J. Electrical Systems 20-7s (2024): 3916-3932

[1]*Ramesh
[2]Mohd. Khursheed
[3]Bindeshwar Singh

Optimal Integration of DGs in Distribution Networks using Realistic Load Models with Hybrid MC-GA Technique

Abstract: - As per conventional demand pattern, there is a daily rise in the need for power consumption. Therefore, producing large amounts of power is important, or losses should be kept to a minimum. This paper presents optimal performance index-based size and location determination of Distributed Generations (DGs) with realistic load models (RLMs) such as RLM-1, RLM-2, RLM-3, RLM-4 and RLM-5 respectively in distribution networks from minimization of real and reactive power losses of the system viewpoint. In this analysis, enhancement of system power factor (SPF) taken as power system performances without and with various types of DGs for different RLMs. The proposed technique for simulation is based on hybrid Monte Carlo-Genetic Algorithm (MC-GA). 16-bus and 37-bus distribution system networks have been carried out to test the proposed methodology. Through comprehensive simulations on a test distribution network, the effectiveness of the proposed approach is demonstrated. Results highlight its potential to optimize the system's performance in terms of reliability, efficiency, and grid stability. This paper contributes to the advancement of optimal DG strategies, emphasizing the importance of addressing realistic load scenarios using a hybrid MC-GA technique.

Keywords: Distributed Generations, Location and size, Monte Carlo-Genetic Algorithm Simulation, Realistic Load Models, Distribution Systems.

I. INTRODUCTION

The ongoing transformation of modern power systems is driven by the integration of DGs presenting a substantial opportunity to enhance system efficiency, reliability, and environmental sustainability. The conventional centralized power generation paradigm is shifting towards a decentralized model, where DGs such as solar photovoltaic (PV) systems, wind turbines, and micro-turbines are seamlessly incorporated into the distribution network. The penertration of DGs brings forth a complex set of challenges. Consequently, optimizing DGs becomes paramount to achieving a resilient and sustainable energy landscape. This paper proposes a novel approach that combines the strengths of the Monte Carlo (MC) simulation method and Genetic Algorithm (GA) optimization technique. This hybrid MC-GA approach is tailored to address the uncertainties inherent in DG by employing probabilistic analysis and evolutionary optimization. In particular, the proposed approach places a strong emphasis on the use of realistic load models, recognizing that accurate load modelling is essential to capture the true operational conditions of the distribution network. The subsequent sections of this paper elaborate on the methodology, incorporating the modelling of DG including various load models. The hybrid MC-GA technique is then detailed, showcasing its ability to effectively address multi-objective optimization problems in the context of DG integration. A comprehensive case study on a test distribution network substantiates the proposed approach's effectiveness in enhancing system performance, reliability, and efficiency. In this research contributes to the growing body of knowledge by presenting a holistic solution for the DGs. By embracing the challenges of realistic load modelling and leveraging the hybrid MC-GA technique, this approach holds the potential to reshape the future of power distribution systems towards a more resilient and sustainable energy landscape.

Jorge *et al.* [1] suggested distributed generating operating mode-aware restoring several faults in a service. The multi-objective optimization to plan DGs using load models was recommended by Singh *et al.* [2]. An ideal scheduling of home appliances using day-ahead pricing and demand response that shapes load algorithms was provided by Paterakis *et al.* [3]. Employing a multi-objective PSO with AA to position and scale DG on distribution systems: a review was recommended by Pooja and Sameena [4]. Gagari *et al.* [5] improved SMO-based DG placement in radial distribution networks was suggested for improving voltage security. Sulaiman *et al.* [6] employing the firefly method, the distribution system optimum DG size and allocation was provided in order to increase system performance. Singh *et al.* [7] focus was on installing EV charging stations powered by solar PV batteries and diesel engines. A multi-objective GA is employed as an optimization method for these problems.

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[1] *Department of Electrical Engineering, Integral University, Lucknow, Uttar Pradesh-226026 (India)
[2] Department of Electrical Engineering, Integral University, Lucknow, Uttar Pradesh-226026 (India)
[3] Department of Electrical Engineering, Kamla Nehru Institute of Technology, Sultanpur, Uttar Pradesh-228118 (India)

Because GA may simultaneously develop several multi-objective solutions, it has lately been recognized as being especially well-suited for multi-objective optimization problems. This approach is utilized in place of an optimization algorithm [8]-[9]. In order to improve system performances, Patel *et al.* [10] addressed a suggested approach for various forms of DGs planning in the distribution system, such as GA-based optimization. A distribution estimate technique based on statistics (Bayesian estimate) is presented for both static and dynamic load models by Li *et al.* [11]. Singh *et al.* [12] suggested utilizing GA to minimize the system's overall real power loss in order to improve the voltage profile in distribution power networks using DG integrated with D-STATCOM and various load models, including constant power, constant current, constant impedance, composite, and reference load models. A review of load modeling and its identification methods is provided by Arif *et al.* [13]. In order to improve system performances, Bokhari *et al.* [14] address the coefficient of ZIP-LMs for DGs planning with load models in distribution systems. Singh and associates [15] GA-based optimization is recommended for the integration of PHEVs, STATCOM, and DGs in distribution networks. GA is used to solve an ODGP that takes dispersed loads, constant power concentrated loads, and variable power concentrated load models into consideration, as explained by Shukla *et al.* [16] and Singh *et al.* [17]. Singh and Goswami developed multi-objective optimization of distributed generation planning utilizing impact indices and trade-off approach, as well as the best distribution of distributed generation units (DGs) based on nodal pricing for profit, loss reduction, and voltage enhancement, including the issue of voltage rise [18]-[19]. A survey on the evaluation of the effects of DG and FACTS controllers in power systems was proposed by Singh *et al.* [20]. From the perspective of the main substation's minimum total MVA intake, a GA was proposed for the effect evaluation of strategically located distributed generation (DGs) with different load models in order to optimize system power performances, including RPL and REPL, environment greenhouse gases, and voltage profile, as indicated by Singh *et al*. [21]. Singh and colleagues [22] developed a GA-based multiobjective optimization approach for distributed generation planning in distribution power systems with DLMs. Joint optimization was proposed by Zhang *et al*. [23] to reduce power loss in distribution systems. A hybrid GA-MCS optimization was presented by Vimlesh *et al.* [24] for DG, DVR, and DSTATCOM planning in distribution systems with ZIP-LMs. Vimlesh *et al.* [25] presented a hybrid GA-MCS optimization for DG and DVR planning in distribution systems with ZIP-LMs. It was recommended that Payasi *et al.* [26] use the DG planning strategy, which uses both conventional and unconventional energy sources to generate electricity. One such source is DG, which delivers high momentum and has a major influence on dispersed networks. Vimlesh *et al.* [27] presented DG planning in distribution networks using hybrid GA-MCS based optimization. Khan *et al.* [28] suggested FACTS controller scheme deployment for improved power system security in an Indian context. According to Siddiqui *et al.* [29], PIDF controller tuning in a parallel control structure is recommended for process integration that includes time delay and inverse response characteristic. A review was suggested for performance-based study of solar PV emulators, Shahabuddin *et al.* [30]. It was suggested by Khursheed *et al.* [31] to tune the controllers for a boost converter that interfaces a battery source to the BTS load of a telecommunication site. It was recommended to use Siddiqui *et al.* [32] to apply the Control of nonlinear jacketed continuous stirred tank reactor with various control schemes.

In these scenario, Challenges are increasing at an accelerated pace with time in distribution networks systems. There is accelerated expansion in DGs penetration. In the midst of them, more focus on DG units that use sporadic sustainable energy sources like solar and wind power. These technology development will represent both the opportunity and the challenges for efficient and effective functioning of the distribution network system. On integrating with DG on a large scale, overloading on the distribution network will be reduced. The interconnection of DGs is not always fruitful and at the same time, few shortcomings which might negatively impact functioning of DG System in terms of security and quality of power of distribution system. DG's potential advantages might also be preserved by reducing or postponing funding in installation of transmission lines, reducing loss due to resistance (ohmic losses), and limited investment in transformers. These practices will be surely prove to be eco-friendly at the same time.

In the course of planning of DGs, consideration is given to the following factors: i) magnitude; ii) geography and place; iii) types/models; and iv) scope of coordination. In my analysis of the literature, it is established that researchers utilised two of the aforementioned characteristics for simulation at a time since there were few RAM processors on the market two decades ago, but that they are currently utilising three parameters at a time because there are more RAM processors on the market. In the future, DGs with EVs analysis will take into account all of the aforementioned elements. The existing input-output and planning parameter connection modelling and optimization methodologies are examined critically in this paper work.

Optimization during DG installation, a critical problem is revealed by a detailed evaluation of these approaches. Planning for DGs; all three possibilities are examined in this work over realistic load models with MC-GA approach in distributed networks system. As high power consumption loads such as DGs are increasing, there are new grid security issues are being faced by the distribution system. Another reason for such security issues arise with the growing DG penetration also.

The remaining portions are set up as follows: *Section 2* discusses the planning of DGs mathematical modelling of the present work. *Section 3* discussed hybrid MC-GA implementation. *Section 4* discusses the simulation and results. Conclusions along with possible future scope of the Article's manifest themselves in *Section 5.*

II. MATHEMATICAL FORMULATION OF DG PLANNING

RLMs [Constant Impedance Current and Power (ZIP)+Induction Motor (IM)] and different types of DGs modelling are presented in sub-sections *A* and *B*.

A. RLMs (ZIP+IM)

Integrating the static and dynamic load models is the main topic of recent research. It was determined that composite models can yield more accurate answers when compared to individual load models with transient disturbances. The most often used model in the US industry for dynamic research is the composite load model, along with RLMs made up of a ZIP code and an induction motor, according to the study in [8]. Numerous composite load models, including ZIP+IM, were taken into consideration in [13]. The study came to the conclusion that loads with a variety of compositions, circumstances, and locations may be modeled using the ZIP+IM structure. Fig.1. Illustrates the ZIP+IM model comparable circuit.

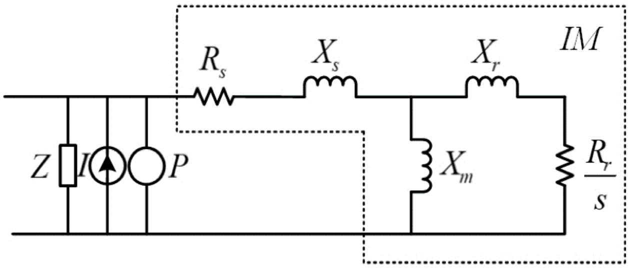

Fig 1. Equivalent circuit of RLMs (ZIP+IM) model

Table 1: RLMs (ZIP+IM) and their behaviours [10 - 13]

RLMs	Appliances(ZIP+IM)	Features/behaviours	Comparisons
RLM1	Incandescent light with IM	Resistive loads consume electrical power in such a manner that the current wave remains in phase with the voltage wave. So p.f. is unity but an inductive loads has lagging p.f.	Dynamic resistive and inductive load
RLM2	Refrigerator with IM	An inductive load causes the current wave to lag the voltage wave. Hence p.f. of an inductive load is lagging.	Highly inductive load
RLM3	Microwave with IM	An inductive load causes the current wave to lag the voltage wave. Hence p.f. of an inductive load is lagging.	Highly inductive load as compared to RLM2
RLM4	Computer with IM	A capacitive load causes the current wave to lead the voltage wave and for inductive load behave opposite to capacitive load.	Low capacitive and inductive load
RLM5	Advanced washing machine with IM	An inductive load causes the current wave to lag the voltage wave. Hence p.f. of an inductive load is lagging.	Highly inductive load as compared to RLM2 and RLM3

Table 2: Active and reactive power coefficients for RLMs (actual cut-off voltages) [24 - 25]

		P		Q						
RLMs	Equipments	V_0	P_0	Q_0	Zp	Ip	Pp	Zq	Iq	Pq
RLM1	Incandescent light with IM	120	3.38	5.85	0.69	0.92	-0.61	1.84	-0.91	0.07
RLM2	Refrigerator with IM	120	119.55	52.47	5.03	-8.48	4.45	17.44	-28.62	12.18

RLM3	Microwave with IM	120	1365.53	451.02	-0.27	1.16	0.11	15.64	-27.74	13.1
RLM4	Computer with IM	120	253	44	0.19	-0.45	1.26	10.18	-18.01	8.83
RLM5	Advanced washing machine with IM	120	855	221	0.92	0.07	0.01	0.91	-0.02	0.11

These various kinds of RLMs exist and might be employed in DG planning to enhance the power system performance parameters such as real power, reactive power losses and improve SPF profile.

B. DG Modelling [26-27]

The DGs are classed as supporting actual and delivered/absorbed reactive power in general.

- DG1 system only accepts real power with a power factor of one. Examples include solar panels, photovoltaics, biogas, etc.
- DG2 system supports both real and reactive power, based on leading power factor of 0.80 to 0.99. Some examples are Tidal, wind, geothermal, wave, etc.
- DG3 system supports Reactive power based on power factor of 0.00. Few examples are, inductor bank, synchronous condenser, capacitors bank etc.
- DG4 having lag power factors ranging from 0.80 to 0.99, It provides the system with active power. and depending on operating conditions, it draws reactive power from the system and either absorbs it or gives it. For instance, wind-powered induction generators that are double fed.

The details these various kinds of DGs are mentioned in Table 3.

Table 3: Different DGs and samples of each

PF ranges	DG model	Power injection capability	Example
Unity	Type 1	Active power only	Fuel cells, microturbines, biogases, and solar photovoltaics *etc.*
0.80 < PF < 0.99, leading	Type 2	Both reactive and active power	Synchronous machines, co-generation, gas turbines, and tidal, geothermal, wind *etc.*
Zero	Type 3	Reactive Power only	Facts controllers, banks of capacitors, inductors, and synchronous condensers, among other components *etc.*
0.80<PF<0.99, lagging	Type 4	Both active and reactive power are used.	Wind power doubly fed induction generators *etc.*

In case of main substation, Total MVA intake without having DGs (S_{WODG}) is provided by equation (1).

$$S_{WODG} = \sqrt{P_i^2 + Q_i^2} \tag{1}$$

In case of main substation, Total MVA intake with different types of DGs (DG1, DG2, DG3 and DG4 respectively) are given in equation (2)-(5):

$$S_{WDG1} = \sqrt{(P_i + P_{DG1})^2 + Q_i^2} \tag{2}$$

$$S_{WDG2} = \sqrt{(P_i + P_{DG2})^2 + \left(Q_i + Q_{DG2}\right)^2} \tag{3}$$

$$S_{WDG3} = \sqrt{P_i^2 + \left(Q_i + Q_{DG3}\right)^2} \tag{4}$$

$$S_{WDG4} = \sqrt{(P_i + P_{DG4})^2 + \left(Q_i \pm Q_{DG4}\right)^2} \tag{5}$$

The SPF without having DGs is provided by equ. (6).

$$SPF_{WODG} = \frac{P_G}{\sqrt{P_G^{\,2} + Q_G^{\,2}}} \tag{6}$$

The SPF with different types of DGs (DG1, DG2, DG3 and DG4 respectively) are given in equation (7)-(10):

$$SPF_{WDG_{LMi}} = \frac{P_G + P_{DG_{LMi}}}{\sqrt{(P_G + P_{DG_{LMi}})^2 + (Q_G \mp Q_{DG_{LMi}})^2}} \tag{7}$$

$$SPF_{WDG_{LMi}} = \frac{P_G + P_{DG_{LMi}}}{\sqrt{(P_G + P_{DG_{LMi}})^2 + (Q_G \mp Q_{DG_{LMi}})^2}} \tag{8}$$

$$SPF_{WDG_{LMi}} = \frac{P_G + P_{DG_{LMi}}}{\sqrt{(P_G + P_{DG_{LMi}})^2 + (Q_G \mp Q_{DG_{LMi}})^2}} \tag{9}$$

$$SPF_{WDG_{LMi}} = \frac{P_G + P_{DG_{LMi}}}{\sqrt{(P_G + P_{DG_{LMi}})^2 + (Q_G \mp Q_{DG_{LMi}})^2}} \tag{10}$$

Where P_G is active power (in MW), Q_G is reactive power (in MVAR), $P_{DG_{LMi}}$ is the real power delivered by DG (in MW), $Q_{DG_{LMi}}$ and is the reactive power delivered by DG (in MVAR) with RLMs. Where i = 1, 2, 3, 4 & 5 for RLMs (RLM1, RLM2, RLM3, RLM4 & RLM5).

Objective function related to Real power loss minimization, represented by $\boldsymbol{P}_{\mathbf{L}}$ in the system, is focused upon minimizing the loss of real power. Mathematical representation using equation is mentioned below (11).

$$P_{Loss} = \frac{{P_{nj\_bus}}^2 + {Q_{nj\_bus}}^2}{\left|V_{n\_bus}\right|^2} r_{nj\_bus} \; for\, n, j \in N \tag{11}$$

The $\boldsymbol{P}_{\mathbf{L}}$ depends on every system bus voltage $\left(V_{i\_bus}\right)$, line resistances $\left(r_{ij\_bus}\right)$.

Objective function related to Reactive power loss minimization represented by QL in the system, is focused upon minimizing the loss of total reactive power. Mathematical representation using equation is mentioned below (12).

$$Q_{Loss} = \frac{{P_{nj\_bus}}^2 + {Q_{nj\_bus}}^2}{\left|V_{n\_bus}\right|^2} x_{nj\_bus} \; for\, n, j \in N \tag{12}$$

The $\boldsymbol{Q}_{\mathbf{L}}$ depends on every system bus voltage. $\left(V_{n\_bus}\right)$, line resistances $\left(x_{nj\_bus}\right)$, and the voltage profile mostly determines the overall loss.

III. IMPLEMENTATION OF HYBRID MC-GA [24 – 27]

Brief overview of the hybrid MC-GA technique and its applicability.

The hybrid MC-GA technique refers to the combination of two optimization methods: Monte Carlo (MC) simulation and Genetic Algorithms (GA). This approach is used to solve complex optimization problems that involve uncertainties and multiple variables, especially in engineering, finance, and various scientific fields.

Genetic Algorithms (GA): Natural selection serves as the model for optimization strategies used in genetic algorithms. They involve the evolution of a population of potential solutions through generations. Solutions are encoded as "chromosomes," and selection, crossover, and mutation are examples of procedures used to simulate the evolutionary process and gradually raise the caliber of solutions. The flowchart for hybrid MC-GA for DG planning and SPF improvement with RLMs from the minimization of the real and reactive power losses viewpoints is shown in Fig. 2.

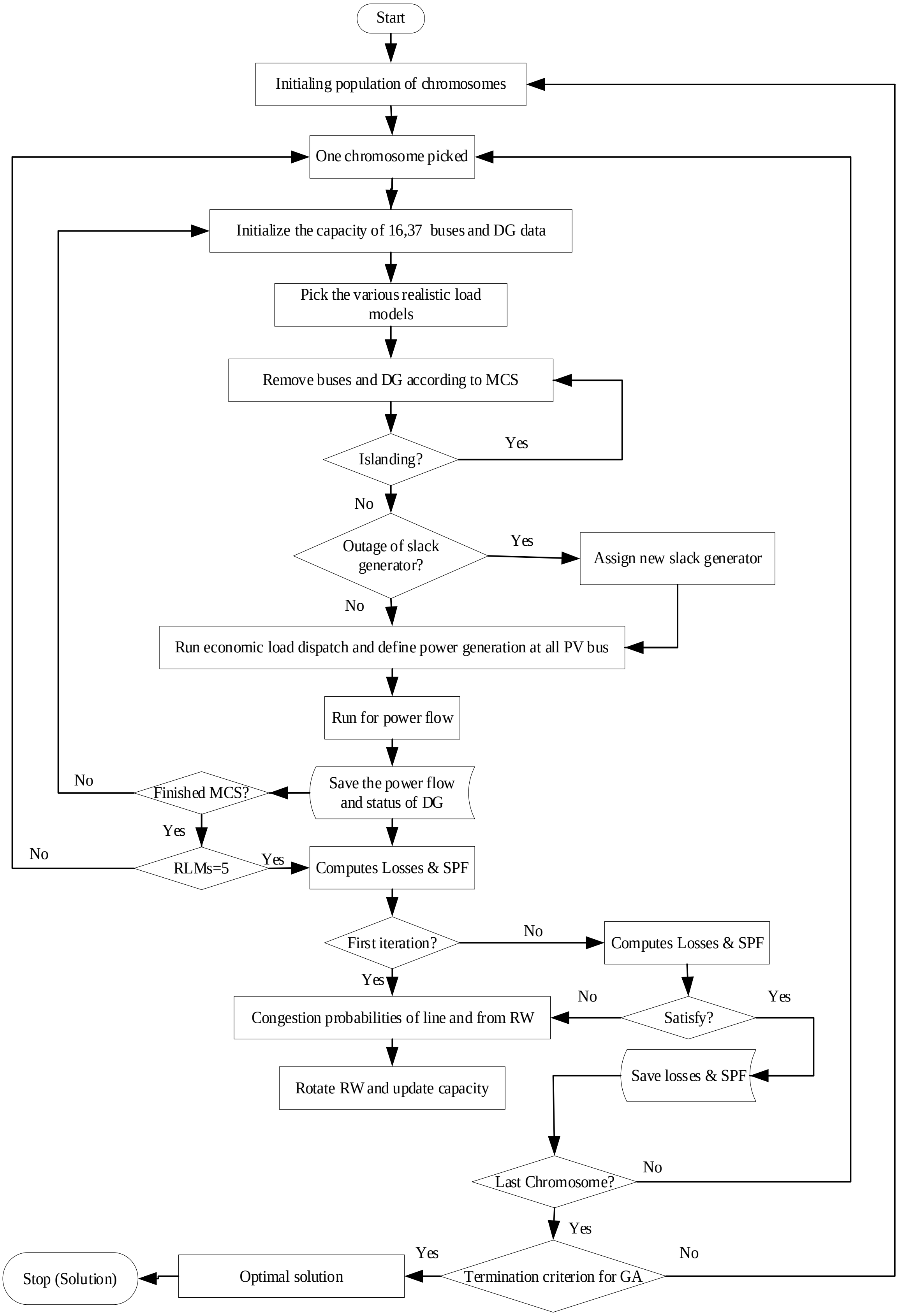

Fig. 2. Suggested optimization flow chart for DG planning and SPF improving with RLMs.

Hybrid MC-GA Technique: The hybrid MC-GA technique combines the strengths of MC simulation and GA optimization to tackle optimization problems that have uncertain parameters. It works as follows:

Initialization: A group of possible fixes (chromosomes) is generated.

Evaluation: Every response is assessed using MC simulation over a range of scenarios, considering the uncertainty in variables.

Selection: GA operators (selection, crossover, and mutation) are applied to the solutions. Solutions with better performance, as determined by the MC simulation, have a higher probability of being selected for crossover and mutation.

New Population: A new population of solutions is created through the application of GA operators.

Iteration: Steps 2-4 are repeated for multiple generations, with the aim of improving the quality of solutions by exploring various combinations of variables and scenarios.

Applicability: The hybrid MC-GA technique is suitable for a variety of optimization problems, especially those involving uncertainty and multiple variables. Some areas where it can be applied include:

Engineering Design: Optimal design of complex systems considering uncertain material properties, loads, and operating conditions.

Financial Portfolio Optimization: Optimizing investment portfolios considering uncertain market conditions and asset performance.

Supply Chain Management: Optimizing supply chain operations while accounting for uncertain demand and supply disruptions.

Environmental Management: Finding optimal solutions for environmental management problems, considering uncertainties in pollution levels and resource availability.

Energy System Design: Designing hybrid energy systems that incorporate renewable and conventional energy sources under uncertain weather conditions and energy demand.

The hybrid MC-GA technique is a powerful approach for solving optimization problems involving uncertainties. By combining the probabilistic assessment capabilities of Monte Carlo simulation with the evolutionary search capabilities of Genetic Algorithms, this technique enables the identification of robust solutions that perform well across a range of scenarios. Its applicability spans various domains where uncertainties play a significant role in decision-making processes.

IV. SIMULATION RESULTS AND DISCUSSION

The proposed methodology for penetration of various types of DGs planning with different RLMs have been implemented on IEEE-16 and 37 bus distribution system and the software runs on a 2.63 GHz Pentium core i7 machine with 32 GB of RAM and was created in the MATLAB 2019b programming language. IEEE-16 bus (17-node) and IEEE-37 bus (38-node) distribution test system, their corresponding data are presented in Fig. 3, Fig. 4, Table 4 and Table 5 respectively. The research statistics are based on a fictitious 12.66-KV, 37-bus system [8]. For the standard arrangement, the total substation loads are 2547.32 KVAr and 5084.26 kW. The overall loss of the system is around 8% of the entire load, indicating poor compensation and lossiness. The expectation of a significant reduction in loss led to the selection of the lossy system. A hypothetical 37-bus test system has a component called the 16-bus test system [8]. The basic values utilized for the aforementioned test systems are 23 kV and 100 MVA. The following is how the comprehensive power flow solution for the 16-bus and 37-bus distribution systems is generated. Initially, the practical range of a DG size is taken into consideration (0-0.63 p.u.). The system is represented by the DG of 0.0 p.u.

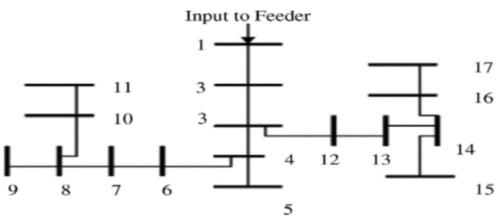

Fig. 3. IEEE 16 Bus (17 Node) distribution test system

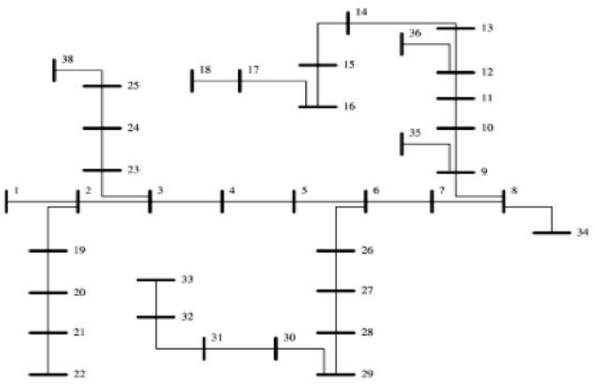

Fig. 4. IEEE 37 Bus (38 Node) distribution test system

Table 4: Line parameter and load data for IEEE-16 bus distribution test system [10]

From	To	Line impedance (p.u.)		Line no.	Ratings (p.u.)	Load on the node (p. u.)	
		R	X	L		P	Q
1	2	0.000574	0.000293	1	2.8	0.1	0.06
2	3	0.00307	0.001564	6	2.5	0.09	0.04
3	4	0.002279	0.001161	11	2.1	0.12	0.08
4	5	0.002373	0.001209	12	0.84	0.06	0.03
4	6	0.0051	0.004402	13	1.5	0.06	0.02
6	7	0.001166	0.003853	22	1.3	0.20	0.10
7	8	0.00443	0.001464	23	1.04	0.20	0.10
8	9	0.006413	0.004608	25	0.48	0.06	0.02
8	10	0.006501	0.004608	27	1.5	0.06	0.02
10	11	0.001224	0.000405	28	0.18	0.045	0.03
3	12	0.002331	0.000771	29	0.64	0.06	0.035
12	13	0.009141	0.007192	31	0.55	0.06	0.035
13	14	0.003372	0.004439	32	0.45	0.12	0.08
14	15	0.00368	0.003275	33	0.12	0.06	0.01
14	16	0.004647	0.003394	34	0.15	0.06	0.02
16	17	0.008026	0.010716	35	0.07	0.06	0.02

P = Real power MW load, *Q*= Reactive power MVAr load

Table 5: Line parameter and load data for IEEE-37 bus distribution test system [2]

From	To	Line impedance (p.u.)		Line no.	Ratings (p.u.)	Load on the node (p. u.)	
		R	X	L		P	Q
1	2	0.000574	0.000293	1	4.60	0.1	0.06
2	3	0.00307	0.001564	6	0.50	0.09	0.04
3	4	0.002279	0.001161	11	0.50	0.12	0.08
4	5	0.002373	0.001209	12	0.21	0.06	0.03
4	6	0.0051	0.004402	13	0.11	0.06	0.02
6	7	0.001166	0.003853	22	4.10	0.20	0.10
7	8	0.00443	0.001464	23	1.05	0.20	0.10
8	9	0.006413	0.004608	25	1.05	0.06	0.02
8	10	0.006501	0.004608	27	0.50	0.06	0.02
10	11	0.001224	0.000405	28	0.10	0.045	0.03
3	12	0.002331	0.000771	29	2.90	0.06	0.035
12	13	0.009141	0.007192	31	2.90	0.06	0.035
13	14	0.003372	0.004439	32	2.90	0.12	0.08
14	15	0.00368	0.003275	33	1.50	0.06	0.01
14	16	0.004647	0.003394	34	1.50	0.06	0.02
16	17	0.008026	0.010716	35	1.50	0.06	0.02
17	18	0.004558	0.003574	36	1.50	0.09	0.04

2	19	0.001021	0.000974	2	1.50	0.09	0.04
19	20	0.009366	0.00844	3	0.50	0.09	0.04
20	21	0.00255	0.002979	4	0.50	0.09	0.04
21	22	0.004414	0.005836	5	0.10	0.09	0.04
3	23	0.002809	0.00192	7	1.50	0.09	0.04
23	24	0.005592	0.004415	8	1.05	0.42	0.2
24	25	0.005579	0.004366	9	0.50	0.42	0.2
6	26	0.001264	0.000644	14	1.05	0.06	0.025
26	27	0.00177	0.000901	15	0.50	0.06	0.025
27	28	0.006594	0.005814	16	1.05	0.06	0.02
28	29	0.005007	0.004362	17	1.05	0.12	0.07
29	30	0.00316	0.00161	18	1.05	0.2	0.6
30	31	0.006067	0.005996	19	0.50	0.15	0.07
31	32	0.001933	0.002253	2	0.50	0.21	0.1
32	33	0.002123	0.003301	21	0.45	0.06	0.04
8	34	0.012453	0.012453	24	0.30	0	0
9	35	0.012453	0.012453	26	0.25	0	0
12	36	0.012453	0.012453	30	0.25	0	0
18	37	0.003113	0.003113	37	0.10	0	0
25	38	0.00313	0.003113	10	0.50	0	0

P = Real power MW load, Q= Reactive power MVAr load

Table 6: Penetration of various types of DGs in 16-Bus system with RLMs (ZIP+IM) and SPF Profile

RLMs (ZIP+IM)	WODG/ WDG	DG Type	DG P.F.	Optimal DG Size	DG Loc.	P_L (p.u.)	Q_L (p.u.)	P_G (p.u.)	Q_G (p.u.)	SPF Profile
RLM1	WODG	-	-	-	-	1.5200	1.3310	0.4112	0.4001	0.7167
	WDG	DG1	1.00	0.1402	7	1.2651	1.1300	0.4112	0.4034	0.7513
		DG2	0.85 ld	0.1410	8	1.2102	1.1103	0.4171	0.4036	0.7712
		DG3	0.00	0.1201	8	1.3853	1.3121	0.4037	0.4091	0.7160
		DG4	0.85 lg	0.1234	8	1.3610	1.2012	0.4101	0.4100	0.7236
RLM2	WODG	-	-	-	-	1.5200	1.3310	0.4112	0.4001	0.7167
	WDG	DG1	1.00	0.1468	7	1.1903	1.1201	0.4112	0.4005	0.7612
		DG2	0.85 ld	0.1471	7	1.1720	1.1121	0.4135	0.4001	0.7721
		DG3	0.00	0.1101	7	1.4338	1.2331	0.4101	0.4001	0.7220
		DG4	0.85 lg	0.1138	8	1.3801	1.2001	0.4099	0.4021	0.7221
RLM3	WODG	-	-	-	-	1.5200	1.3310	0.4112	0.4001	0.7167
	WDG	DG1	1.00	0.1501	8	1.3001	1.1102	0.4112	0.4001	0.7800
		DG2	0.85 ld	0.1510.	8	1.2501	1.1001	0.4136	0.4032	0.7821
		DG3	0.00	0.1178	8	1.4531	1.2568	0.4110	0.4015	0.7360
		DG4	0.85 lg	0.1228	5	1.4219	1.2103	0.4135	0.4001	0.7366
RLM4	WODG	-	-	-	-	1.5200	1.3310	0.4112	0.4001	0.7167
	WDG	DG1	1.00	0.1402	7	1.2100	1.1368	0.4112	0.4001	0.7821
		DG2	0.85 ld	0.1421	8	1.1331	1.0991	0.4112	0.4102	0.7880
		DG3	0.00	0.1211	8	1.4201	1.2250	0.4178	0.4106	0.7210
		DG4	0.85 lg	0.1234	7	1.3881	1.1668	0.4121	0.4003	0.7212
RLM5	WODG	-	-	-	-	1.5200	1.3310	0.4112	0.4001	0.7167
	WDG	DG1	1.00	0.1467	8	1.1821	1.1228	0.4112	0.4001	0.7881
		DG2	0.85 ld	0.1470	7	1.1331	1.1035	0.4101	0.4021	0.7891
		DG3	0.00	0.1100	7	1.3991	1.3012	0.4123	0.4100	0.7212
		DG4	0.85 lg	0.1121	9	1.3228	1.1538	0.4101	0.4101	0.7256

The variation of optimal DG size for RLMs in distribution systems are given in Fig.5. The optimal size of DG1 (0.1501 p.u.) is maximum in RLM3 and DG1(0.1402 p.u.) minimum in RLM1& RLM4 load model in comparison to other load model. Similarly, optimal size of DG2 (0.1510 p.u.) is maximum in RLM3 and DG2 (0.1410 p.u.) minimum in RLM1, optimal size of DG3 (0.1211 p.u.) is maximum in RLM4 and DG3 (0.1100 p.u.) minimum in RLM5, optimal size of DG4 (0.1234 p.u.) is maximum in RLM1 & RLM4 and DG4 (0.1121 p.u.) minimum in RLM5 load model in comparison to other load model.

Fig.6. Show the optimal DG location and Fig.7. display how the true power loss profile changes for RLMs both with and without DGs. Comparing the RLM5 load model with DG1, the real power loss decrease (1.1821 p.u.) is noteworthy when compared to other LMs. Therefore, bus 8 is the best place for DG1 to be located. When DG2 is used in the RLM4 & RLM5 load model, the real power loss decrease (1.1331 p.u.) is also noteworthy. Therefore, bus 7 and 8 are the best places for DG2 to be. In the RLM1 load model, the real power loss reduction of 1.3853 p.u. using DG3 is noteworthy. Hence, bus 8 is the best place for DG3 to be. With RLM5 load conditions, the actual power loss (1.3228 p.u.) is also at a minimum for DG4, and bus 9 with 0.85 lag power factor is the best bus site for DG4 deployment. Based on the analysis, bus 7 & 8 with DG2 for real power loss reduction is the best position in the RLM4 & RLM5 load model condition because DG2 provides the system with both reactive and real power at leading power factors of 0.80 to 0.99. The best real power loss reduction with RLMs are achieved in case of DG2 whereas the poorest real power loss reduction with RLMs are achieved in case DG3. The descending order of real power loss reduction with RLMs are as follows: DG2 > DG1 > DG4 > DG3

The reactive power loss profile variation for RLMs with and without DGs is displayed in Fig. 8. In the RLM3 load model, DG1 significantly reduces reactive power loss (1.1102 p.u.) as compared to other LMs. With DG2 having a 0.85 lead power factor in the RLM4 load model, the reduction in reactive power loss (1.0991 p.u.) is also noteworthy. In the RLM4 load model, the reduction in reactive power loss (1.2250 p.u.) using DG3 is noteworthy. For DG4, the minimal reactive power loss (1.2001 p.u.) under RLM2 load conditions corresponds to a 0.85 lag power factor. When using RLMs, DG2 achieves the best reduction in reactive power loss, whereas DG3 achieves the lowest decrease in reactive power loss. The descending order of reactive power loss reduction with RLMs are as follows: DG2 > DG1 > DG4 > DG3

Fig.9. Show that the SPF varied values resulting from the integration of several kinds of distribution system DGs (DG1, DG2, DG3, and DG4) with RLMs (RLM-1, RLM-2, RLM-3, RLM-4, and RLM-5, respectively). The variation of the SPF profile is better when DG is added to DNs with RLMs and contrasted with the SPF without DG, which is computed as 0.7167. The best SPFs (0.7891) for RLM5 are achieved in case of DG2 whereas the poorest SPFs (0.7160) for RLM1 are achieved in case DG3. These are the SPFs with RLMs in decreasing order.: DG2 > DG1 > DG4 > DG3.

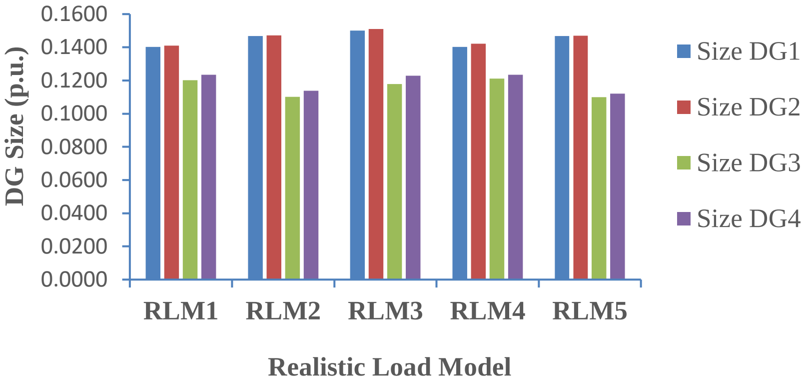

Fig.5: Comparison of various optimal DG size (p.u.) profile of 16-bus system for RLMs

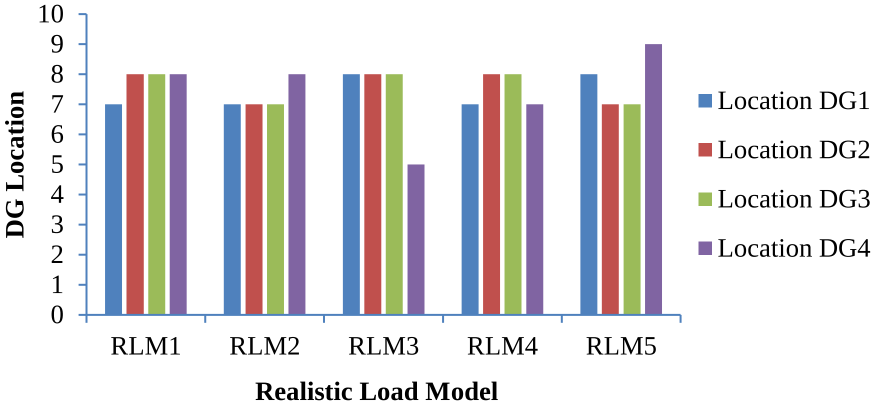

Fig.6: Comparison of various optimal DG location profile of 16-bus system for RLMs

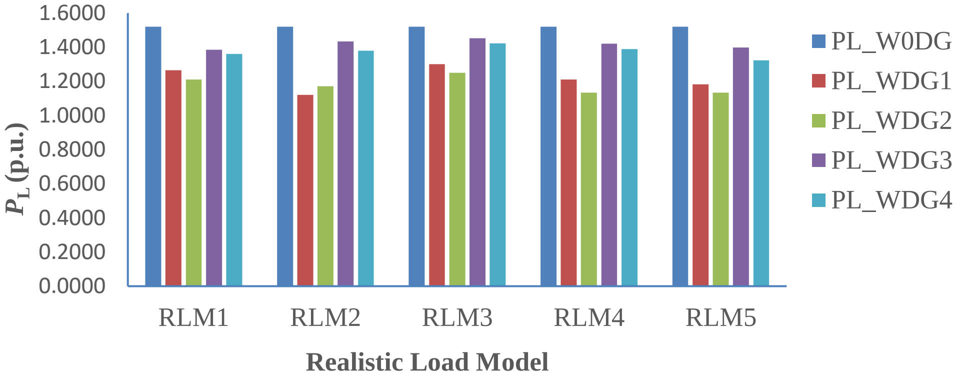

Fig.7: Comparison of P_L (p.u.) profile without and with DGs of 16-bus system for RLMs

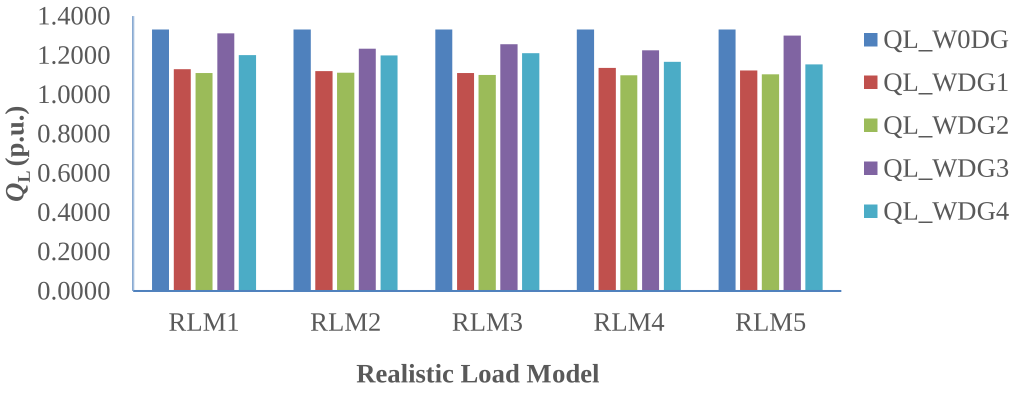

Fig.8: Comparison of Q_L (p.u.) profile without and with DGs of 16-bus system for RLM

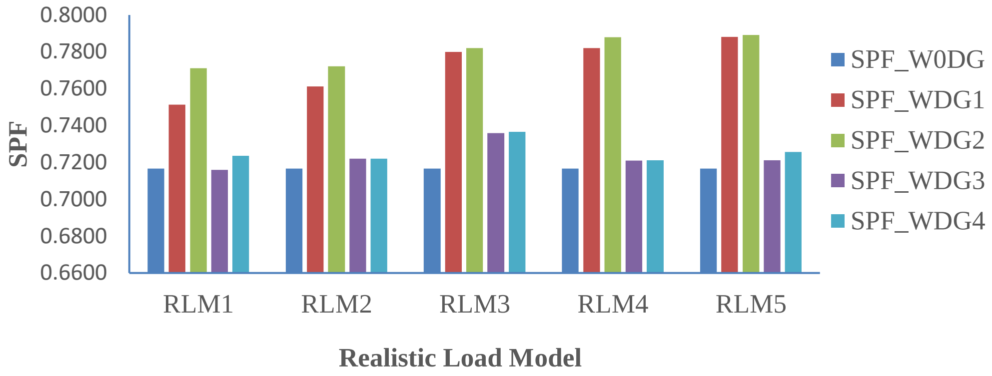

Fig.9: Comparison of SPF profile without and with DGs of 16-bus system for RLMs

Table 7: Penetration of various types of DGs in 37-Bus system with RLMs (ZIP+IM) and SPF Profile

RLMs (ZIP+IM)	WODG/ WDG	DG Type	DG P.F.	Optimal DG Size	DG Loc.	P_L (p.u.)	Q_L (p.u.)	P_G (p.u.)	Q_G (p.u.)	SPF Profile
RLM1	WODG	-	-	-	-	0.1607	0.1408	0.3620	0.3485	0.7204
	WDG	DG1	1.00	0.0571	14	0.1201	0.1012	0.3620	0.3485	0.7688
		DG2	0.85 ld	0.0853	25	0.0923	0.0901	0.3630	0.3685	0.7812
		DG3	0.00	0.0502	25	0.1411	0.1204	0.3630	0.3485	0.7208
		DG4	0.85 lg	0.0513	25	0.1402	0.1201	0.3630	0.3385	0.7340
RLM2	WODG	-	-	-	-	0.1607	0.1408	0.3620	0.3485	0.7204
	WDG	DG1	1.00	0.0568	14	0.1203	0.1120	0.3640	0.3480	0.7692
		DG2	0.85 ld	0.0981	25	0.0913	0.0903	0.3701	0.3521	0.7832
		DG3	0.00	0.0521	26	0.1368	0.1203	0.3621	0.3684	0.7300
		DG4	0.85 lg	0.0612	25	0.1302	0.1183	0.3621	0.3601	0.7368
RLM3	WODG	-	-	-	-	0.1607	0.1408	0.3620	0.3485	0.7204
	WDG	DG1	1.00	0.0610	14	0.1205	0.1101	0.3678	0.3481	0.7698
		DG2	0.85 ld	0.0831	27	0.1012	0.0927	0.3535	0.3521	0.7902
		DG3	0.00	0.0601	26	0.1321	0.1254	0.3731	0.3485	0.7301
		DG4	0.85 lg	0.0712	25	0.1234	0.1203	0.3603	0.3502	0.7356
RLM4	WODG	-	-	-	-	0.1607	0.1408	0.3620	0.3485	0.7204
	WDG	DG1	1.00	0.0742	14	0.1205	0.1036	0.3620	0.3486	0.7638
		DG2	0.85 ld	0.1021	26	0.0925	0.0921	0.3620	0.3491	0.7860
		DG3	0.00	0.0625	25	0.1478	0.1250	0.3750	0.3560	0.7250
		DG4	0.85 lg	0.0734	25	0.1435	0.1205	0.3712	0.3521	0.7283
RLM5	WODG	-	-	-	-	0.1607	0.1408	0.3620	0.3485	0.7204
	WDG	DG1	1.00	0.0631	14	0.1278	0.1103	0.3620	0.3482	0.7740
		DG2	0.85 ld	0.1101	30	0.1103	0.1037	0.3710	0.3480	0.7990
		DG3	0.00	0.0501	27	0.1301	0.1297	0.3668	0.3568	0.7301
		DG4	0.85 lg	0.0503	25	0.1298	0.1270	0.3598	0.3621	0.7354

The variation of optimal DG size for RLMs in distribution systems are given in Fig.10. The optimal size of DG1 (0.0742 p.u.) is maximum in RLM4 and DG1(0.0568 p.u.) minimum in RLM2 load model in comparison to other load model. Similarly, optimal size of DG2 (0.1101 p.u.) is maximum in RLM5 and DG2 (0.0831 p.u.) minimum in RLM3, optimal size of DG3 (0.0625 p.u.) is maximum in RLM4 and DG3 (0.0501 p.u.) minimum in RLM5, optimal size of DG4 (0.0734 p.u.) is maximum in RLM4 and DG4 (0.0503 p.u.) minimum in RLM5 load model in comparison to other load model.

Fig.11. Show the optimal DG location and Fig.12. show the difference between the true power loss profile for RLMs with and without DGs. When compared to other LMs, the actual power loss reduction (0.1201 p.u.) with DG1 in the RLM1 load model is noteworthy. Thus, bus 14 is the best place for DG1 to be located. With DG2 having a 0.85 lead power factor in the RLM2 load model, the real power loss decrease (0.0913 p.u.) is also noteworthy. Hence, bus 25 is the best place for DG2. In the RLM5 load model, the actual power loss decrease (0.1301 p.u.) using DG3 is noteworthy. Hence, bus 27 is the best place for DG3. With RLM2 load conditions, the actual power loss (0.1302 p.u.) is likewise at its lowest for DG4, and bus 25 with 0.85 lag power factor is the best bus site for DG4 deployment. Based on the research, bus 14 with DG2 for real power loss reduction is the best position in the RLM2 load model condition because DG2 provides the system with both real and reactive power at leading power factors of 0.80 to 0.99. While DG2 achieves the highest actual power loss reduction with RLMs, DG3 achieves the lowest real power loss reduction with RLMs. The descending order of real power loss reduction with RLMs are as follows: DG2 > DG1 > DG4 > DG3

Fig.13. show the difference between the reactive power loss profile for RLMs with and without DGs. Compared to other LMs, DG1 in the RLM1 load model significantly reduces reactive power loss (0.1012 p.u.). With DG2 having a 0.85 lead power factor in the RLM1 load model, the reactive power loss decrease (0.901 p.u.) is also noteworthy. In the RLM2 load model, the reduction in reactive power loss (0.1203 p.u.) using DG3 is noteworthy. For DG4, the minimal reactive power loss (0.1183 p.u.) under RLM2 load conditions corresponds to a 0.85 lag power factor. When using RLMs, DG2 achieves the best reduction in reactive power loss, whereas DG3 achieves the lowest decrease in reactive power loss. The descending order of reactive power loss reduction with RLMs are as follows: DG2 > DG1 > DG4 > DG3

Fig.14. Show that the SPF varied values resulting from the integration of several kinds of distribution system DGs (DG1, DG2, DG3, and DG4) with RLMs (RLM-1, RLM-2, RLM-3, RLM-4, and RLM-5, respectively). When DG is added to DNs with RLMs, the variance in the SPF profile is better than when the SPF without DG is computed, which is 0.7204. For RLM5, DG2 achieves the highest SPFs (0.7990), whereas DG3 achieves the lowest SPFs (0.7208) for RLM1. The descending order of SPFs with RLMs are as follows: DG2 > DG1 > DG4 > DG3.

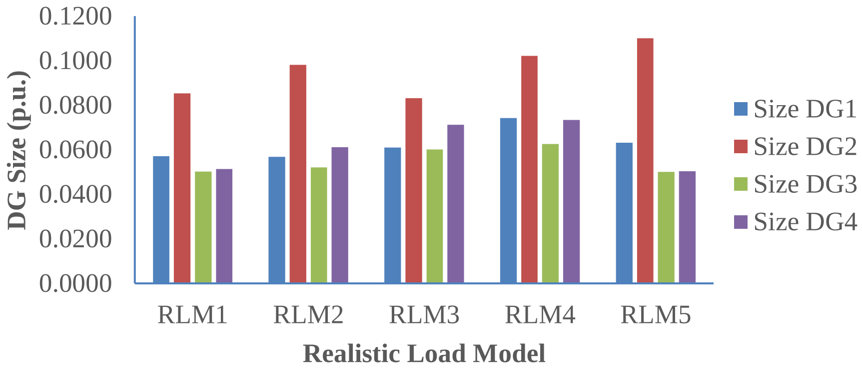

Fig.10: Comparison of various optimal DG size (p.u.) profile of 37-bus system for RLMs

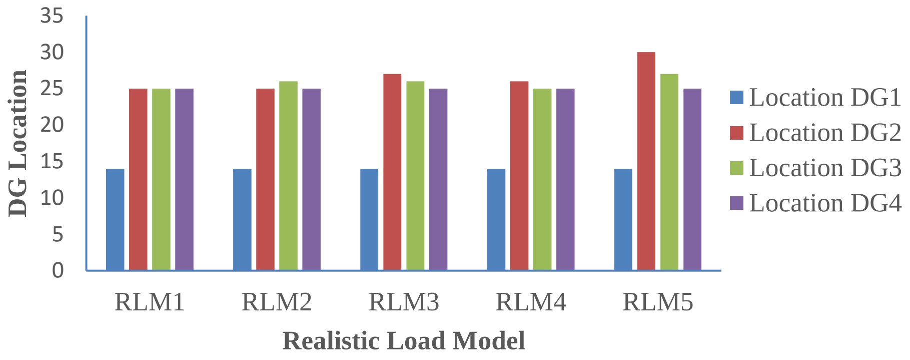

Fig.11: Comparison of various optimal DG location profile of 37-bus system for RLMs

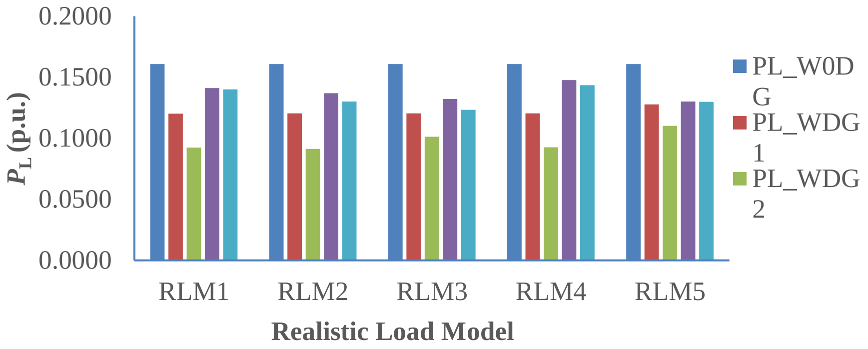

Fig.12: Comparison of P_L (p.u.) profile without and with DGs of 37-bus system for RLMs

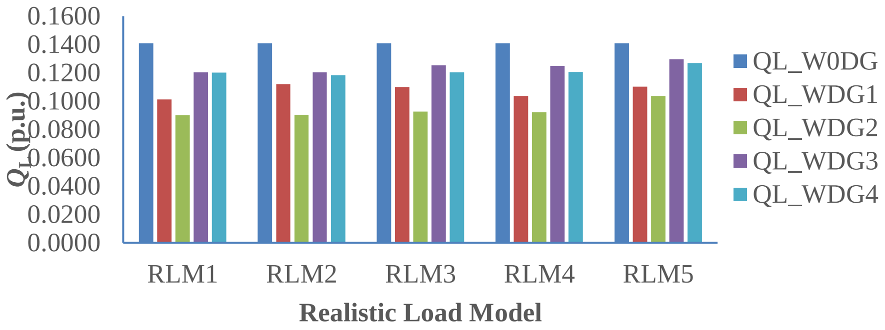

Fig.13: Comparison of Q_L (p.u.) profile without and with DGs of 37-bus system for RLMs

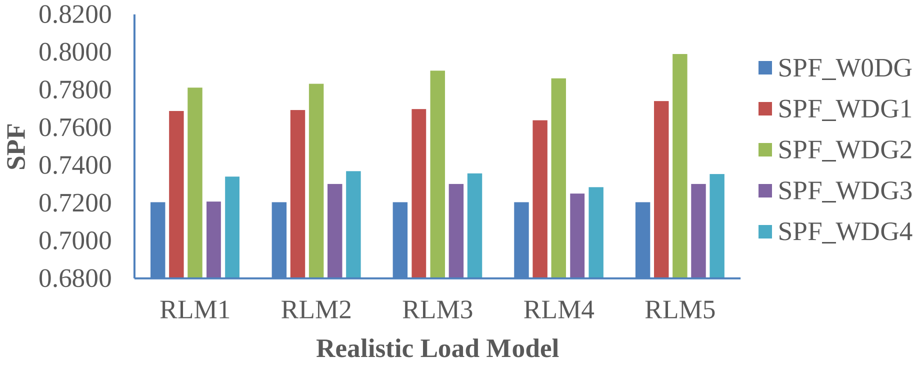

Fig.14: Comparison of SPF profile without and with DGs of 37-bus system for RLMs

V. CONCLUSIONS AND FUTURE SCOPE OF RESEARCH WORK

The conclusions and future scope of research work are presented in Subsections *A* and *B*.

A. Conclusions

The following conclusion made from this research work as follows:

- Find optimal size and location of different type DGs (i.e. DG1, DG2, DG3 and DG4 respectively) for IEEE-16 and 37- bus system in DNs with various RLMs.
- The system actual and reactive power losses should be kept to a minimum by placing and sizing DGs in DNs with RLMs appropriately.
- In comparison of the current method, hybrid MC-GA optimization technique can provide prompt and precise results.
- The performance order of different type of DGs for RLMs are: DG2> DG1> DG4> DG3.
- Boost the system actual and reactive power support by penetration of various type of DGs in 16 and 37-bus system.
- The SPF is enhance when DGs penetrates in the DNs with RLMs by hybrid MC-GA optimization than without DGs.

B. Future scope of research work

The scientific activity in this approach has the following future scopes:

- The proposed methodology can also be used for DG integration with EVs and or other FACTS controller such as dynamic voltage restoral (DVR), distributed-STATCOM, unified power flow controller (UPQC), hybrid power flow controller (HPFC) and static war compensator (SVC) etc. for RLMs.
- In the future, integrate DGs and EVs for the Western Electricity Coordinating Council's (WECC) complicated road model, artificial neural network-based modeling, and complex load model (CLOD) to improve the SPF and reduce actual and reactive power losses.
- For the purpose of validating the suggested methodology's resilience, it is also employed for higher IEEE bus test systems, such as IEEE-57, IEEE-75, 246-Indian test system, etc.
- Further, enhanced additional power system performance parameters by DGs penetration in DNs with RLMs include power quality parameters (distortion harmonic, voltage sag and swell, etc.).
- In future, enhance the SPF and minimize real and reactive power losses by integration of DGs with SVC & UPSC for RLMs on the bases of proposed methodology.

ACKNOWLEDGMENT

Mr. Ramesh is thankful to Integral University, Lucknow, UP-226026 (India), for providing Manuscript Communication Number (MCN): IU/R&D/2024-MCN0002759 and also thankful to Department of Electrical Engineering, Kamla Nehru Institute of Technology, Sultanpur, Uttar Pradesh-228118 (India) for providing all the facilities for carrying out this work.

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