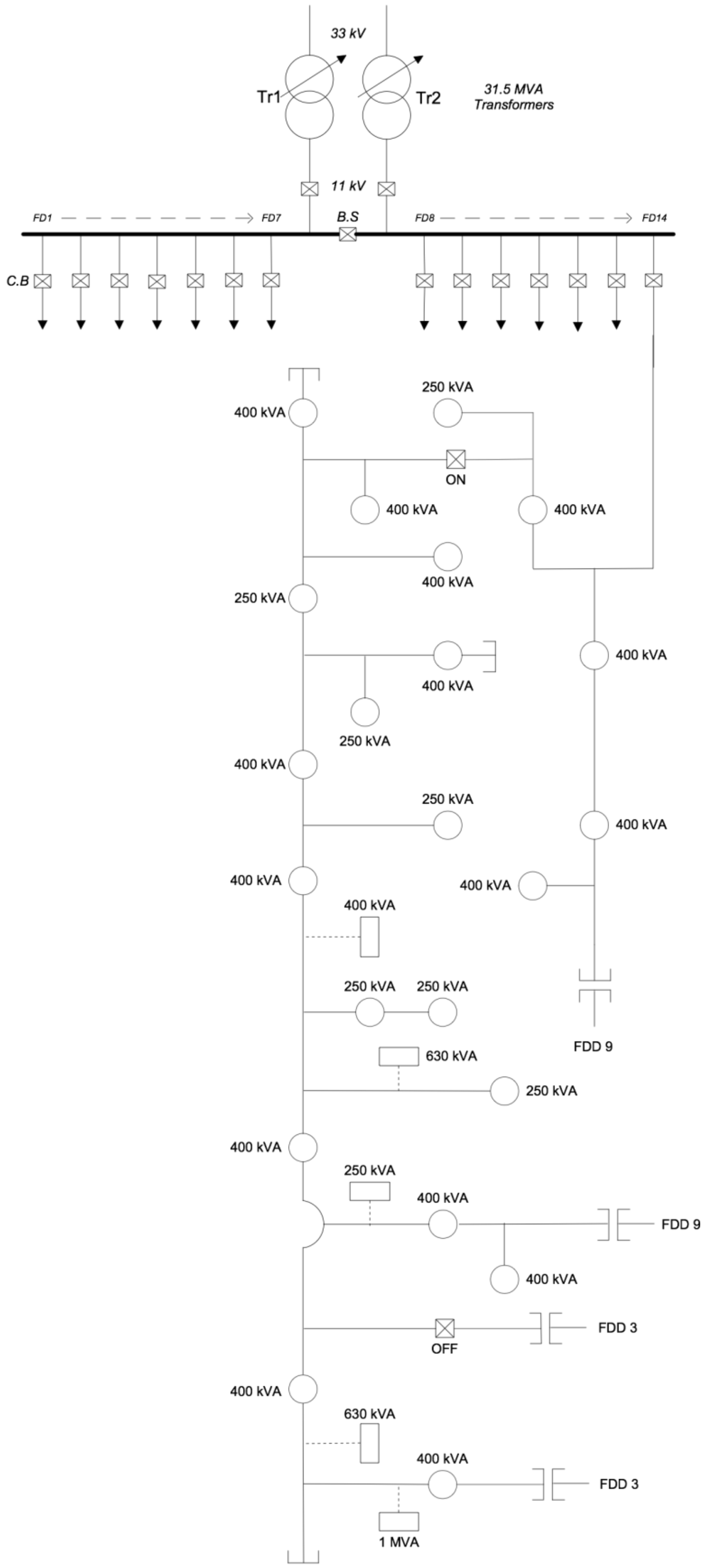

Figure 2. Sana’a sub-station.

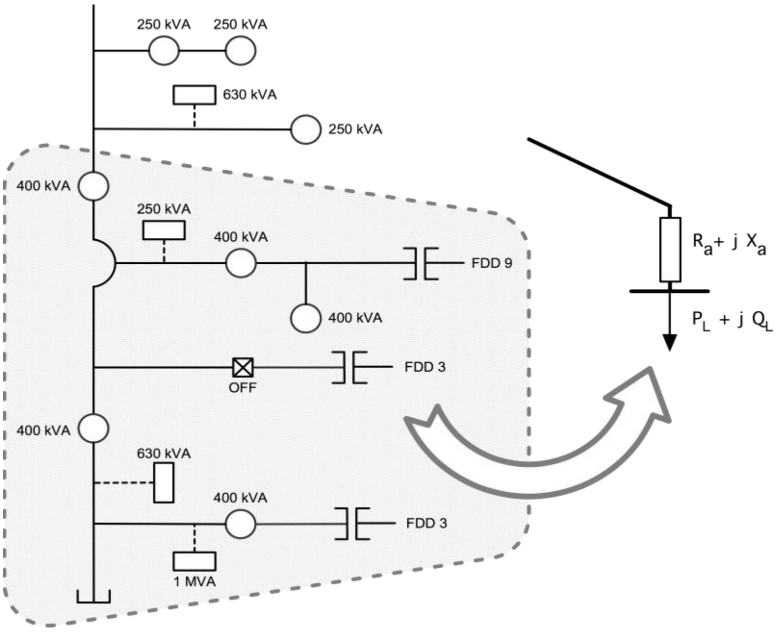

Figure 3. Aggregation process (phase 1&2).

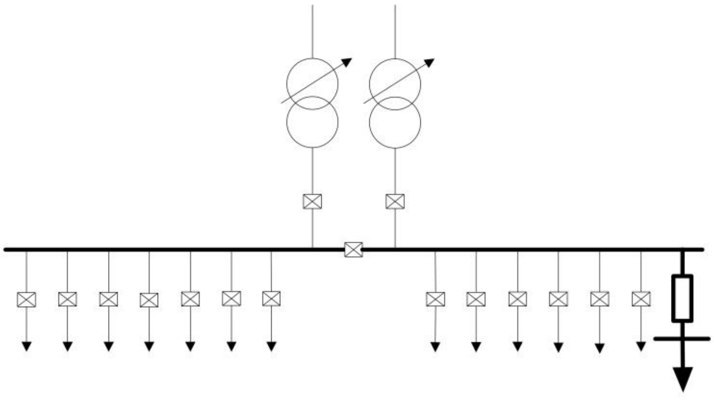

Figure 4. Aggregation process (phase 3)**.**

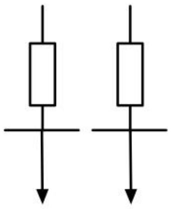

Figure 5. Aggregation Process (Phase 4).

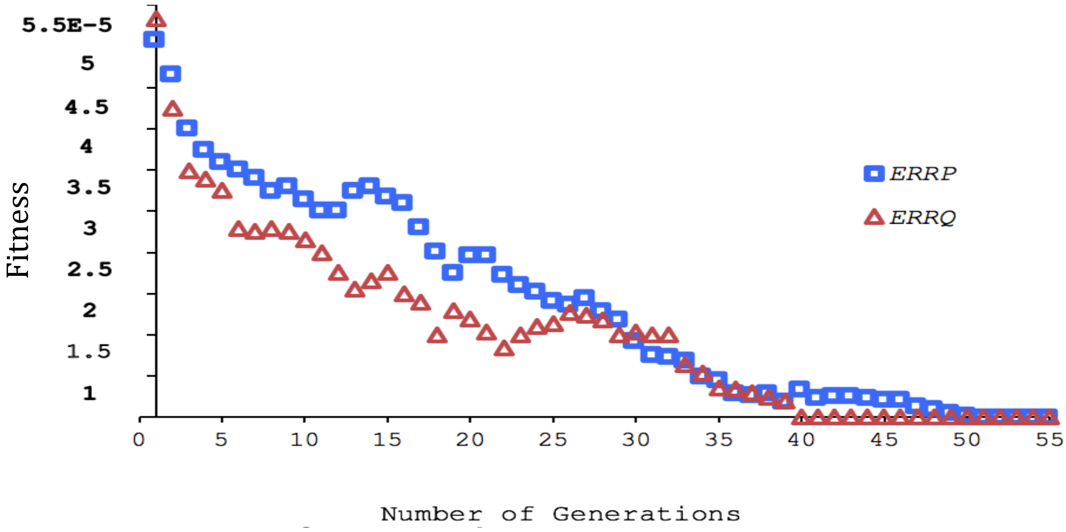

Figure 6. GA fitness convergence route

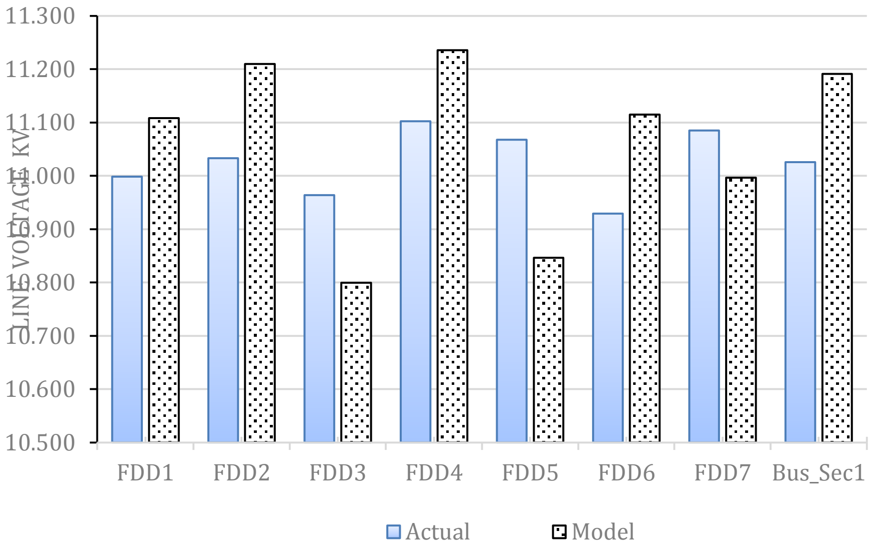

Figure 7. Voltage validation bus section 1.

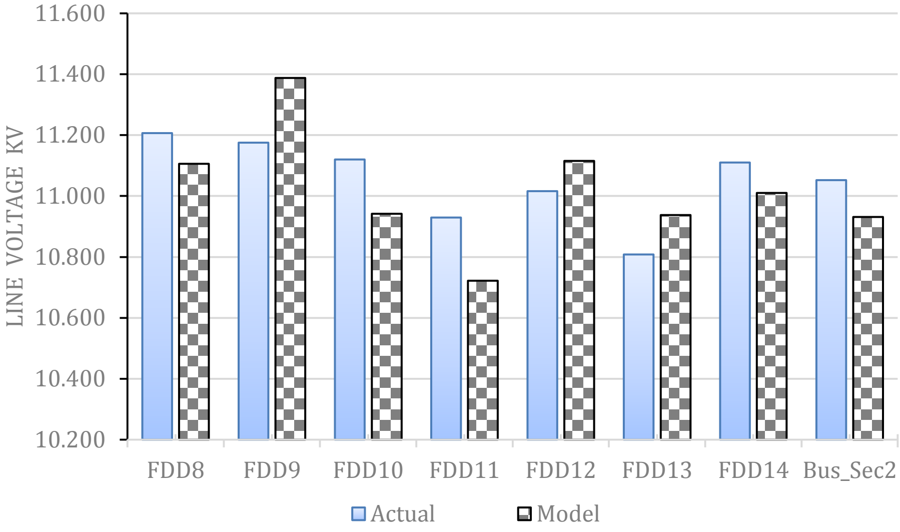

Figure 8. Voltage validation bus section 2.

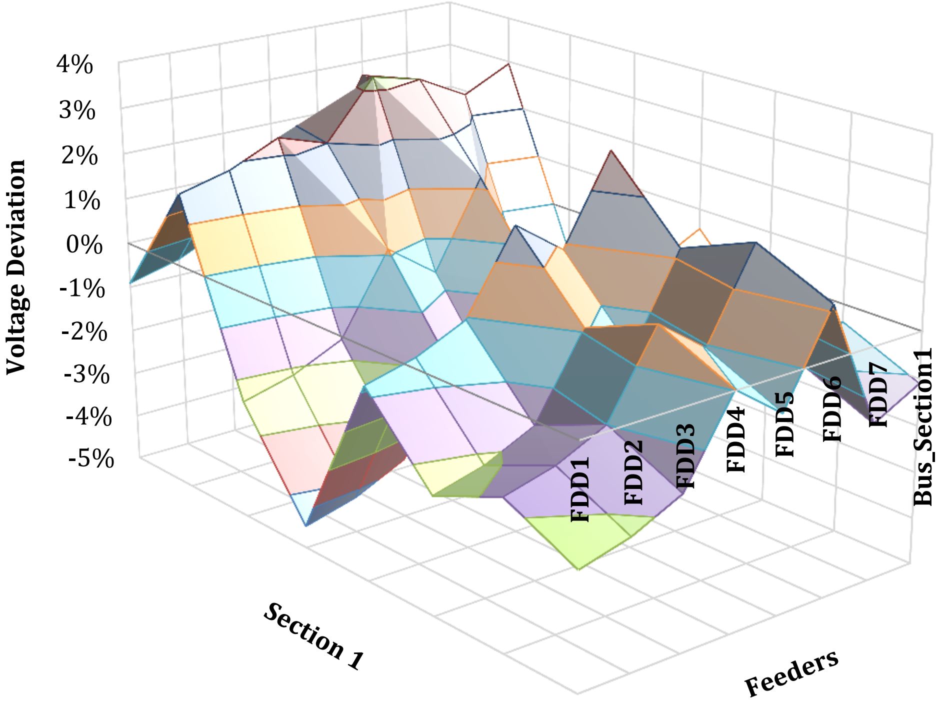

Figure 9. Voltage diviation for bus section 1.

Table 1A. Sample gathered data for sana'a 33/11kV substation part 1.

Reading	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Date ***(jan 2012)***	14	14	14	15	15	15	15	15	15	15
Hour	21:30	22:30	23:30	0:30	1:30	2:30	3:20	4:30	5:30	6:30
Frequency ***(Measured)***	49.3	49.2	50.1	48.8	49.4	49.3	49.7	49.8	49.1	49.2
L-N Voltage ***(kV Measured)***	6.38	6.37	6.4	6.36	6.35	6.35	6.46	6.46	6.35	6.35
Current ***(Amp Measured)***	236.8	238.3	234.9	229.1	217.9	215.8	201.2	182.2	181.6	183.7
P.F ***(Measured)***	0.9	0.9	0.91	0.88	0.89	0.89	0.88	0.88	0.87	0.88
L-L Voltage ***(kV Estimated)***	11.05	11.03	11.09	11.02	11	11	11.19	11.19	11	11
Active Power ***(kW Estimated)***	4079.12	4098.52	4104.17	3846.68	3694.39	3658.78	3431.35	3107.31	3009.75	3079.55
Reactive Power ***(kVAR Estimated)***	1975.61	1985	1869.92	2076.22	1892.69	1874.45	1852.04	1677.15	1705.7	1662.16
Apparent Power ***(kVA Estimated)***	4532.35	4553.91	4510.08	4371.23	4151	4110.99	3899.26	3531.04	3459.48	3499.49

Reading	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
Date ***(jan 2012)***	15	15	15	15	15	15	15	15	15	15
Hour	7:30	8:30	9:30	10:30	11:30	12:30	13:30	14:30	15:30	16:30
Frequency ***(Measured)***	49.3	49.4	49.1	49.8	49.4	49.4	50.2	49	50	49.5
L-N Voltage ***(kV Measured)***	6.33	6.34	6.35	6.44	6.31	6.33	6.5	6.37	6.24	6.36
Current ***(Amp Measured)***	184.2	190.3	205.5	211.9	254.1	262.8	265.4	259	263.9	253.2
P.F ***(Measured)***	0.89	0.89	0.89	0.9	0.91	0.91	0.91	0.91	0.92	0.91
L-L Voltage ***(kV Estimated)***	10.96	10.98	11	11.15	10.93	10.96	11.26	11.03	10.81	11.02
Active Power ***(kW Estimated)***	3113.18	3221.36	3484.15	3684.52	4377.2	4541.42	4709.52	4504.04	4544.99	4396.26
Reactive Power ***(kVAR Estimated)***	1594.93	1650.35	1784.98	1784.49	1994.31	2069.13	2145.72	2052.1	1936.16	2003
Apparent Power ***(kVA Estimated)***	3497.96	3619.51	3914.78	4093.91	4810.11	4990.57	5175.3	4949.49	4940.21	4831.06

Table 1B. Sample gathered data for sana'a 33/11kV substation part 2

Reading	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**
Date *(jan 2012)*	15	15	15	15	15	15	15	16	16	16
Hour	17:30	18:30	19:30	20:30	21:30	22:30	23:30	0:30	1:30	2:30
Frequency *(Measured)*	49.6	50.4	49.5	49.4	50	50	49.9	50.1	50	50
L-N Voltage *(kV Measured)*	6.33	6.41	6.41	6.37	6.47	6.37	6.37	6.44	6.37	6.37
Current *(Amp Measured)*	248.5	240.9	244.9	245.5	244.6	247.8	250.4	243	238.2	230.7
P.F *(Measured)*	0.91	0.91	0.9	0.89	0.9	0.91	0.9	0.9	0.91	0.9
L-L Voltage *(kV Estimated)*	10.96	11.1	11.1	11	11.21	11.03	11.03	11.15	11.03	11.03
Active Power *(kW Estimated)*	4294.3	4215.58	4238.48	4162.89	4272.92	4309.27	4306.63	4225.28	4142.32	3967.81
Reactive Power *(kVAR Estimated)*	1956.54	1920.68	2052.79	2132.71	2069.47	1963.36	2085.8	2046.4	1887.3	1921.7
Apparent Power *(kVA Estimated)*	4719.02	4632.51	4709.43	4600	4747.69	4735.46	4785.14	4694.76	4552	4408.68

Reading	**31**	**32**	**33**	**34**	**35**	**36**	**37**	**38**	**39**	**40**
Date *(jan 2012)*	16	16	16	16	16	16	16	16	16	16
Hour	3:30	4:30	5:50	6:30	7:30	8:30	9:30	10:30	11:30	12:30
Frequency *(Measured)*	49.9	50	49.9	50	50	50	49.9	50	50	50
L-N Voltage *(kV Measured)*	6.38	6.38	6.42	6.36	6.39	6.41	6.47	6.39	6.41	6.35
Current *(Amp Measured)*	229.7	212	202	199	209.4	218.9	230.3	249.8	255.4	260
P.F *(Measured)*	0.92	0.89	0.89	0.9	0.83	0.92	0.9	0.91	0.92	0.92
L-L Voltage *(kV Estimated)*	11.05	11.05	11.12	11.02	11.07	11.1	11.21	11.07	11.1	11
Active Power *(kW Estimated)*	4044.74	3611.34	3462.56	3417.23	3331.78	3872.69	4023.11	4357.69	4518.43	4556.76
Reactive Power *(kVAR Estimated)*	1723.05	1850.14	1773.92	1655.04	2238.97	1649.76	1948.48	1985.42	1924.85	1941.17
Apparent Power *(kVA Estimated)*	4396.46	4057.68	3890.52	3796.92	4014.2	4209.45	4470.12	4788.67	4911.34	4953

Table 1C. Sample gathered data for sana'a 33/11kV substation part 3

Reading	**41**	**42**	**43**	**44**	**45**	**46**	**47**	**48**	**49**	**50**
Date ***(jan 2012)***	16	16	16	16	16	16	16	16	16	16
Hour	13:30	14:30	15:30	16:30	17:30	18:30	19:30	20:30	21:30	22:30
Frequency ***(Measured)***	50	49.9	50.1	50.1	50.1	50.1	50	50	50	50.1
L-N Voltage ***(kV Measured)***	6.4	6.33	6.35	6.36	6.4	6.44	6.4	6.36	6.4	6.31
Current ***(Amp Measured)***	268.4	267.2	261.4	264.5	253.4	234.2	241.1	241.6	238.6	231.3
P.F ***(Measured)***	0.92	0.92	0.92	0.92	0.92	0.91	0.91	0.91	0.9	0.9
L-L Voltage ***(kV Estimated)***	11.09	10.96	11	11.02	11.09	11.15	11.09	11.02	11.09	10.93
Active Power ***(kW Estimated)***	4741.02	4668.2	4581.3	4642.93	4476.06	4117.52	4212.5	4194.85	4123.01	3940.66
Reactive Power ***(kVAR Estimated)***	2019.67	1988.64	1951.62	1977.88	1906.79	1876	1919.27	1911.23	1996.86	1908.55
Apparent Power ***(kVA Estimated)***	5153.28	5074.13	4979.67	5046.66	4865.28	4524.74	4629.12	4609.73	4581.12	4378.51

Reading	**51**	**52**	**53**	**54**	**55**	**56**	**57**
Date ***(jan 2012)***	16	17	17	17	17	17	17
Hour	23:30	0:30	1:30	2:30	3:30	4:30	5:30
Frequency ***(Measured)***	50	50	50	50	50.1	50.1	50
L-N Voltage ***(kV Measured)***	6.41	6.42	6.4	6.395	6.37	6.4	6.36
Current ***(Amp Measured)***	221.1	209.3	209	207.3	186	179.9	174.4
P.F ***(Measured)***	0.9	0.9	0.9	0.9	0.9	0.9	0.89
L-L Voltage ***(kV Estimated)***	11.1	11.12	11.09	11.08	11.03	11.09	11.02
Active Power ***(kW Estimated)***	3826.58	3628.01	3611.52	3579.35	3199.01	3108.67	2961.52
Reactive Power ***(kVAR Estimated)***	1853.3	1757.12	1749.14	1733.56	1549.35	1505.6	1517.23
Apparent Power ***(kVA Estimated)***	4251.75	4031.12	4012.8	3977.05	3554.46	3454.08	3327.55

Table 2. Genetic algorithm factors.

Number of Parameters		2
Population Size		100
Crossover Points		1
Mutation Rate		0.0156
Fitness	*Minimum*	1×10^{-7}
	Maximum	1×10^{-4}

Table 3. Optimal load coefficients voltage dependent only $(C_P=C_q=0)$.

	a_1	**a_2**	**a_3**	**b_1**	**b_2**	**b_3**
FD1	0.732	0.068	0.396	0.384	0.359	0.453
FD2	0.747	0.170	0.280	0.465	0.145	0.586
FD3	0.653	0.110	0.433	0.483	0.133	0.580
FD4	0.702	0.157	0.337	0.530	0.069	0.597
FD5	0.690	0.160	0.346	0.360	0.248	0.589
FD6	0.744	0.123	0.329	0.345	0.299	0.553
FD7	0.687	0.078	0.432	0.462	0.257	0.477
FD8	0.693	0.105	0.398	0.384	0.367	0.445
FD9	0.565	0.099	0.532	0.552	0.061	0.584
FD10	0.566	0.092	0.538	0.430	0.280	0.487
FD11	0.646	0.101	0.450	0.370	0.337	0.489
FD12	0.767	0.191	0.238	0.475	0.227	0.494
FD13	0.603	0.144	0.450	0.303	0.300	0.593
FD14	0.751	0.129	0.316	0.372	0.235	0.590

Table 4. Optimal load coefficients voltage & frequency dependent**.**

	P_o	Q_o	a_1	a_2	a_3	b_1	b_2	b_3
FD_1	3.9	1.71	0.612	0.057	0.331	0.321	0.3	0.379
FD_2	4.5	1.615	0.624	0.142	0.234	0.389	0.121	0.49
FD_3	4.15	1.748	0.546	0.092	0.362	0.404	0.111	0.485
FD_4	3.55	1.653	0.587	0.131	0.282	0.443	0.058	0.499
FD_5	4.25	0.76	0.577	0.134	0.289	0.301	0.207	0.492
FD_6	3.15	0.57	0.622	0.103	0.275	0.288	0.25	0.462
FD_7	4.45	1.9	0.574	0.065	0.361	0.386	0.215	0.399
FD_8	3.75	1.52	0.579	0.088	0.333	0.321	0.307	0.372
FD_9	4.5	1.843	0.472	0.083	0.445	0.461	0.051	0.488
FD_{10}	4.25	1.653	0.473	0.077	0.45	0.359	0.234	0.407
FD_{11}	4.1	1.558	0.54	0.084	0.376	0.309	0.282	0.409
FD_{12}	3.95	1.14	0.641	0.16	0.199	0.397	0.19	0.413
FD_{13}	4.55	1.71	0.504	0.12	0.376	0.253	0.251	0.496
FD_{14}	4.3	1.767	0.628	0.108	0.264	0.311	0.196	0.493

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