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Application of Genetic Algorithm Solution Approach to Voltage Drop Issues on 33 kV/11 kV Injection Feeders: A Case Study of Ogbomoso, South West, Nigeria

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Authors' contributions

This work was carried out in collaboration between both authors. Author MOO designed the study, performed the statistical analysis, wrote the protocol, and wrote the first draft of the manuscript. Authors MOO and EOO managed the analyses of the study. Author EOO managed the literature searches. Both authors read and approved the final manuscript.

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ABSTRACT

The place of good quality and quantity of electricity supply by electric power provider in national growth cannot be underestimated**.** But, sadly the quantity and quality of electricity in most third world countries such as Nigeria is plagued by quite a number of power quality disturbances and technical losses inherent within the system. Voltage drop affects the quantity of available electricity and it is a major concern of electric power providers as it challenged their sole responsibility of supplying customers with the required voltage level at all times. Surprisingly, the causes and effects of voltages drops on 33kV/11kV transmission systems have not been extensively looked at in Nigeria. This paper presents application of genetic algorithm solution approach to voltage drop issues on 33kV/ 11kV Injection feeders: a case study of Ogbomoso, South West, Nigeria. The result of the analysis showed that the receiving end voltage is of low proportion compared to the sending end

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voltage. The parametric modeling of voltage drop revealed several causes of voltage drop in the study area. Different cable sizes were used to mitigate the effect voltage drop, it was discovered that, to attain minimum voltage drop in this station, the 65 mm^2 cable used has to be augmented to 85 mm^2 or reduce to 50 mm^2 while the number of the injection stations should be increase.

Keywords: 33kV/11kV injection feeder; cable size; electricity; genetic algorithm; voltage drop.

1. INTRODUCTION

The touch of electricity since its discovery cuts across every facets of human endeavor such as administrative, industrial, commercial and residential; this multi-dimensional application of electricity had re-shaped man and its activities with a proven track records ranging from homes, health care delivery, social services, industry, education, agriculture and enhanced transportation system in some advance nations of the world [1,2]. The next basic necessity of man for comfortably living in this modern world of today apart from air and water is electricity, this is evidently seen as many man's domestics activities such as cooking, refrigerating, washing, ironing, lighting, entertainment, air conditioning, pumping of water among others, involves the use of electrically operated device in one way or the other [3,4]. The use of electricity in domestic activities is not unconnected to the associated merits such as saving of time, stress reduction and conservation of energy as compared to the manual approach of getting these activities done [5].

Sadly, the quality and quantity of electricity supplied to the end users in most third world countries such as Nigeria is plagued by many power quality disturbances such as voltage sag, voltage swell, interruption, oscillatory transient and impulsive transient among others [6,7]. Power quality disturbances on the system are non-stationary and transitory in nature with significant adverse effects on the electrical / electronic equipment connected by the end users of electricity [8]. Also, there is always a wide margin between quantity of electricity made available to the end users and the quantity transmitted, this difference appears inform of voltage drop [9]. Voltage drop is a major concern of electric power providers as it challenged their sole responsibility of supplying customers with the required voltage level at all times. It as well affects the expected income on the energy transmitted for sale and from the economic point of view, voltage drop is revenue lost in disguise [10].

Researchers like [11] viewed voltage drop as wasted electricity; which is simply the difference between the voltage measurement at the source and the voltage measurement at the point of use. In the absence of voltage drop, the receiving-end voltage and the sending-end voltage should be the same, but what operates in practical system is a complete aberration from this perspective; the receiving-end voltage most of time, is lesser in magnitude than the sending-end voltage. Voltage drops along the line accounts for this difference and it causes can be attributed to the combined effects of resistance and impedance of the conducting media through which it is transported [9,11].

In recent times, several studies had been carried out by researchers on causes, effects and ways of mitigating occurrences of voltage drop on feeder using different test case systems. An investigation into the causes and effects of voltage drops on 33kV/11 kV feeder using sub-transmission system of Electricity Company of Ghana was carried out by [9], the work revealed the major causes of voltage drop on the test system are poor jointing and terminations, use of undersized conductors and use of different types of conductor materials. The effect of line resistance and poor power factor as causes of voltage drop was investigated; a new condition for price inversion at sending-end even under lagging power factor condition was proposed and implemented by [12].

Researcher [13] proposed that voltage drop in radial distribution networks can be applied for all voltage levels; the work established that voltage drop is one of the core indicators of power quality. Performance evaluation of domestic AC voltage stabilizers in meeting low voltage problems in Nigeria was implemented by [14]; the work established that larger percentage of stabilizers out of 12 different brands examined was unable to adequately meet the current worsened low voltage situation. Also, a model for calculating voltage drop in power distribution network was developed by [14]; from the model developed it was observed that voltage drop increases with temperature rise, increase in load and decreases with conductor diameter.

Analysis of voltage drop and design of urban distribution feeders was presented by [15], the work recommended that the existing feeder should be operated at 0.88 p.f, a temperature of 2000C, and conductor size should be augmented from 65mm2 (DOG) and 48mm2 (RACCOON) to 80mm2 (LEOPARD) and 50mm2 (OTTER) respectively. Based on the reviewed works, limited local researchers have attempted to dig more into causes, effect and mitigation approaches of problem of voltage drop. Also, there is limited information on the use of Artificial Intelligence technique to mitigate voltage drop occurrences on local feeders in Nigeria. This paper therefore presents application of genetic algorithm (GA) solution approach to voltage drops issues on 33kV/11kV injection feeders: a case study of Ogbomoso, South West, Nigeria and the proposed approach was implemented in MATLAB environment. Genetic Algorithm (GA) is a metaheuristic technique inspired on genetics and evolution theories [16]. In recent years, its areas of application in power system engineering covers optimal design of control systems [17], load forecasting [18]; OPF in systems with FACTS [19]; networks feeder reconfiguration [20]; reactive power planning [21]; maintenance scheduling [22]; economic load dispatch [23], generation scheduling and its sub-problems [24] among others.

2. STUDY LOCATION

Ogbomoso is one of the three largest metropolises in Oyo State, South Western region of Nigeria. In 1979/1980 a distribution injection station was built at Isale-General, along Ilorin road to cater for the power demand of this metropolis and its environs. This injection station took its supply from Transmission Company of Nigeria (TCN) Ganmo (about 60km away), Ilorin, Kwara State, North-Central region of Nigeria. The transformer at this injection station is fed with input of 33 kV and produced an output voltage of 11kV which are then distributed to three main feeders under the control axis. These feeders are named thus; Taki-Road Feeder, Ilorin-Road Feeder and Oke-Ado Feeder and served the one hundred and forty-nine (149) distribution transformers installed across the municipal.

Taki-Road Feeder feeds sixty–one (61) transformers and carries about 41% of the metropolis loads, Ilorin-Road Feeder supplies fifty-five (55) transformers and responsible for 37% of the municipal loads, while Oke-Ado feeder has the least number transformers within its control which is thirty-three (33) and this accounts for remaining 22% of the municipal loads. It needs to be pointed out that in Nigeria, the operating frequency is 50Hz, the line to neutral terminal voltage for small consumers is 220V and the line to line voltage for large

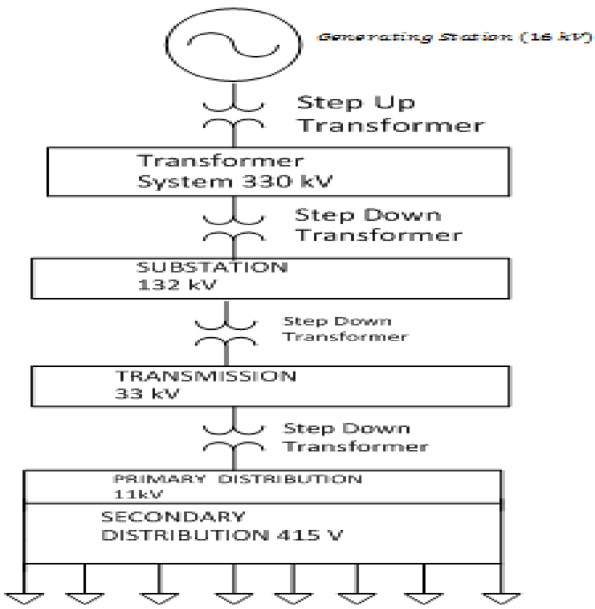

Fig. 1. The national power grid system

consumers is 415V. The National Power Grid of Nigeria showing the respective generation and transmitting voltage levels are clearly indicated in Fig. 1.

3. MATERIALS AND METHODS

3.1 Materials

The data required for this analysis are: sending end voltage from of Transmission Company of Nigeria (TCN), Ganmo, Ilorin, Kwara State, transformer turn ratio, cable diameter, cable length, conductor resistivity, operating temperature and receiving end voltage at injection feeder station. Samples of sending end voltages were collected for five consecutive days and it is as shown in appendix A.

3.2 Methodology

The research was based on fundamentals of concept of Ohm's Law and transformer voltage – turns ratio. The basic assumption used to obtain the receiving end voltage is that given the sending end voltage and standard transformer turn ratio, the receiving end voltage can be obtained. Also, the maximum acceptable percentage voltage drop in the system is 5% of the supply voltage line-to-neutral. The receiving end voltage is obtained thus;

$$\frac{Es}{Ep} = \frac{Ns}{Np} \quad (1)$$

where:

Np = number of turns in the primary
Ep = voltage applied to the primary
Es = voltage induced in the secondary
Ns = number of turns in the secondary

It should be noted that the E_P (voltage applied to the primary) will serve as the receiving end or incoming voltage at the injection station.

3.2.1 <u>Development of the voltage drop solution using GA optimization</u>

The goal is to reduce voltage drop on the distribution system to an acceptable percentage using Genetic Algorithm (GA) to optimize load distribution on the feeder. GA is a powerful artificial intelligence optimization algorithm, it can be used to minimize or maximize a given objective function based on the need at hand. In this work, voltage drop was modelled as the objective (or fitness) function. The GA was used to minimize the objective function by selecting the set of loads (or power consumptions) that gives minimal percentage voltage drop on the feeder. A set of loads consists of the loads of all sections of the feeder represents a chromosome in the GA.

The current (I) passing through a conductor is given as;

$$I = \frac{V}{R} \quad (2)$$

where; V = supply voltage, R = Resistance of the conductor or cable,
The resistance R, of the conductor or cable is given by;

$$R = \frac{\rho l}{A} \quad (3)$$

where; R = Resistance of the conductor or cable, $\rho =$ Resistivity of the material of cable, l = Length of distance of the cable, A = Surface area or size of the cable

The load or power consumption is given by

$$P = IV \quad (2)$$

The voltage drop is a function of the resistance, power consumption and current, and is given by;

$$V_d = \sum_{i=1}^{N} IR - \frac{P}{I} \quad (3)$$

where; N is the total number of sections or branches on the feeder. The GA is to minimize equation (5) such that the lowest possible voltage drop is obtained. The simulation parameters and their specification both for the 11kV feeder and the GA used for this analysis is as shown in Table 1 and Table 2 respectively.

The procedural step taken to achieve the set objective is as presented below;

BEGIN

Set simulation parameters
Calculate R, I
Generate initial population (i.e. Load/Power consumptions)
Compute the fitness function
FOR k = 1 to Maximum Generation
Select 2 fittest chromosomes
Perform crossover on selected chromosomes and use it to replace the weakest
Perform mutation

  Compute the fitness function
  Keep the new generation for next iteration
END

  Calculate performance measures
  Display Results
END

Table 1. Simulation parameters for the 11kV feeder

Parameter	Specification
Feeder	11 kV
Number of sections/branches on feeder	21
Supply voltage (nominal)	220 V
Resistivity of conductor (copper)	$1.72 \times 10^{-8}\Omega m$
Conductor size	$50mm^2, 65mm^2\ and\ 80mm^2$

Table 2. Simulation parameters for the GA

Parameter	Specification
Number of generations	100
Population size	50
Mutation probability	0.1
Crossover probability	0.2
Chromosome length	21

4. RESULTS AND DISCUSSION

The proposed approach was implemented MATLAB/SIMULINK, it was run on a portable computer with an Intel Core2 Duo (1.8GHz) processor, 2GB RAM memory and MS Windows 8 as an operating system. Table 3 shows the comparison between the sending end voltage (V_{SE}) and the calculated receiving end voltage (V_{RE}) for five consecutive days. Table3 established the fact that appreciable voltage drop exist between sending voltage and the receiving end voltage. Note; B/O means period of black-out (area of zero voltage).

The summary of results obtained with post genetic algorithm optimization using different cable sizes of 65 mm^2, 50 mm^2, and 80 mm^2 respectively at ambient temperature of 40ºC was

Table 3. Comparison between the sending end voltage (V_{SE}) and receiving end voltage (V_{RE})

Day1		Day 2		Day 3		Day 4		Day 5	
V_{SE} (kV)	V_{RE} (kV)	V_{SE} (kV)	V_{RE} (kV)	V_{SE} (kV)	V_{RE} (kV)	V_{SE} (kV)	V_{RE}(kV)	V_{SE} (kV)	V_{RE} (kV)
34	33.3	34	33.3	33	30.6	33	30.6	34	31.2
34	33.3	34	30.0	33	30.6	33	31.8	34	31.2
34	32.7	34	32.7	B/O	B/O	B/O	B/O	34	31.8
34	33.0	34	32.1	B/O	B/O	B/O	B/O	34	31.8
34	33.0	33	30.9	B/O	B/O	B/O	B/O	34	31.8
34	33.0	33	30.3	B/O	B/O	34	30.0	33	30.9
34	33.3	34	33.3	B/O	B/O	34	32.1	33	29.7
34	33.0	34	32.1	B/O	B/O	34	32.4	33	29.1
34	33.0	33	30.3	B/O	B/O	34	33.0	33	32.7
33	32.4	33	29.4	B/O	B/O	34	33.0	33	30.6
33	31.8	33	30.0	B/O	B/O	34	33.0	33	30.9
33	31.2	33	30.0	33	30.6	34	33.3	33	27.6
33	32.1	33	30.9	33	31.5	33	30.6	33	26.4
33	31.5	33	30.9	34	30.0	33	29.4	33	25.8
33	31.2	33	30.3	B/O	B/O	33	31.5	33	27.6
34	33.3	33	30.3	B/O	B/O	34	31.8	33	28.5
34	31.2	33	30.0	B/O	B/O	34	30.0	33	28.5
33	30.3	B/O	B/O	B/O	B/O	B/O	B/O	33	27.6
33	30.9	34	33.0	B/O	B/O	B/O	B/O	33	29.7
33	30.3	33	29.1	B/O	B/O	33	31.5	33	29.4
33	32.1	33	28.5	34	33.3	33	31.8	B/O	B/O
33	31.8	B/O	B/O	34	32.7	33	27.9	34	33.0
33	30.6	B/O	B/O	34	33.0	33	29.7	34	33.0
33	32.7	33	30.3	34	32.1	33	30.9	34	33.0

Table 4. Results of GA optimization of load distribution on 11kV feeder

Cable sizes	Total load on feeder (kVA)	Total voltage drop on feeder (V)	Percentage voltage drop reduction
65 mm^2 (Existing cable-size on the feeder)	72018	32.674	-
50 mm^2 (GA optimization)	49005	30.666	6.14
65 mm^2 (GA optimization)	48608	23.607	27.74
80 mm^2 (GA optimization)	52184	19.928	39.01

as presented in Table 4. The existing cable size was 65mm^2, the total load on the feeder was 72018 kVA and the estimated total voltage drop was 32.674 V. To minimize the voltage drop on the feeder, different cable sizes were used. It was observed that 50mm^2 cable has the highest voltage drop, followed by 65mm^2 cable and then 80mm^2 cable had the least voltage drop when GA was employed for optimization. Also, as the conductor sizes increases, the load on the feeder reduced in appreciable amount with a significant reduction in the feeder's voltage drop as evidently seen in Table 4.

The total load distribution against different cable sizes after optimization is as presented in Fig. 2. It can be observed that 65 mm^2 cable size without been optimized had the highest distribution voltage followed by 80mm^2 fully optimized while 65mm^2 and 50mm^2 cable sizes optimized had fairly the same voltage distribution.

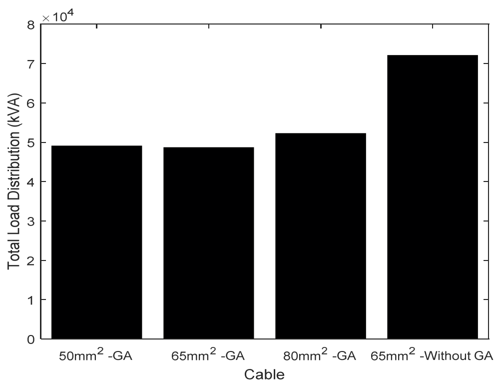

Fig. 2. Total load distribution (kVA) against cable sizes

Also, Fig. 3 shows the voltage drop against different cable sizes after optimization with the proposed artificial intelliegence, the result revealed that 65mm^2 without optimization had the highest voltage drop and after optimization 80 mm^2 cable has the least voltage drop, the voltage drop with 65mm^2 cable is a bit higher while the 50 mm^2 cable experienced the highest voltage drop.

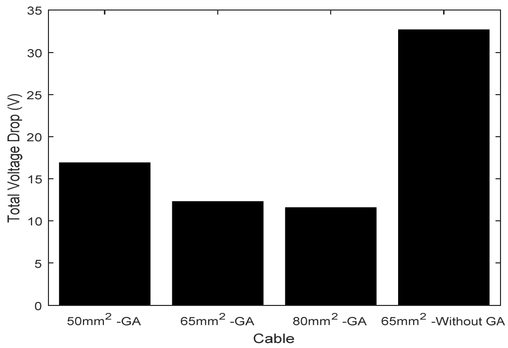

Fig. 3. Total voltage drop against different cable sizes

A curve illustrating how well different cables sizes examined were able to perform their intended function termed fitness value is as shown in Fig. 4. It can be clearly seen that best result in term of minimum voltage drop can be obtained by augmenting the 65 mm^2 cable to 80mm^2 or reducing it to 50mm^2 coupled with increase the number of the injection distribution station.

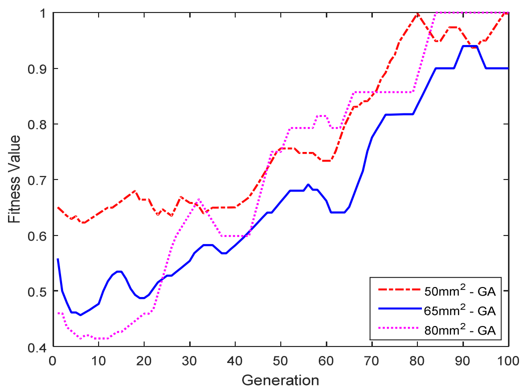

Fig. 4. Fitness value against generation

5. CONCLUSION

Application of genetic algorithm solution approach to voltage drop issues on 11kV injection feeders: a case study of Ogbomoso, South West, Nigeria was presented in this paper. The amount of voltage drop was established by comparing the magnitude of sending end voltage and the receiving end voltage. The study showed that, the significant voltage drop in study area is caused by: inappropriate cable size (surface area of the cable), poor joints and termination, hot spots, non-uniform conductor material, incessant increase in load on the feeder, extremely long feeder route length and inappropriate operating temperature.

Based on the analysis, it was observed that appropriate choice of conductor sizes will go a long way to minimize, if not completely eliminated voltage drop issues on the case study feeder. In view of this, for better performance of Ogbomoso 11kV injection feeder, the paper recommends that the 65mm^2 cable used by the station should be augmented to 80mm^2 or on the alternative, it should be reduced to 50mm^2 with corresponding increase in the number of the injection stations within the metropolis.

COMPETING INTERESTS

Authors have declared that no competing interests exist

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APPENDIX-A

Table A1: Measured voltage drop data at 40°C of 11kV feeder

S/N	Section	Cable size	Cable distance(m)	Load (kVA)	Voltage Drop(V)	Consumer Receive Voltage (V)	%age Receive Voltage(%)
1	AB	65mm^2	772	6322	6.075	213.93	97.24
2	BC	65mm^2	160	5359	1.074	218.93	99.51
3	CD	65mm^2	470	5259	3.097	216.9	98.59
4	DE	65mm^2	464	5196	3.023	216.98	98.63
5	E'E1	65mm^2	240	5171	1.556	218.44	99.29
6	E1E2	65mm^2	798	5071	5.078	214.92	97.69
7	E2F	65mm^2	542	5061	3.443	216.56	98.44
8	FG	65mm^2	240	4361	1.322	218.68	99.4
9	GH	65mm^2	146	4046	0.749	219.25	99.66
10	HI	65mm^2	134	3546	0.607	219.39	99.72
11	IJ	65mm^2	145	3446	0.639	219.36	99.71
12	JK	65mm^2	52	3246	0.217	219.78	99.9
13	KL	48mm^2	740	2533	2.45	217.55	98.89
14	LM	48mm^2	100	2423	0.318	219.68	99.85
15	MN	48mm^2	26	2398	0.082	219.92	99.96
16	NO	48mm^2	140	2048	0.382	219.62	99.83
17	OP	65mm^2	654	1948	1.705	218.3	99.23
18	PQ	65mm^2	45	1738	0.106	219.89	99.95
19	QR	65mm^2	100	1423	0.198	219.8	99.91
20	RS	65mm^2	315	1173	0.528	219.47	99.76
21	ST	65mm^2	45	250	0.025	219.98	99.99
	Total		**6328**	**72018**	**32.674**		

Table A2. GA-optimized Voltage Drop Data at 40^{o}C and Cable Size of 65mm^2

S/N	Section	Cable size	Cable distance (m)	Load (kVA)	Voltage Drop (V)	Consumer Receive Voltage (V)	%age Receive Voltage (%)
1	AB	65mm^2	772	5811	5.6	214	97.27
2	BC	65mm^2	160	4975	1	219	99.55
3	CD	65mm2	470	4765	2.818	217	98.64
4	DE	65mm^2	464	4765	2.782	217	98.64
5	E'E1	65mm^2	240	4507	1.365	219	99.55
6	E1E2	65mm^2	798	2673	2.777	217	98.64
7	E2F	65mm^2	542	2448	1.739	218	99.09
8	FG	65mm^2	240	2448	0.77	219	99.55
9	GH	65mm^2	146	2012	0.392	220	100
10	HI	65mm^2	134	2012	0.36	220	100
11	IJ	65mm^2	145	1671	0.33	220	100
12	JK	65mm^2	52	1555	0.111	220	100
13	KL	65mm^2	740	1555	1.58	218	99.09
14	LM	65mm^2	100	1274	0.18	220	100
15	MN	65mm^2	26	1146	0.043	220	100
16	NO	65mm^2	140	1146	0.23	220	100
17	OP	65mm^2	654	1020	0.975	219	99.55
18	PQ	65mm^2	45	806	0.056	220	100
19	QR	65mm^2	100	708	0.112	220	100
20	RS	65mm^2	315	679	0.341	220	100
21	ST	65mm^2	45	632	0.046	220	100
	Total		**6328**	**48608**	**23.607**		

Table A3. GA-optimized voltage drop data at 40°C and cable size of 50 mm^2

S/N	Section	Cable size	Cable distance (m)	Load (kVA)	Voltage Drop (V)	Consumer Receive Voltage (V)	%age Receive Voltage (%)
1	AB	50 mm^2	772	6026	7.54	212	96.36
2	BC	50 mm^2	160	6026	1.563	218	99.09
3	CD	50 mm^2	470	4507	3.474	217	98.64
4	DE	50 mm^2	464	4216	3.218	217	98.64
5	E'E1	50 mm^2	240	4080	1.614	218	99.09
6	E1E2	50 mm^2	798	2887	3.877	216	98.18
7	E2F	50 mm^2	542	2794	2.554	217	98.64
8	FG	50 mm^2	240	2687	1.091	219	99.55
9	GH	50 mm^2	146	2448	0.609	219	99.55
10	HI	50mm^2	134	1948	0.454	220	100
11	IJ	50 mm2	145	1555	0.402	220	100
12	JK	50 mm^2	52	1555	0.144	220	100
13	KL	50 mm^2	740	1516	2.009	218	99.09
14	LM	50mm^2	100	1388	0.251	220	100
15	MN	50 mm^2	26	1388	0.065	220	100
16	NO	50 mm^2	140	679	0.197	220	100
17	OP	50 mm^2	654	679	0.919	219	99.55
18	PQ	50mm^2	45	679	0.063	220	100
19	QR	50 mm^2	100	675	0.14	220	100
20	RS	50 mm^2	315	636	0.422	220	100
21	ST	50 mm^2	45	636	0.06	220	100
	Total		**6328**	**49005**	**30.666**		

Table A4. GA-optimized voltage drop data at 40^{o}C and cable size of 80mm^2

S/N	Section	Cable size	Cable distance (m)	Load (kVA)	Voltage Drop (V)	Consumer Receive Voltage (V)	%age Receive Voltage (%)
1	AB	80mm^2	772	5510	4.323	216	98.18
2	BC	80mm^2	160	5510	0.896	219	99.55
3	CD	80mm^2	470	4807	2.309	218	99.09
4	DE	80mm^2	464	4673	2.219	218	99.09
5	E'E1	80mm^2	240	4368	1.076	219	99.55
6	E1E2	80mm^2	798	3003	2.514	217	98.64
7	E2F	80mm^2	542	3003	1.707	218	99.09
8	FG	80mm^2	240	2873	0.725	219	99.55
9	GH	80mm^2	146	2231	0.35	220	100
10	HI	80mm^2	134	2202	0.317	220	100
11	IJ	80mm^2	145	2202	0.343	220	100
12	JK	80mm^2	52	2071	0.116	220	100
13	KL	80mm^2	740	1991	1.599	218	99.09
14	LM	80mm^2	100	1991	0.216	220	100
15	MN	80mm^2	26	1555	0.045	220	100
16	NO	80mm^2	140	1446	0.228	220	100
17	OP	80mm^2	654	675	0.572	219	99.55
18	PQ	80mm^2	45	675	0.039	220	100
19	QR	80mm^2	100	547	0.075	220	100
20	RS	80mm^2	315	547	0.236	220	100
21	ST	80mm^2	45	304	0.023	220	100
	Total		**6328**	**52184**	**19.928**		

Peer-review history:
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