UNIVERSITI PUTRA MALAYSIA

DETERMINING PENETRATION LIMIT OF CENTRAL DISTRIBUTED GENERATION TOPOLOGY IN RADIAL DISTRIBUTION NETWORKS

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By

MOHAMED SAAD ABDELGADIR SULIMAN

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Master of Science

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DEDICATION

This Thesis is dedicated to my father's soul may Allah subahanhu wa taa'ala mercy his soul and gather us with him in Jannah insha Allah

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Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science

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January 2021

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Distributed generation has become one of the major electric power system elements. The advantages of utilizing distributed generations in power systems include economic, environmental, and technical benefits. The optimum utilization of distributed generation units offers potential benefits to the electric systems such as network reliability, peak loads reduction, voltage support, and power quality improvement. Improper utilization of distributed generation units in distribution networks lead to frequency variations, raise system power losses, voltage deviation, and altering the fault current value. The potentials of renewable energy sources are categorized based on theoretical, geographical, technical, and economical potentials. The geographic potentials are related to the implementation area, which shall be usable, sufficient, and stable to host the renewable energy sources, particularly photovoltaic solar plants sites are restricted with legal and technical constraints.

Distribution network operators are practicing various topologies to align the optimal geographic sites with the optimal points of connection in the distribution networks. These topologies include the central photovoltaic solar plants, which consolidate the optimal distributed generation capacity at one central location, while the power are transferred to multiple optimal locations. On the other hand, the conventional scientific allocation methodology accommodates the optimal size of distributed generation directly to next to the optimal location. Although the scientific research community have investigated the optimal allocation of renewable energy sources from various perspectives that involve sophisticated theoretical, geographical, technical, and economical multi-objective functions, however it lacks a fundamental evidence that directly compares the conventional bus dedicated topology versus the central distributed generation topology on a typical distribution network using a typical methodology. In addition, the applied distributed generation topology directly affects the network penetration limit, which influence network operational limits consequently. Therefore, the study proposed a comparison between the conventional bus dedicated distributed generation topology and the central distributed generation topology.

The optimal sizing and allocation of distributed generation problem is based on active power loss reduction and voltage profiles improvement. The scope involved deterministic load flow formulation to obtain the essential power system parameters of the optimal distributed generation allocation. The load flow is performed using the Newton-Raphson method. On the other hand, to test the network operational limits when uncertainties of the photovoltaic generation and load demand are included, the probabilistic load flow was simulated using Monte Carlo Simulation method. The beta probability density functions were used to model the photovoltaic generation, while the normal probability density functions were used to model the load demand. The effectiveness of the proposed topology was validated on IEEE 33 and 69-bus distribution networks. Biogeography based optimization method was formulated to solve the optimal allocation problem, then manual method has been applied to accommodate the central unit. The manual accommodation of the optimally sized central unit was preferred to be applied, which removes the contradictions of comparing two different optimization allocation methodologies.

The biogeography based optimization method has been proven to have better performance than artificial bee colony, genetic algorithm, particle swarm optimization, hybrid of particle swarm optimization and constriction factor approach, and hybrid of ant colony optimization and artificial bee colony methods in terms of active power loss reduction. Meanwhile, the central distributed generation unit topology was proved to have better performances over bus dedicated distributed generation topology and the results showed 6.25% and 14.7% higher active power losses reduction in the central topology of IEEE 33 and 69 bus distribution networks respectively. The voltage profiles, distributed generation capacity required, and the penetration limit have shown better performances on the central distributed generation topology over the bus dedicated distributed generation topology. Furthermore, the probabilistic boundaries at minimum, mean, and maximum of power loss reduction, penetration levels, and voltage profiles have shown better performances when the central distributed generation topology is applied.

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Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia
sebagai memenuhi keperluan untuk ijazah Sarjana Sains

MENENTUKAN HAD PENEMBUSAN TOPOLOGI PENJANAAN PENGEDARAN PUSAT KEATAS RANGKAIAN PENGEDARAN RADIAL

Oleh

MOHAMED SAAD ABDELGADIR SULIMAN

Januari 2021

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Penjanaan yang diedarkan telah menjadi salah satu elemen sistem kuasa elektrik utama . Kelebihan menggunakan penjanaan yang diedarkan dalam sistem kuasa merangkumi faedah ekonomi, alam sekitar, dan teknikal . Penggunaan optimum unit penjanaan yang diedarkan menawarkan potensi keuntungan kepada sistem elektrik seperti realibiliti rangkaian, pengurangan beban puncak , sokongan voltan, dan peningkatan kualiti kuasa . Penggunaan unit penjanaan yang tidak betul dalam rangkaian pengedaran dapat menyebabkan variasi frekuensi, meningkatkan kehilangan kuasa daya sistem, penyimpangan voltan, dan mengubah nilai kesalahan arus . Potensi sumber tenaga baru boleh dikategorikan berdasarkan;teori,geografi,teknikal,dan ekonomi. Potensi geografik berkaitan untuk kawasan pelaksanaan, yang hendaklah berguna, mencukupi, dan stabil ke hos sumber tenaga diperbaharui, terutamanya plan solar photovoltaic yang terhad dengan kekangan undang-undang dan teknikal .

Pengendali rangkaian distribusi atau edaran mengamalkan pelbagai topologi untuk menyelaraskan kawasan geografik yang optimum dengan titik optimal yang disambungan dalam rangkaian pengedaran. Topologi ini merangkumi loji solar photovoltaic pusat, yang menggabungkan kapasiti distribusi penjanaan optimum di satu lokasi pusat, sementara kuasa dipindahkan ke beberapa lokasi optimum. Walau bagaimanapun, metodologi peruntukan optimum saintifik konvensional menampung ukuran generasi agihan optimum secara langsung di sebelah lokasi optimum. Walaupun komuniti penyelidikan ilmiah telah menyelidiki peruntukan optimum sumber tenaga boleh diperbaharui dari pelbagai perspektif yang melibatkan fungsi teori , geografi , teknikal , dan

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ekonomi yang pelbagai objektif, namun ia tidak mempunyai bukti asas yang secara langsung membandingkan topologi khusus bas konvensional dengan topologi penjanaan pusat pada rangkaian pengedaran khas menggunakan metodologi khas. Topologi penjanaan yag digunakan, memberi kesan langsung kepada had penembusan rangkaian, yang mempengaruhi rangkaian had operasi seterusnya . Oleh itu, kajian ini mencadangkan perbandingan antara topologi penjanaan edaran bas konvensional khusus dan topologi penjanaan pusat.

Saiz yang optimal dan masalah peruntukan penjanaan yang diedarkan adalah berdasarkan pengurangan kehilangan kuasa aktif dan baik pulih profil voltan. Skopnya melibatkan formulasi aliran beban deterministik untuk mendapatkan parameter sistem kuasa penting dari peruntukan penjanaan edaran optimum . Aliran beban dilaksanakan menggunakan kaedah Newton-Raphson. Sebaliknya,untuk menguji had operasi rangkaian apabila ketidaktentuan penjanaan photovoltaic dan permintaan beban dimasukkan,kebarangkalian aliran beban disimulasikan dengan kaedah Monte Carlo Simulation . Fungsi kebarangkalian ketumpatan beta telah digunakan untuk model penjanaan photovoltaic, manakala fungsi kebarangkalian ketumpatan normal digunakan untuk model permintaan beban. Keberkesanan topologi yang dicadangkan adalah sahih dalam rangkaian distribusi IEEE 33 dan 69-bas. Kaedah pengoptimuman berasaskan biogeografi telah digubal untuk menyelesaikan masalah peruntukan optimum, lalu kaedah manual telah digunakan untuk menampung unit pusat . penampungan manual unit pusat bersaiz optimum lebih dipilih untuk digunakan , dimana ia mengeluarkan percanggahan-percanggahan yang membandingkan dua pengoptimuman metodologi peruntukan berbeza.

Kaedah pengoptimuman berdasarkan biogeografi telah terbukti untuk mempunyai prestasi yang lebih baik berbanding koloni lebah buatan ,algoritma genetik, pengoptimuman kawanan zarah,kacukan pengoptimuman kawanan zarah dan pendekatan faktor penyempitan, dan kacukan pengoptimuman koloni semut dan kaedah koloni lebah tiruan dari segi pengurangan kehilangan kuasa aktif.Sementara itu , unit topologi penjanaan edaran pusat terbukti mempunyai prestasi yang lebih baik berbanding topologi penjanaan edaran khas yang didedikasikan oleh bas dan hasilnya menunjukkan pengurangan kehilangan daya aktif 6.25% dan 14.7% lebih tinggi dalam topologi pusat IEEE 33 dan 69 rangkaian pengedaran bas. Profil voltan , kapasiti penjanaan distribusi yang diperlukan, dan had penembusan telah menunjukkan hasil yang lebih baik pada topologi penjanaan distribusi pusat lebih daripada topologi penjanaan pengedaran bas. Tambahan pula, had probabilistik pada pengurangan kehilangan kuasa minimum, min, dan maksimum, tahap penembusan, dan profil voltan telah menunjukkan prestasi yang lebih baik dalam topologi penjanaan pusat yang diedarkan.

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04-02-2021.

This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Master of Science. The members of the Supervisory Committee were as follows:

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This is to confirm that:

- the research conducted and the writing of this thesis was under our supervision;
- supervision responsibilities as stated in the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) are adhered to.

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LIST OF ABBREVIATIONS

ABC	Artificial Bee Colony
ACO-ABC	Hybrid of Ant Colony Optimization and Artificial Bee Colony Algorithm
ALOA	Ant Lion Optimization Algorithm
BBO	Biogeography Based Optimization
CDF	Cumulative Distribution Functions
CPVDG	Central Photovoltaic Distributed Generation
DG	Distributed Generation
DLF	Deterministic Load Flow
GA	Genetic Algorithm
HIS	Habitat Suitability Index
IRENA	International Renewable Energy Agency
MCS	Monte Carlo Simulation
MTLBO	Modified Teaching-Learning Based Optimization
PDF	Probability Density Function
PLF	Probabilistic Load Flow
PSO	Particle Swarm Optimization
PSO–CFA	Particle Swarm Optimization and Constriction Factor Approach
PV	Photovoltaic
PVDG	Photovoltaic Distributed Generation
RES	Renewable Energy Sources
SCCC	Short Circuit Current Capacity
SIV	Suitability Index Variables
SKHA	Stud Krill Herd Algorithm
WT	Wind Turbine

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CHAPTER 1

INTRODUCTION

1.1 Research Background

The major role of electric power system is to provide reliable electric power supply to meet customer demand. This supply shall be within specific operational limits in an economical and technical manner. The major functional stages in electric power system are power generation stage, power transmission stage, and distribution stage [1]. Recently, distributed generation (DG) has become one of the major electric power system stages. Defining the DG by the context of its location, DG is defined as electric power generation units installed and operate directly at the distribution network stage, or installed at the network on the side of load centres where the network X/R ratio is lower than the transmission stage [2]. The impacts of DG utilization can be analysed from several aspects such as, DG rating, purpose, power delivery area, DG technology, environmental impact, mode of operation and penetration level [2].

The advantages of utilizing distributed generations in power systems include economic, environmental, and technical benefits [3]. More importantly, the need for additional power plants and transmission lines are reduced, DG units are easier to assign, unlike huge generation plants. DG units can produce electricity with high efficiency, reliability, and lower transmission losses [3]. The optimum utilization of DG units offers potential benefits to the electric systems which include network reliability, reduce peak loads, voltage support, and improve power quality [4]. Improper utilization of DG units in distribution networks could lead to frequency variations, raise system power losses, voltage deviation, and altering the fault current value [4].

1.2 Problem Statement

The optimal allocation of DG units is analyzed from several perspectives which involve DG rating, purpose, power delivery area, DG technology, environmental impact, mode of operation, and penetration level [1]. The potentials of renewable energy sources (RES) are categorized based on; theoretical, geographic, technical, and economic potentials [5]. The geographic potentials are related to the implementation area, which shall be usable, sufficient, and stable to host the RES, particularly photovoltaic (PV) solar plants are restricted with legal and technical constraints [6]. The geographic potentials assessment outcomes are directly proportional with the technical and economic potentials [7]. Although the earlier research contributions of finding the optimal size and locations of DG units have developed a comprehensive objective functions using sophisticated

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methodologies, however all the contributions are based on singular topology [8,9,10]. This topology has become the conventional scientific topology, which integrates the optimal size of DG units directly to the optimum location as bus dedicated DG topology [10]. Meanwhile, the distribution network operators are practicing various topologies to incorporate RES into the distribution networks [11,12]. For instance, due to the required space restrictions of photovoltaic distributed generation (PVDG), distribution network operators are consolidating the optimum sizes at central location, then transfer the power to various multiple locations [11]. Therefore, scientific research community lacks a fundamental evidence that directly compares the conventional bus dedicated topology versus the central DG topology on a typical distribution network using typical methodology.

On the other hand, the penetration level of DG units incorporated into distribution networks affect the system operational limits in a technical and economic manners [13]. The definition of penetration level of DG units in distribution networks varies widely among researchers [13], few of whom have considered it based on transformer capacity, which is more relevant to power flows in or out of the network during operation [14]. Some have defined it as the ratio of DG peak capacity to the peak load consumption, which determined using deterministic values [15]. Others have considered the penetration at a certain point of time as ratio of DG output to the actual power consumption, which needs real time monitoring [16]. However, the penetration limit in distribution networks is described as the point where the distribution network has no more optimally host the DG capacities, whereas the penetration level is the ratio of the DG injected power into the network to the network load amount [17]. Thus, at the planning stage, the penetration limit is ordinarily determined using probabilistic simulations to test the system's operational boundaries [18].

Consequently, the earlier contributions of DG optimal allocations have investigated the DG allocation directly next to the optimum location as bus dedicated DG topology [10], while distribution network operators are practicing various topologies to align the potentials of RES [11,12]. In addition, the applied topology affects the associated penetration level of the distribution network, which is reflected on the system operational limits [13]. Hence, the study proposes a new aspect of comparison by implementing different topologies to incorporate DG units into distribution networks. The central DG unit topology is proposed to distribute the consolidated optimum sizes to the optimum locations, while the penetration limit of the proposed topology is to be compared with the conventional bus dedicated topology.

1.3 Objectives of the Study

The main objective of the study is to analyse the impact of applying central DG topology into the distribution networks in terms of active power loss reduction, and voltage profiles improvement. The specific objectives are:

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i. To formulate the objective function of determining the optimal size and location of central DG unit into the distribution networks based on active power loss reduction and voltage profiles improvement using biogeography based optimization method.

ii. To compare the deterministic impact of utilizing central DG topology and bus dedicated DG topology on distribution networks, in terms of active power loss reduction and voltage profiles improvement.

iii. To determine the probabilistic penetration limit of the central DG topology and bus dedicated DG topology when load demand and solar generation uncertainties are considered.

1.4 Scope of the Study

The scope of the study work is given in the following:

i. The study focuses in the evaluation of the effectiveness of the proposed central DG topology in comparison with the results obtained from bus dedicated DG topology.

ii. Cost, installation, and efficiency of PVDG modules are not considered in this research.

iii. Technical aspects of PVDG power plant and quality of PV power before inverter is not the subject of this study.

iii. Evaluation of the short-term prediction horizon less than one hour is not considered in this research.

1.5 Thesis Organization

Chapter 1, introduces an overview of the research background as fundamentals of DG roles in power systems. The problem statement has been presented by clarifying the relation of penetration level with the associated DG topology. The objectives and scope of this research are proposed in this chapter.

Chapter 2, presents a review of DG applications in power systems. As well as, it covers the latest conventional optimization techniques of finding the optimal size and location of DG units in distribution networks.

Chapter 3, discusses the approaches employed in this work such as the load flow analysis using Newton-Raphson method, the use of biogeography based optimization to find optimal size and locations of DG units, and the uncertainty modeling of load demand and renewable power generation using probability density functions.

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Chapter 4, presents and discusses the results obtained from the specified topologies on 33 and 69 bus IEEE test distribution networks.

Chapter 5, is the final chapter that concluding the findings and discussions of the research objectives.

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APPENDICES

APPENDIX-A

IEEE 33-bus radial distribution network [66]

Table A-1: Bus Data of IEEE 33-bus radial distribution network

Bus No.	From	To	R (ohms)	X (ohms)	Nominal load		Cable Length (m)
					P (kW)	Q(kVAr)	
1	1	2	0.0922	0.0470	0	0	100
2	2	3	0.4930	0.2511	100	60	500
3	3	4	0.3660	0.1864	90	40	350
4	4	5	0.3811	0.1941	120	80	350
5	5	6	0.8190	0.7070	60	30	800
6	6	7	0.1872	0.6188	60	20	200
7	7	8	0.7114	0.2351	200	100	700
8	8	9	1.0300	0.7400	200	100	1000
9	9	10	1.0440	0.7400	60	20	1000
10	10	11	0.1966	0.0650	60	20	200
11	11	12	0.3744	0.1298	45	30	350
12	12	13	1.4680	1.1550	60	35	1500
13	13	14	0.5416	0.7129	60	35	550
14	14	15	0.5910	0.5260	120	80	600
15	15	16	0.7463	0.5450	60	10	750
16	16	17	1.2890	1.7210	60	20	1300
17	17	18	0.7320	0.5740	60	20	700
18	2	19	0.1640	0.1565	90	40	150
19	19	20	1.5042	1.3554	90	40	1500
20	20	21	0.4095	0.4784	90	40	400
21	21	22	0.7089	0.9373	90	40	700
22	3	23	0.4512	0.3083	90	40	450
23	23	24	0.8980	0.7091	90	50	900
24	24	25	0.8960	0.7011	420	200	900
25	6	26	0.2030	0.1034	420	200	200
26	26	27	0.2842	0.1447	60	25	300
27	27	28	1.0590	0.9337	60	25	1000
28	28	29	0.8042	0.7006	60	20	800
29	29	30	0.5075	0.2585	120	70	500
30	30	31	0.9744	0.9630	200	600	950
31	31	32	0.3105	0.3619	150	70	300
32	32	33	0.3410	0.5302	210	100	350
33	0	0	0	0	60	40	0

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APPENDIX-B

IEEE 69-bus radial distribution network [67]

Table B-1: Bus Data of IEEE 69-bus radial distribution network.

Bus No.	From	To	Resistance (ohms)	Reactance (ohms)	Nominal load P (kW)	Nominal load Q (kVAr)	Cable Length(m)
1	1	2	0.0005	0.0012	0	0	800
2	2	3	0.0005	0.0012	0	0	700
3	3	4	0.0015	0.0036	0	0	600
4	4	5	0.0251	0.0294	0	0	700
5	5	6	0.3660	0.1864	0	0	600
6	6	7	0.3811	0.1941	2.6	2.2	600
7	7	8	0.0922	0.0470	40.4	30	600
8	8	9	0.0493	0.0251	75	54	800
9	9	10	0.8190	0.2707	30	22	600
10	10	11	0.1872	0.0619	28	19	800
11	11	12	0.7114	0.2351	145	104	800
12	12	13	1.0300	0.3400	145	104	700
13	13	14	1.0440	0.3450	8	5	700
14	14	15	1.0580	0.3496	8	5.5	600
15	15	16	0.1966	0.0650	0	0	800
16	16	17	0.3744	0.1238	45.5	30	600
17	17	18	0.0047	0.0016	60	35	600
18	18	19	0.3276	0.1083	60	35	700
19	19	20	0.2106	0.0690	0	0	600
20	20	21	0.3416	0.1129	1	0.6	700
21	21	22	0.0140	0.0046	114	81	600
22	22	23	0.1591	0.0526	5	3.5	800
23	23	24	0.3463	0.1145	0	0	600
24	24	25	0.7488	0.2475	28	20	600
25	25	26	0.3089	0.1021	0	0	800
26	26	27	0.1732	0.0572	14	10	700
27	3	28	0.0044	0.0108	14	10	600
28	28	29	0.0640	0.1565	26	18.6	600
29	29	30	0.3978	0.1315	26	18.6	800
30	30	31	0.0702	0.0232	0	0	700
31	31	32	0.3510	0.1160	0	0	700
32	32	33	0.8390	0.2816	0	0	700
33	33	34	1.7080	0.5646	14	10	600

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34	34	35	1.4740	0.4873	9.5	14	800
35	3	36	0.0044	0.0108	6	4	600
36	36	37	0.0640	0.1565	26	18.55	700
37	37	38	0.1053	0.1230	26	18.55	600
38	38	39	0.0304	0.0355	0	0	700
39	39	40	0.0018	0.0021	24	17	800
40	40	41	0.7283	0.8509	24	17	800
41	41	42	0.3100	0.3623	1.2	1	600
42	42	43	0.0410	0.0478	0	0	800
43	43	44	0.0092	0.0116	6	4.3	700
44	44	45	0.1089	0.1373	0	0	800
45	45	46	0.0009	0.0012	39.22	26.3	600
46	4	47	0.0034	0.0084	39.22	26.3	600
47	47	48	0.0851	0.2083	0	0	700
48	48	49	0.2898	0.7091	79	56.4	600
49	49	50	0.0822	0.2011	384.7	274.5	800
50	8	51	0.0928	0.0473	384.7	274.5	800
51	51	52	0.3319	0.1114	40.5	28.3	600
52	52	53	0.1740	0.0886	3.6	2.7	800
53	53	54	0.2030	0.1034	4.35	3.5	800
54	54	55	0.2842	0.1447	26.4	19	700
55	55	56	0.2813	0.1433	24	17.2	600
56	56	57	1.5900	0.5337	0	0	800
57	57	58	0.7837	0.2630	0	0	600
58	58	59	0.3042	0.1006	0	0	800
59	59	60	0.3861	0.1172	100	72	700
60	60	61	0.5075	0.2585	0	0	600
61	61	62	0.0974	0.0496	1244	888	800
62	62	63	0.1450	0.0738	32	23	600
63	63	64	0.7105	0.3619	0	0	600
64	64	65	1.0410	0.5302	227	162	700
65	11	66	0.2012	0.0611	59	42	700
66	66	67	0.0047	0.0014	18	13	600
67	12	68	0.7394	0.2444	18	13	600
68	68	69	0.0047	0.0016	28	20	700
69	0	0	0	0	28	20	0

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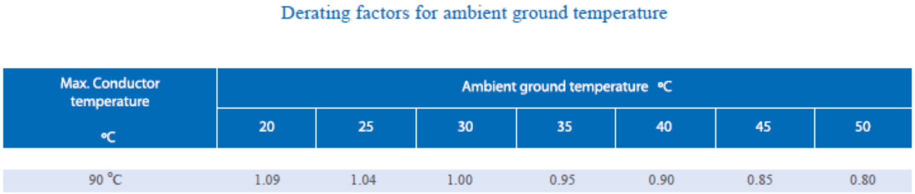
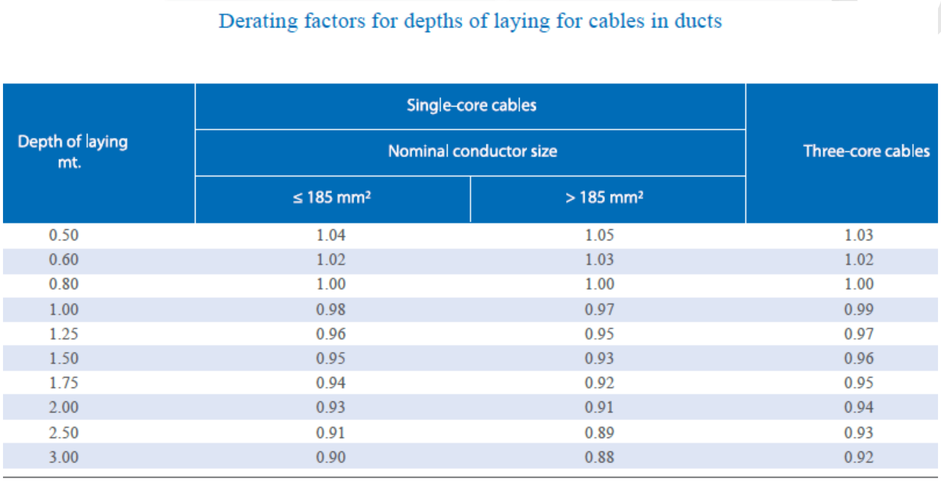
APPENDIX-C

IEC 60287 Cable Derating Factors From Supplier Catalogue [70]



Derating factors for ambient ground temperature

Max. Conductor temperature °C	Ambient ground temperature °C						
	20	25	30	35	40	45	50
90 °C	1.09	1.04	1.00	0.95	0.90	0.85	0.80

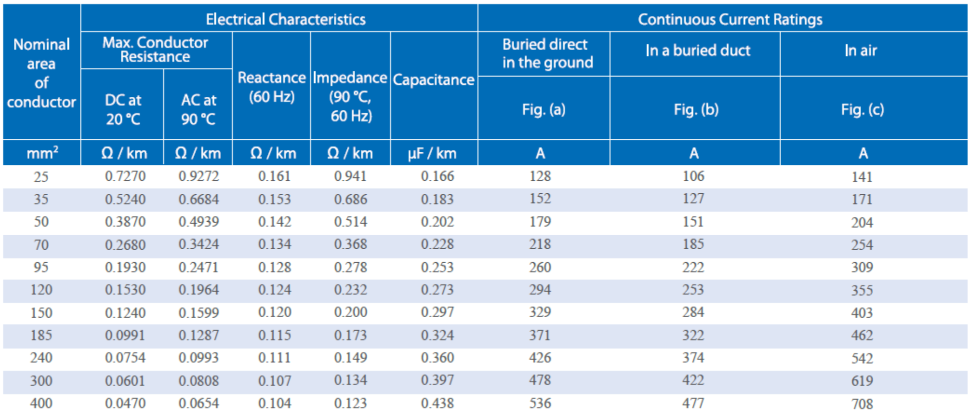


Derating factors for depths of laying for cables in ducts

Depth of laying mt.	Single-core cables		Three-core cables
	Nominal conductor size		
	≤ 185 mm²	> 185 mm²	
0.50	1.04	1.05	1.03
0.60	1.02	1.03	1.02
0.80	1.00	1.00	1.00
1.00	0.98	0.97	0.99
1.25	0.96	0.95	0.97
1.50	0.95	0.93	0.96
1.75	0.94	0.92	0.95
2.00	0.93	0.91	0.94
2.50	0.91	0.89	0.93
3.00	0.90	0.88	0.92

APPENDIX-D

Cables Electrical Data From Supplier Data Sheet [70]



Nominal area of conductor	Electrical Characteristics					Continuous Current Ratings		
	Max. Conductor Resistance		Reactance (60 Hz)	Impedance (90 °C, 60 Hz)	Capacitance	Buried direct in the ground	In a buried duct	In air
	DC at 20 °C	AC at 90 °C				Fig. (a)	Fig. (b)	Fig. (c)
mm²	Ω / km	Ω / km	Ω / km	Ω / km	µF / km	A	A	A
25	0.7270	0.9272	0.161	0.941	0.166	128	106	141
35	0.5240	0.6684	0.153	0.686	0.183	152	127	171
50	0.3870	0.4939	0.142	0.514	0.202	179	151	204
70	0.2680	0.3424	0.134	0.368	0.228	218	185	254
95	0.1930	0.2471	0.128	0.278	0.253	260	222	309
120	0.1530	0.1964	0.124	0.232	0.273	294	253	355
150	0.1240	0.1599	0.120	0.200	0.297	329	284	403
185	0.0991	0.1287	0.115	0.173	0.324	371	322	462
240	0.0754	0.0993	0.111	0.149	0.360	426	374	542
300	0.0601	0.0808	0.107	0.134	0.397	478	422	619
400	0.0470	0.0654	0.104	0.123	0.438	536	477	708

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APPENDIX-F

MATLAB Coding

- **Admittance Matrix**

```
%  This program obtains th Bus Admittance Matrix for
power flow solution
j=sqrt(-1); i = sqrt(-1);
nl = linedata(:,1); nr = linedata(:,2); R =
linedata(:,3);
X = linedata(:,4); Bc = j*linedata(:,5); a =
linedata(:, 6);
nbr=length(linedata(:,1)); nbus = max(max(nl),
max(nr));
basemva=100;
KVb=12.66;
Zb=(KVb^2)/basemva;
Zo = R + j*X;
Z=Zo./Zb;
y= ones(nbr,1)./Z;
for n = 1:nbr
if a(n) <= 0  a(n) = 1; else end
Ybus=zeros(nbus,nbus);     % initialize Ybus to zero
               % formation of the off diagonal elements
for k=1:nbr;
       Ybus(nl(k),nr(k))=Ybus(nl(k),nr(k))-y(k)/a(k);
       Ybus(nr(k),nl(k))=Ybus(nl(k),nr(k));
    end
end
              % formation of the diagonal elements
for  n=1:nbus
     for k=1:nbr
         if nl(k)==n
         Ybus(n,n) = Ybus(n,n)+y(k)/(a(k)^2) + Bc(k);
         elseif nr(k)==n
         Ybus(n,n) = Ybus(n,n)+y(k) +Bc(k);
         else, end
     end
end
clear Pgg
Ybus;
```

- **Newton Raphson**

```
%   Power flow solution by Newton-Raphson method
accuracy=0.000001;
basemva=100000;
maxiter=100;
ns=0; ng=0; Vm=0; delta=0; yload=0; deltad=0;
nbus = length(busdata(:,1));
```

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```
for k=1:nbus
n=busdata(k,1);
kb(n)=busdata(k,2); Vm(n)=busdata(k,3);
delta(n)=busdata(k, 4);
Pd(n)=busdata(k,5); Qd(n)=busdata(k,6);
Pg(n)=busdata(k,7); Qg(n) = busdata(k,8);
Qmin(n)=busdata(k, 9); Qmax(n)=busdata(k, 10);
Qsh(n)=busdata(k, 11);
    if Vm(n) <= 0  Vm(n) = 1.0; V(n) = 1 + j*0;
    else delta(n) = pi/180*delta(n);
         V(n) = Vm(n)*(cos(delta(n)) +
j*sin(delta(n)));
         P(n)=(Pg(n)-Pd(n))/basemva;
         Q(n)=(Qg(n)-Qd(n)+ Qsh(n))/basemva;
         S(n) = P(n) + j*Q(n);
    end
end
for k=1:nbus
if kb(k) == 1, ns = ns+1; else, end
if kb(k) == 2 ng = ng+1; else, end
ngs(k) = ng;
nss(k) = ns;
end
Ym=abs(Ybus); t = angle(Ybus);
m=2*nbus-ng-2*ns;
maxerror = 1; converge=1;
iter = 0;
% Start of iterations
clear A  DC   J  DX
while maxerror >= accuracy & iter <= maxiter % Test for
max. power mismatch
for i=1:m
for k=1:m
   A(i,k)=0;      %Initializing Jacobian matrix
end, end
iter = iter+1;
for n=1:nbus
nn=n-nss(n);
lm=nbus+n-ngs(n)-nss(n)-ns;
J11=0; J22=0; J33=0; J44=0;
   for i=1:nbr
     if nl(i) == n | nr(i) == n
        if nl(i) == n,  l = nr(i); end
        if nr(i) == n,  l = nl(i); end
        J11=J11+ Vm(n)*Vm(l)*Ym(n,l)*sin(t(n,l)-
delta(n) + delta(l));
        J33=J33+ Vm(n)*Vm(l)*Ym(n,l)*cos(t(n,l)-
delta(n) + delta(l));
        if kb(n)~=1
        J22=J22+ Vm(l)*Ym(n,l)*cos(t(n,l)- delta(n) +
delta(l));
```

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```
        J44=J44+ Vm(l)*Ym(n,l)*sin(t(n,l)- delta(n) +
delta(l));
        else, end
        if kb(n) ~= 1  & kb(l) ~=1
        lk = nbus+l-ngs(l)-nss(l)-ns;
        ll = l -nss(l);
      % off diagonalelements of J1
        A(nn, ll) =-Vm(n)*Vm(l)*Ym(n,l)*sin(t(n,l)-
delta(n) + delta(l));
              if kb(l) == 0  % off diagonal elements of
J2
              A(nn, lk) =Vm(n)*Ym(n,l)*cos(t(n,l)-
delta(n) + delta(l));end
              if kb(n) == 0  % off diagonal elements of
J3
              A(lm, ll) =-
Vm(n)*Vm(l)*Ym(n,l)*cos(t(n,l)- delta(n)+delta(l)); end
              if kb(n) == 0 & kb(l) == 0  % off
diagonal elements of  J4
              A(lm, lk) =-Vm(n)*Ym(n,l)*sin(t(n,l)-
delta(n) + delta(l));end
        else end
     else , end
   end
   Pk = Vm(n)^2*Ym(n,n)*cos(t(n,n))+J33;
   Qk = -Vm(n)^2*Ym(n,n)*sin(t(n,n))-J11;
   if kb(n) == 1 P(n)=Pk; Q(n) = Qk; end   % Swing bus
P
     if kb(n) == 2  Q(n)=Qk;
         if Qmax(n) ~= 0
           Qgc = Q(n)*basemva + Qd(n) - Qsh(n);
           if iter <= 7                  % Between the
2th & 6th iterations
              if iter > 2                % the Mvar of
generator buses are
                if Qgc  < Qmin(n),       % tested. If
not within limits Vm(n)
                Vm(n) = Vm(n) + 0.01;    % is changed
in steps of 0.01 pu to
                elseif Qgc  > Qmax(n),   % bring the
generator Mvar within
                Vm(n) = Vm(n) - 0.01;end % the
specified limits.
              else, end
           else,end
         else,end
     end
   if kb(n) ~= 1
     A(nn,nn) = J11;  %diagonal elements of J1
     DC(nn) = P(n)-Pk;
   end
```

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```
   if kb(n) == 0
     A(nn,lm) = 2*Vm(n)*Ym(n,n)*cos(t(n,n))+J22;
%diagonal elements of J2
     A(lm,nn)= J33;        %diagonal elements of J3
     A(lm,lm) =-2*Vm(n)*Ym(n,n)*sin(t(n,n))-J44;
%diagonal of elements of J4
     DC(lm) = Q(n)-Qk;
   end
end
DX=A\DC';
for n=1:nbus
  nn=n-nss(n);
  lm=nbus+n-ngs(n)-nss(n)-ns;
    if kb(n) ~= 1
    delta(n) = delta(n)+DX(nn); end
    if kb(n) == 0
    Vm(n)=Vm(n)+DX(lm); end
 end
  maxerror=max(abs(DC));
     if iter == maxiter & maxerror > accuracy
   fprintf('\nWARNING: Iterative solution did not
converged after ')
   fprintf('%g', iter), fprintf(' iterations.\n\n')
   fprintf('Press Enter to terminate the iterations and
print the results \n')
   converge = 0; pause, else, end

end
```

-

- **Biogeography Based Optimization**

```
% Project Title: Biogeography-Based Optimization (BBO) in
MATLAB
clc;
clear;
close all;

%% Problem Definition

CostFunction=@(OPT) CalculationFunction4(OPT);        %
Cost Function

nVar=8;                % Number of Decision Variables

nVarsize=nVar/2;

VarSize=[1 nVarsize];    % Decision Variables Matrix Size

VarMin=0;              % Decision Variables Lower Bound
VarMax= 2000;            % Decision Variables Upper Bound
```

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```
LocMin=2;
LocMax=33;
%% BBO Parameters

MaxIt=100;          % Maximum Number of Iterations

nPop=50;            % Number of Habitats (Population Size)

KeepRate=0.2;                   % Keep Rate
nKeep=round(KeepRate*nPop);     % Number of Kept Habitats

nNew=nPop-nKeep;                % Number of New Habitats

% Migration Rates
mu=linspace(1,0,nPop);          % Emmigration Rates
lambda=1-mu;                    % Immigration Rates

alpha=0.9;

pMutation=0.1;

sigma1=0.02*(VarMax-VarMin);
sigma2=0.02*(LocMax-LocMin);

%% Initialization

% Empty Habitat
habitat.Position=[];
habitat.Cost=[];

% Create Habitats Array
pop=repmat(habitat,nPop,1);

% Initialize Habitats
for i=1:nPop

pop(i).Position=[(unifrnd(VarMin,VarMax,VarSize)),(randi([
LocMin,LocMax],VarSize))];
    pop(i).Cost=CostFunction(pop(i).Position);
end

% Sort Population
[~, SortOrder]=sort([pop.Cost]);
pop=pop(SortOrder);

% Best Solution Ever Found
BestSol=pop(1);

% Array to Hold Best Costs
BestCost=zeros(MaxIt,1);
```

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```
%% BBO Main Loop

for it=1:MaxIt

    newpop=pop;
    for i=1:nPop
        for k=1:nVar
            % Migration
            if rand<=lambda(i)
                % Emmigration Probabilities
                EP=mu;
                EP(i)=0;
                EP=EP/sum(EP);

                % Select Source Habitat
                j=RouletteWheelSelection4(EP);
                % Migration
                if k>4

newpop(i).Position(k)=round(pop(i).Position(k)+alpha*(pop(
j).Position(k)-pop(i).Position(k)));
                elseif k<=4

newpop(i).Position(k)=pop(i).Position(k)+alpha*(pop(j).Pos
ition(k)-pop(i).Position(k));
                end

            end

            % Mutation
            if rand<=pMutation
                if k>4

newpop(i).Position(k)=newpop(i).Position(k)+sigma2*randn;
                elseif k<=4

newpop(i).Position(k)=newpop(i).Position(k)+sigma1*randn;
                end
            end
        end

        % Apply Lower and Upper Bound Limits
        newpop(i).Position([1 2 3 4]) =
max(newpop(i).Position([1 2 3 4]), VarMin);
        newpop(i).Position([1 2 3 4]) =
min(newpop(i).Position([1 2 3 4]), VarMax);
        newpop(i).Position([5 6 7 8]) =
round(newpop(i).Position([5 6 7 8]));

        % Evaluation
        newpop(i).Cost=CostFunction(newpop(i).Position);
```

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```
        end
        
        % Sort New Population
        [~, SortOrder]=sort([newpop.Cost]);
        newpop=newpop(SortOrder);
        
        % Select Next Iteration Population
        pop=[pop(1:nKeep)
             newpop(1:nNew)];
        
        % Sort Population
        [~, SortOrder]=sort([pop.Cost]);
        pop=pop(SortOrder);
        
        % Update Best Solution Ever Found
        BestSol=pop(1);
        
        % Store Best Cost Ever Found
        BestCost(it)=BestSol.Cost;
        
        % Show Iteration Information
       % disp(['Iteration ' num2str(it) ': Best Cost = '
num2str(BestCost(it))]);
    
    end
```

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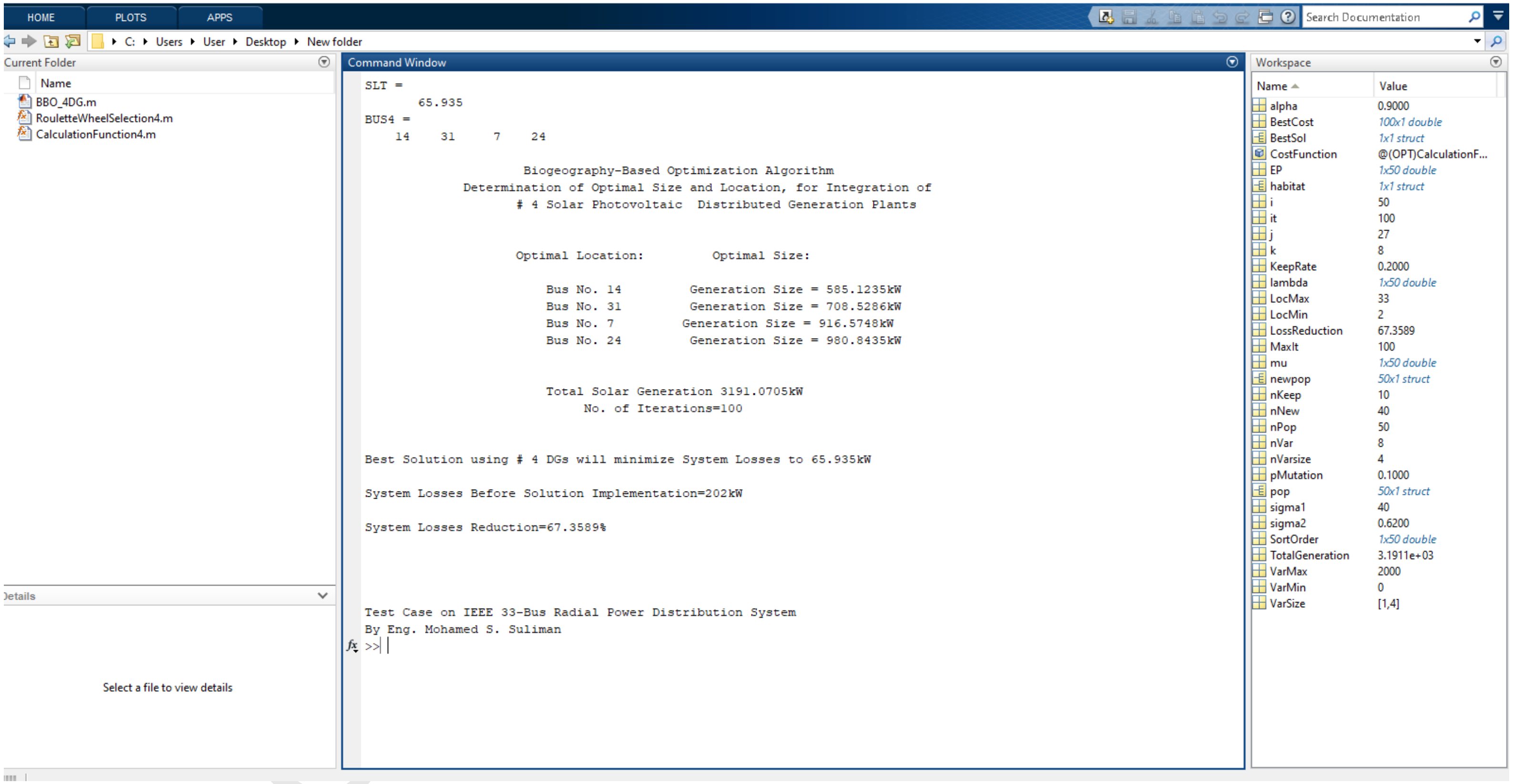
APPENDIX-G

BBO Matlab Output Interface for 4 DG Units



```
SLT =
       65.935
BUS4 =
    14    31     7    24

                     Biogeography-Based Optimization Algorithm
             Determination of Optimal Size and Location, for Integration of
                    # 4 Solar Photovoltaic  Distributed Generation Plants


                    Optimal Location:          Optimal Size:

                        Bus No. 14          Generation Size = 585.1235kW
                        Bus No. 31          Generation Size = 708.5286kW
                        Bus No. 7          Generation Size = 916.5748kW
                        Bus No. 24          Generation Size = 980.8435kW


                        Total Solar Generation 3191.0705kW
                             No. of Iterations=100


Best Solution using # 4 DGs will minimize System Losses to 65.935kW

System Losses Before Solution Implementation=202kW

System Losses Reduction=67.3589%




Test Case on IEEE 33-Bus Radial Power Distribution System
By Eng. Mohamed S. Suliman
>>
```

Name	Value
alpha	0.9000
BestCost	100x1 double
BestSol	1x1 struct
CostFunction	@(OPT)CalculationF...
EP	1x50 double
habitat	1x1 struct
i	50
it	100
j	27
k	8
KeepRate	0.2000
lambda	1x50 double
LocMax	33
LocMin	2
LossReduction	67.3589
MaxIt	100
mu	1x50 double
newpop	50x1 struct
nKeep	10
nNew	40
nPop	50
nVar	8
nVarsize	4
pMutation	0.1000
pop	50x1 struct
sigma1	40
sigma2	0.6200
SortOrder	1x50 double
TotalGeneration	3.1911e+03
VarMax	2000
VarMin	0
VarSize	[1,4]

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BIODATA OF STUDENT

Mohamed Saad Suliman was born 1988 in Sudan. In 2015 he received his B.Sc in Electrical and Electronic Engineering from Management and Science University, Selangor, Malaysia. He worked as an Electrical Design Engineer at Alfanar Electrical Systems from 2015 to 2019, Riyadh, Saudi Arabia. His area of expertise is power distribution networks in terms of protection schemes coordination, switchgears design, and network analysis. He is currently M.Sc candidate in Electrical Power Engineering at Universiti Putra Malaysia. His research interests are power system optimization, distributed generation, renewable energy optimal utilization, and artificial intelligence applications.

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PUBLICATION

[1] Suliman, Mohamed Saad; Hizam, Hashim; Othman, Mohammad Lutfi: "Determining penetration limit of central PVDG topology considering the stochastic behaviour of PV generation and loads to reduce power losses and improve voltage profiles", 2020, IET Renewable Power Generation, 14, (14), p. 2629-2638.

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