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Optimal transformer allocation in electrical distribution using genetic algorithm

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The optimization of transformers allocation is a major challenge to the operators of electrical energy distribution in several developing countries. In this research, a Generic Algorithm model for the optimization of transformer allocation in electrical distribution networks is developed. The algorithm employed the principles of selection, crossover and mutation to allocate transformers of different capacities to various substations in order to achieve their optimum performance. The objective function was subjected to cost and power capacity of each transformer as well as the growth rate and power consumption of the region. The initial population of chromosomes was generated at random with each consisting of potential solution to the problem. The chromosomes were decrypted and used to estimate the objective function. The GA operations were carried out on the chromosomes to know the ones that are best fit for consideration in the next generation. Results of a case study of transformer allocation in Osogbo District of Power Holding Company of Nigeria exhibited best-fit strategies for massive exchange (redistribution) of transformers in the district.

Key words: Genetic algorithm, transformer allocation, power distribution network, optimization and power generator.

INTRODUCTION

Electricity is one of the major driving forces behind modern machines and it is the backbone of a progressive economy. A nation with erratic supply of electricity will definitely be a nation with unstable economic growth. In modern times, the supply of electricity is manned by major electricity companies and passes through the stages of generation, transmission, distribution and consumption. Most electricity is generated using coal, oil, natural gas, nuclear energy, or hydropower. Some production is done with alternative fuels like geothermal energy, wind power, biomass, solar energy or fuel cells (Milbrandt and Mann, 2009). Majority of the electricity is produced at power plants with the use of steam turbines where mechanical energy is changed into electrical energy by using various energy sources such as coal, natural gas and oil. These fuels heat water in a boiler to produce steam. The steam under tremendous pressure is used to turn a series of blades mounted on a shaft turbine. The force of the steam rotates a shaft that is connected to a generator. The spinning turbine shafts turn electromagnets that are surrounded by heavy coils of copper wire inside generators. This creates a magnetic field which causes the electrons in the copper wire to move from atom to atom creating electricity (Culverco, 2005).

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Utility companies anticipate demand for electricity and transmit it at very high voltage along system of power lines to consumers through transformers where the high voltage is “step up” or “step down”. The power lines can be high as 765,000 volts which travel many hundreds of miles in a transmission grid (BOPL, 2012). Electric power distribution reliability is a measurement of how well the system provides customer adequate and secured supply of power to meet daily requirements. The concept of adequacy is generally considered to be the existence of sufficient facilities within the system to satisfy customers’ demand. Several methods in which Generic Algorithm (GA) formed the bedrock have been proposed for sufficient and constant transmission of electricity to consumers through suitable and appropriate allocation of transformers. GA is a programming technique that mimics biological evolution as a problem-solving strategy. They are based on a biological metaphor, which view learning as a competition among a population of evolving candidate problem solutions (Luger, 2002; Adam, 2004). This paper presents a suitable case study, a GA-based optimization procedure for transformers allocation as one of the key elements in electrical distribution networks.

Related works

The theoretical foundations for GA were presented in (Holland, 1975; Kumara et al., 2009; Melanie, 1999) as a global search technique for solving optimization problems which is basically focused on the theory of natural selection, the process that drives biological evolution. Genetic algorithms consist of a population of binary string and searching many peaks in parallel (Bhasker et al., 2013; Li, 2009). The authors in (Mahela and Ola, 2013) studied the possibility of reducing the value of real power losses for global system transmission lines by choosing the best location to install shunt capacitors. GA is used to calculate the optimal allocation and sizing considering the value of real power losses with injection of reactive power as an indicator of the ability of reducing losses at load buses. In Carpinelli et al. (2010) optimal sizing and allocation of dispersed generation, distributed storage systems and capacitor banks are presented. The optimization focused on minimizing the sum of the costs sustained by the distributor for the power losses, network upgrading, reactive power service and the storage and capacitor installation over the planning period. A hybrid procedure based on a GA and a sequential quadratic programming-based algorithm was implemented on an 18-busbar MV balanced 3-phase network and the results confirmed its feasibility.

A heuristic backtracking search algorithm is proposed in Chia-Hung et al. (2007) for adjusting the phasing arrangement of primary feeders and laterals for phase balancing of distribution systems. The phase unbalance index of distribution feeders is calculated based on the phasing current magnitude of each line segment and branch which has been solved by a 3-phaseload flow program. Bogdan et al. (2013) proposed a method for achieving optimization through the reconfiguration of distribution systems taking into account various criteria in a flexible and robust approach.

A method for finding the optimal values of the fixed and switched capacitors in the distribution networks based on the Real Coded GA (RCGA) is presented in (Rahmat-Allah and Mohammad, 2007). The modeling of the loads at different levels is simulated with low and medium voltage capacitors. With various parameters in the optimization problem, RCGA is used to find the real optimal network with the best rate for the capacitors. A determination method of optimal allocation and transfer of Step Voltage Regulators (SVRs) in distribution feeders with Renewable Energy Sources (RES) is presented in (Takahashi et al., 2012). The proposed method determines the optimal allocation and transfer of SVRs based on the forecasted amount of Photovoltaic (PV) system. In the proposed method, voltage margin is maximized under a constraint that all the node voltages are controlled within the proper range for a certain period of years.

Sreejaya and Iyer (2012) presents a GA based reactive power optimization for voltage profile improvement and real power loss minimization in AC-DC system. The reactive power control devices such as generators, tap positions of on-load tap changer of transformers, shunt capacitors, converter transformer tap positions and firing angles (Al-Abdulwahab, 2007; Ellithy et al., 2008) were used to correct voltage limits violations while simultaneously reducing the system power losses. Shahram (2006) proposed a system for evaluating the optimum allocation of any power system elements such as power plant, substation and capacitors. The system operates on GA and uses heuristic rules for its operations. The system finds substation allocation in optimum point with regard to its place and size. The mathematical model of the problem uses minimum investment costs and power loss to obtain the goal. Tiago et al. (2011) made a comparison between GA and particle swarm optimization (PSO) as tools for providing solution to switch allocation problem. The two algorithms used fuzzy expert system (FES) for making engineering judgment in the solution of the switch allocation problem. The models and techniques proposed were validated and applied in a large scale substation with the results showing the performance level of the two algorithms. The authors in Lijun et al. (2008) present optimal choice and allocation of devices in multi-machine power systems using GA. Focus was on achieving the power system economic generation allocation and dispatch in deregulated electricity market.

PROPOSED GA MODEL FOR OPTIMAL TRANSFORMER ALLOCATION

The first phase of the algorithm is concerned with the survey of some baseline data of transformer in each substation. The baseline data include power rating of transformer, estimated power consumption in the service area that is being serviced by the transformer, age of the transformer, classification of consumer (residential/commercial/industrial) and estimated percentage load growth of the area.

The second phase is concerned with developing a model of genetic algorithm procedure with a view of placing transformers in a substation for maximum capacity utilization. The model is characterized by a database of substation. The system employs a mono-objective optimization technique which is aimed at maximizing the capacity utilization of a transformer relative to its position in the electrical distribution network. The technique has a mechanism for guiding against over-utilization which can lead to quick ageing or breakdown of the transformer. Moreover, it involves the re-allocation of the existing transformers in the distribution network and resizing of an existing network by providing the capability of adding new nodes.

The third phase is concerned with the repositioning of transformers for better performance such that, the transformers that have less power to supply their substation are replaced. The design is presented under the transformer allocation in electrical distribution networks and data entry, genetic algorithm processing and result presentation design.

A typical substation comprises a distribution transformer, an incoming high voltage line, switches, circuit breakers, and other equipment needed to deliver electric power to the customer at the required voltages (U.S. Department of Labor, 2009). The factors that affect and determine the performance of transformers in an electrical distribution network include weather (storms, snow, temperature and humidity), contamination and humidity, excessive ambient temperature, excessive load and ageing. The design of transformer allocation in electrical distribution networks is driven by power flow analysis, load growth analysis and ageing factor.

Genetic representation of transformers in distribution network

The basis of genetics in nature is a chromosome. In the search space, each solution to the problem at hand, need to be encoded so that it can be thought of as a chromosome. Originally, genetic algorithm was designed with the idea of using binary string as a means of encoding (Mitchell, 1999). However, in a problem such as this, encoding binary string is not a natural way for representing the problem instead, what is designed is an encoding based upon the ordinary value where the position of each value represents where the transformer should be transferred to. In transformer allocation, the transformers are represented by 3-digits, while the position of the 3-digit gene in the chromosome represents the substation where the transformer is to be taken to. Each chromosome in the population is associated with a fitness value that is calculated using the fitness function. The fitness value indicates the satisfactory level of the solution being offered by the chromosome (Mitchel, 1999). This information is used to select the chromosomes that will contribute to the formation of the next generation of solution.

Crossover basically means that first part of the chromosome is exchanged with a part of the second chromosome, while the other parts of the chromosomes are equally exchanged. In a nutshell, crossover involved the genes of two chromosomes to be exchanged in an orderly manner. The individual chromosomes randomly organized pair wise, have their space location consumed in such a way that each former pair of individuals give rise to a new pair. The prompt to be used for Crossover is chosen randomly, different result is achieved by positioning the crossover point randomly.

Some individuals in the chromosome are randomly modified, that is, one (1) will change to 0 and 0 will change to one (1). Mutation is required after crossover because it prevents the solution from converging towards local optimal. Mutation involves selecting a gene represented by 3-digits in the chromosome and randomly altering one of the 3 digits.

Design of optimal allocation of transformers

Genetic algorithms are mainly used for optimization techniques (either to minimize or maximize). The model here is to maximize the capacity utilization of each transformer in the distribution system subject to the various parameters attached to each substation. The framework for the design in the system is provided in Figure 1 and has data entry, optimization procedure and result presentation.

The data to be entered into the system will basically serve as input to the genetic algorithm processing procedure. The kind of data required are not the type that is processed in peace-meal, but is bounded for processing as a whole. The required data for the system are divided into the following:

a. Genetic algorithm control parameters: The value of the control parameters influences the performance of the genetic algorithm processing module (Ellithy, 2007). It is used to alter the behavioral pattern of how the algorithm operates. For example, generations required by the optimization depends on the value of the control parameters. The control parameters that will be entered into the system include population size, crossover type, mutation probability, number of years for the model and number of iterations.

b. Substation records: Depending on the number of substations to be considered in the optimization system, the following parameters are used to test the objective function for optimizing the transformer in each substation:

i. Power rating of the transformer,
ii. Estimated power consumption of the area,
iii. Age (years) of the transformer,
iv. Consumer classification (Residential or Industrial),
v. Growth rate of the area.

The data are obtained and sent to the genetic algorithm procedure for processing and storage into a database for future retrieval and reprocessing. The database is as follows:

a. District {district name, state of origin, substation, population size, mutation probability, crossover type, number years of model, number of iteration},
b. Substation {substation id, transformer id, transformer power rating, transformer type, age of transformer, power consumption in the area, consumer classification},
c. Optimized transformer {substation id, initial substation id, transformer id, transformer power rating, transformer type, power consumption in the area, consumer classification}.

The data entry system represents an interface between the genetic algorithm processing and the stored substation records. At the data entry system, users request is transformed into a structured query language (SQL). The system dynamically fetches all the substation records regarding the district and is sent to the genetic algorithm processing unit.

Objective function: Based on the factors that affect the performance of a transformer in a distribution network, the mono-objective task of this genetic algorithm is based on the maximization of capacity utilization of individual transformers in the distribution networks considering the following parameters relating to a substation:

a. Power rating of the transformer,
b. Power consumption of the area (load demand),

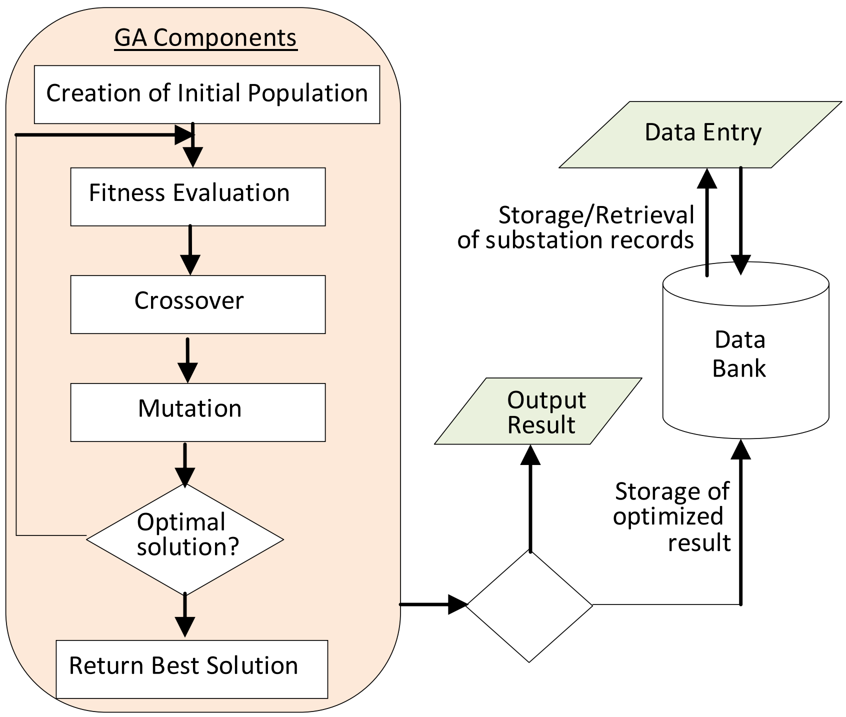

Figure 1. The design architecture.

c. Appreciation of power demand of the area for the specified period of time (load growth),
d. Ageing factor of the transformer,
e. Marginal fluctuation in power demand in the area.

The objective function, Z for the optimal transformer allocation in electrical distribution networks is given as:

$$Max\ Z = (T[i] - A[i]) - (P[i] + L[i] + M)$$

Subject to the decision variables: $T[i]$ = power rating of the transformer at the substation, $A[i]$ represents ageing factor of the transformer, $P[i]$ = the power consumption at the substation, $L[i]$ = the annual load growth of the area, and M = electricity marginal variation in demand.

Optimization procedure

Genetic algorithms use a "chromosomal" representation which requires the solution to be coded as a finite length of string (Ellithy, 2007). The procedure for optimizing the allocation of transformers in electrical distribution networks is based on the following processes:

a. String representation: In genetic algorithm, a chromosome represents a potential solution in a way to the domain problem. In the context of transformer allocation, a chromosome is a string of bits (comprising of 0's and 1's) which when decoded, represent a complete arrangement of the transformers in the distribution network. In the context of genetic algorithm for optimizing the allocation of transformers in electrical distribution networks, a gene is a group of 3 digits, which when decoded, represent the substation number (position) in which the transformer is to be placed in the distribution system. The substations in the distribution network are numbered from 1, 2, 3, …., N, where N is the number of substations.

Hence, a chromosome comprises of bits that are three times the number of substations in the distribution network. Each 3 group of digits which is a gene is decoded to represent the substation position of the transformer in the distribution network. For example, supposing T1, T2, T3, …T_N are transformers in substations S1, S2, S3, …, S_N respectively, a chromosome defined as: 020 017 005…..128 will give the arrangement as in Table 1.

This means that Transformer T1 is allocated to substation 20, Transformer T2 is allocation to substation 17, transformer T3 is allocated to substation 5 and transformer T_N is allocated to substation 128.

b. Initial population generation: The population refers to the number of chromosomes which will undergo evolutionary procedure to eventually produce a single chromosome that will be picked as the optimal value. The illustration above represents just one chromosome. For instance, if the population size selected for the algorithm is 700, then this number of chromosomes will be generated at random. Initially, they may hold no promise, but after they have undergone the evolutionary procedure of genetic algorithm, they will eventually produce a single chromosome that 'best-fit' the arrangement of transformers in the distribution network.

c. Fitness evaluation: The gene (location) for each transformer is tested in their environment (substation) using the various parameters relating to that substation such as:

i. Power rating of the transformer,
ii. Power consumption of the area (load demand),
iii. Power load growth of the area for the specified period of time,
iv. Ageing factor of the transformer,

Table 1. Chromosome arrangement of the transformers.

T1	T2	T3	………………	T_N
020	017	005	………………	128

v. Marginal fluctuation in power demand in the area.

The estimated value of the fitness of all the transformers in their virtual substation are added together to form the objective function value. This fitness evaluation is carried out on all the chromosomes to see which of them will have the highest objective function value. The chromosomes with low fitness values are replaced with newly generated ones, while the ones with high fitness value will undergo selection, crossover and mutation (evolutionary procedures) and move to the next generation (iteration) with the hope of producing better fitness.

d. Selection and reproduction: A set of old chromosomes are selected to reproduce a set of new chromosomes according to the probability which is proportional to their fitness. They are carried out to preserve better solution candidates. Less fit candidates are discarded and new ones are generated to replace them.

e. Crossover: This is performed on two chromosomes at periods that are selected from the population. Each of the two strings is splinted into two and the head of the first is joined to the tail of the second, while the head of the second is joined to the tail of the first. The conceptual diagram of the process of a Crossover of Parents 1 and 2 chromosomes is shown in Figure 2.

f. Mutation: This involves selecting a chromosome and changing one of its bits from 0 to 1 or vice versa as shown in Figure 3.

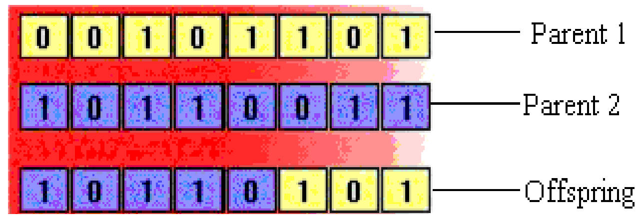

Figure 2. A visual diagram for crossover.

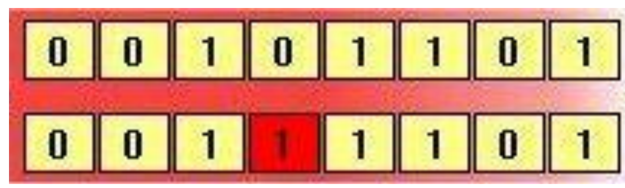

Figure 3. A visual diagram for mutation.

The optimization procedure requires an objective function and the encoding techniques for the parameters of each transformer in each of the substations, which are used to estimate its fitness. After the substation records and control parameters have been entered, the methodology employed is as follows:

a. The solution begins with the random generation of initial population of chromosomes,
b. For each chromosome, evaluate the objective function and the fitness value. The objective function is determined according to the summation of the capacity utilization of all the transformers in the network,
c. If chromosome population converge or the specified number of iterations has been carried out (optimum solution likely reached), then the chromosome with the highest fitness value is obtained as the optimal solution,
d. Select the new population using the principle of selection and reproduction described above (evolutionary principle),
e. Apply crossover and mutation on the new population and go to Step b.

The block diagram of the procedures described above is shown in Figure 4. At the end of the optimization procedure, the chromosome with the highest fitness value is taken as the optimal solution.

IMPLEMENTATION OF THE PROPOSED ALGORITHM

Prior to implementation, several choices were made concerning the parameters that serve as tools in controlling the GA procedure. Care was taken to ensuring that the set of choices is fit enough to produce optimal results. Before optimization, the position of transformers in electrical distribution system is processed, the required information, which comprise of the control parameters for the processing and substation in the District were determined. The input forms for creating the control parameters and the substation databases are shown in Figures 5 and 6, respectively. Parameters such as population size, the number of substations/transformers in the system, crossover type (Single Point) in this case, mutation probability, number of years and iterations were appropriately selected.

Processing via GA begins with the reading of district and substations record from the database as shown in Figure 7. Read data are then converted into a set of strings where a substation is represented by a 3-digit string which the GA procedure can work upon. Therefore, the number of strings that form a chromosome will be three times the number of substation. The procedure is iterative and at the end of each iteration, genetic operators act on the chromosomes that allocate each transformer in the system (crossover and mutation). At the end, the fitness of each chromosome is evaluated using the objective function. The one that has the highest fitness is temporarily stored for future comparison. Those with the least fitness are discarded and new chromosomes are generated to continue the processes until the number of required iteration is reached. At the end of the whole process, the best-fit chromosomes

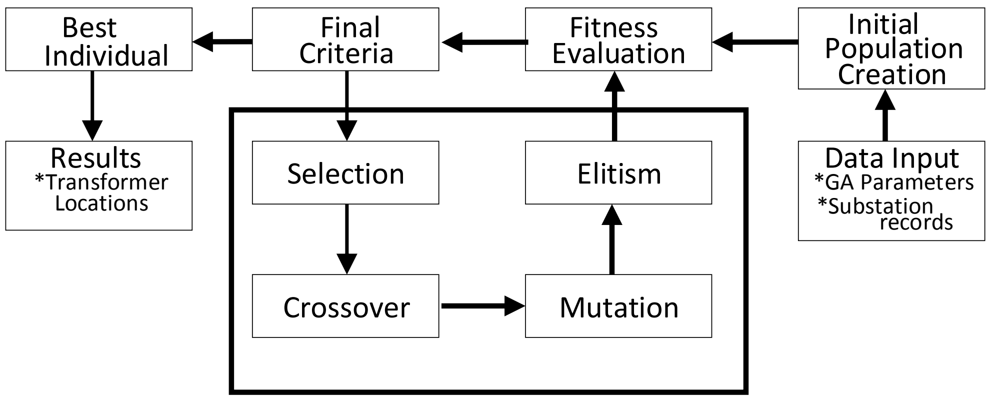

Figure 4. Optimization procedural block diagram for optimal transformer allocation in electrical distribution networks.

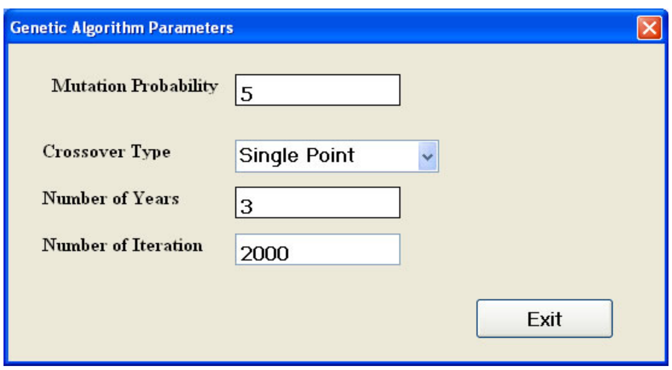

Figure 5. Input form for GA control parameters.

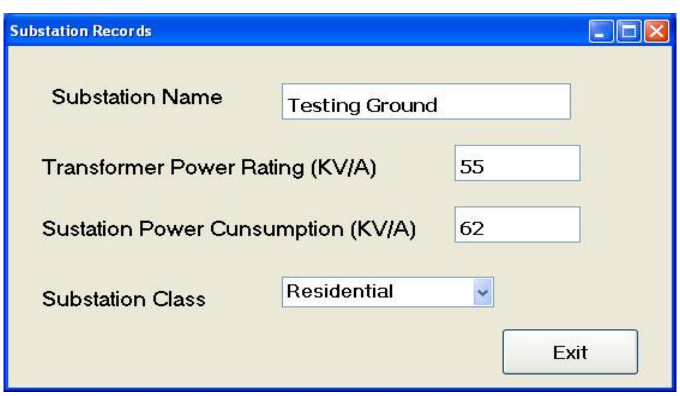

Figure 6. Entering form for substations data.

stored for each of the iterations are compared and the one that evaluates to best fitness is chosen for the allocation of transformers into the appropriate substations. For optimal performance, all underused or overused transformers are relocated to appropriate and rightful substations.

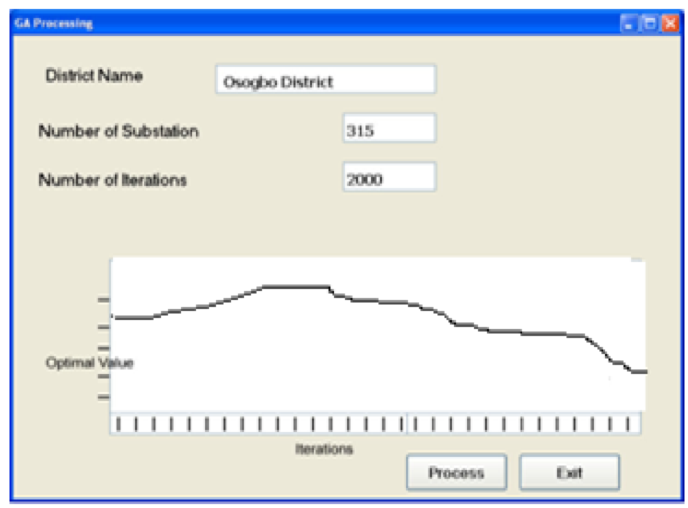

Figure 7. Processing via GA.

A case study of Osogbo electricity distribution district (OEDD) of Power Holding Company of Nigeria (PHCN) was carried out. The schematic diagram of the district is shown in Appendix 1. OEDD is one of the oldest districts of the electricity company in Nigeria and several other districts had been carved out from it. Presently, the district has a customer population of about 571,056 spreading across its 135 substations in five geographical units or undertakings that include Osogbo, Okefia, Ayetoro, Ikirun and Ila. Electricity is distributed to the end users in the district from a 33 KVA power source (Ojo, 2012). The matrix of the current and optimized transformer allocations in the district is presented in Table 2. Optimization of transformer allocations via GA indicates a fair but un-optimized allocation of transformers in the network with significant numbers of sub-utilized (SU) as well as over-utilized (OU) transformers.

Table 2. Current and optimized transformer allocation in Osogbo District, Nigeria.

Sub Id	Name of substation	Current transformer allocation		Optimized transformer allocation	
		Capacity Distr. T/F (KVA)	Loading (KVA)	Capacity Distr. T/F (KVA)	From Sub Id
1	Nulge	500	280	500	113
2	Osogbo Local Govt.	300	399	200	35
3	Idi Baba	300	105	200	38
4	Oke Ijetu	300	330	200	77
5	Federal Housing	300	120	200	80
6	Owode Village	200	198	100	47
7	Egbeda	200	136	200	9
8	Cooker III	200	110	300	3
9	Cooker II	200	100	200	10
10	Cooker I	200	106	200	11
11	Oredunmi	200	106	100	134
12	Gaa Fullani	200	156	200	8
13	Industrial Park	1000	820	1000	13
14	LAUTECH (Asubiaro)	500	440	300	62
15	OSBC	500	475	500	53
16	Uniosun	500	280	300	61
17	UNESCO	500	365	300	4
18	Nursing School Hostel	300	204	300	64
19	Crown Hotel	200	240	300	5
20	Fountain University	200	196	200	78
21	Asubiaro State Hospital	200	144	100	87
22	Mini Water Works	200	132	300	122
23	Auxilliary (Odi Olowo)	100	92	100	133
24	MTN Idi Baba	50	37.5	50	24
25	MTN (Ife Oluwa)	50	38.5	50	25
26	Ebenezer	500	385	500	115
27	Station Rd.	500	365	500	49
28	Terminus	500	440	300	58
29	Old garage	500	380	500	17
30	Igbonna	500	535	500	27
31	Fagbewesa	300	243	300	65
32	Adenle	300	219	315	129
33	Orisunbare Market	500	530	500	72
34	LAUTECH Teaching Hosp	500	610	500	29
35	TIB/Spring Bank	200	174	300	125
36	UBA	300	195	300	124
37	Wema Bank	300	291	200	82
38	Fist Bank PLC	200	176	200	131
39	OSICOL Water	200	148	200	22
40	Computer	200	200	200	81
41	STB/UBA	100	61	100	41
42	Union Bank	100	72	100	68
43	District Office	100	73	100	45
44	O'Net Otakiti	100	94	100	100
45	SKYE Bank Fagbewesa	100	65	100	94
46	Ademola Rasaq	100	89	300	130
47	Intercontinenter Bank	100	99	100	42
48	MTN Opp.Post Office	50	56.5	50	135

Table 2. Contd.

49	Coca-Cola	500	335	500	69
50	Baruwa	500	540	500	26
51	Eleyele Estate	500	385	500	51
52	Ogo-Oluwa	500	570	500	116
53	Omigade	500	320	500	117
54	Odetoyinbo	500	645	500	55
55	Sazo	500	395	500	120
56	Ibuamo Abija Area	500	190	300	123
57	Olosan II Ogo-Oluwa Area	500	295	300	2
58	Folakunle	300	354	300	66
59	Heritage	300	150	500	56
60	Olosan	300	225	300	127
61	Zarah	300	321	300	36
62	Ataoja Est.	300	318	200	20
63	Oladipo	300	423	200	6
64	Ibukunoluwa	300	177	200	40
65	Palm Crest Hotel	300	177	300	18
66	Olasamson	300	186	200	83
67	Kamar Dairo	200	80	200	7
68	Raji Kolade	100	64	100	100
69	Gov's Office I	500	380	500	114
70	Gov's Office II	500	270	500	118
71	Abere I	500	485	500	74
72	CBN I Opposite NECO	500	375	500	111
73	CBN II Abere	500	440	300	63
74	Amorite	500	410	300	32
75	House of Assembly I	300	237	500	14
74	House of Assembly II	300	144	500	121
75	Fed. High Court	300	225	300	128
76	Custom	300	291	300	60
77	Olaniyi Aina Petrol	200	176	200	86
78	First Bank	200	120	300	126
79	Access Bank	200	142	200	79
80	Health Trust Fund	200	176	200	21
81	INEC	200	134	300	74
82	NTA Osogbo	200	184	200	39
83	Fidelity Bank	200	210	300	59
84	Tantalizer	200	154	200	84
85	Federal Pay Office	200	166	200	12
86	Bank PHB	200	138	300	129
87	Oceanic Bank	100	120	100	134
88	Zenith Bank	100	80	100	43
89	Ayinke Tower	100	86	100	132
90	GTB	100	79	100	102
91	Diamond Bank	100	75	100	91
92	FCMB	100	89	100	90
93	MTEL Ogo-Oluwa	100	94	100	99
94	Fed. Inland Revenue	100	69	200	67
95	FRSC	100	85	100	88
96	Living Spring Hotel	100	97	100	103
97	MTN Oke Pupa	100	95	100	101
98	AIG Office	100	93	100	108

Table 2. Contd.

99	Celtel, Owode Abere	100	79	200	133
100	Celtel, Gbongan /Ibadan Rd	100	68	100	89
101	Abere Streetlighting	100	83	100	104
102	Afri Bank	100	74	100	46
103	Street Lighting	100	82	100	92
104	Heritage Hotel	100	86	100	23
105	Streetlighting	100	96	100	98
106	Union Bank Gb/Ib Road	100	94	100	44
107	Streetlighting	100	95	100	93
108	Sterling Bank	100	84	100	106
109	SSS Office	50	48	50	109
110	Zain Opp. Access Bank	50	53.5	50	110
111	Jaleyemi	500	415	500	28
112	Matanmi	500	605	500	73
113	Exchange	500	300	500	15
114	Oja-Oba	500	400	500	71
115	Kajola	500	330	500	33
116	Oke Abesu	500	385	500	30
117	Oke Baale	500	385	500	50
118	Custain	500	405	500	52
119	Fadilulahi	500	230	500	112
120	ST Charles	500	395	500	34
121	Fadilulahi II	500	215	500	54
122	Osogbo Local Govt	300	120	300	75
123	Jimoh Buraimoh	300	396	500	119
124	BetterLife	300	183	300	75
125	Asubiaro I	300	123	200	19
126	Asubiaro II	300	138	300	131
127	Onireke	300	192	300	31
128	Ifelodun	300	222	500	70
129	Isale Aro	300	159	500	1
130	Ikolaba	300	69	500	57
131	Iso Ewe	300	240	500	16
132	Ita-Olokan	300	288	300	76
132	Bishop’s Court(Oke Ayepe)	300	285	200	85
133	Etisalat	300	285	300	132
133	Iso Ata(Back of Palace)	200	84	100	97
129	IDC II	315	179.55	300	133
130	IDC I	300	165	300	132
131	Palace	200	128	100	107
132	Street Lighting Jaleyemi	100	73	300	130
133	Sttreet Lighting, Ita-Olokan	100	60	300	37
134	Tajudeen Oladipupo	100	108	100	105
134	MTN Oke Ayepe	100	72	100	96
135	Yetty Guest House	50	44	50	48

Visual inspection of the figures presented in Table 2 revealed that practical implementation of the algorithm will require several exchanges of transformers to where they best fit in the distribution network. For instance, transformers at substations with identifier 113, 35, 38, 77 and 80 could have been located at Nulge, Osogbo Local government, Ido Baba, Oke Ijetu and Federal Housing, respectively. It is also shown that some transformers are to be disposed for new ones, for smooth and reliable distribution of electricity. Future research focuses on improving the algorithm to attain fully optimized transformer allocations in an electricity distribution network. This is expected to be achieved via the inclusion of some other relevant decision variables like customers' social class (private, commercial government) and environmental factors (temperature, humidity) in the objective function.

Conclusions

GA optimization technique has been proposed for resolving inadequacies inherent with the conventional or manual allocation of transformers in electrical distribution networks. The optimization procedure adequately allocated transformers to where they are best fit for energy transmission over reasonable lifespan in an electrical distribution. The system has an advantage over the manual system because it can be executed repeatedly and very helpful in the determination of how existing electricity distribution network could accommodate expansion.

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Appendix 1. Conceptual diagram of Osogbo, Nigeria District 11KVA.