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Power loss mitigation and voltage profile improvement by optimizing distributed generation

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Abstract. In a developing country, electricity has become the necessity of the growth industries; thus, the distribution system power quality and reliability are crucial. With low carbon initiatives, renewable energy or distributed generation (DG) is a promising source of electricity and leads the complex distribution system. Vital rises in DGs in power grids will significantly impact the system reliability and security, especially in power losses and voltage profiles parameters. This research focuses on an optimization placement and size of DGs in distribution systems to minimize power loss and improve voltage profile using the Modified Lightning Search Algorithm (MLSA). This research has modelled the practical 69-bus radial distribution system. Then MLSA with a weight summation approach is used to identify the suitable location and size for the DGs in the design proposal stage. The optimization objectives are to reduce power losses and improve the voltage profile, especially at the connection point of DGs. Besides that, load profile, DGs constant load and the solar load in distribution system modelled using MATLAB software. The results of the simulation using MLSA indicated that the optimization allocation and sizes of solar DGs applied with current load and load changes can minimize the power losses and improve voltage profile. These results verify the proposed approach's effectiveness and success in determining the optimal location and sizing of solar DGs to reduce power losses as well as improve voltage profiles.

1. Introduction

The purpose of the global energy transformation is to restrict the increase of global average temperature. However, the conventional energy scenarios do not fully capture the implication of the Paris agreement for the energy sector [1]. Converted from fossil fuels to low-carbon solutions will become essential in energy-related carbon dioxide emissions, representing two-thirds of all greenhouse gases [2]. Thus, the latest technologies' innovations transition traditional energy production to renewable-based distributed generation (DG) usage. Other than that, the active usage of renewable DGs will avail the cost of generating electricity, especially for capital investment. In most developing countries, electricity becomes the basic need of the growth industries. Thus, the power quality and trustworthiness of the distribution system are critical [3]. However, despite the low carbon initiatives, renewable energy or DGs by the government may reflect the system performance [4]. Introduction DGs in power grids will impact the system reliability and security in power losses and voltage level [5-6]. Proper design of the massive solar DGs could bring positive influence and impact to the DG. The reliability and stable parameters such as voltage could be maintained, and the power loss could be control and reduced.

From past research, most distribution systems blended with DGs, generating the power without considering DG load profile and distribution system capability, and this such circumstance may lead to issues in power quality, especially in power losses and voltage profile [6-7]. Next, the existing connection and installation of DGs do not stress the mandatory technical requirement in generating power by optimizing power losses and voltage profile during daily operations of DGs. The previous paper discussed the allocation and size of the DGs but did not consider the future growth or increasing the DGs plant at the existing or other's new location [8]. Besides that, the growth of the existing and new DG plant needs to be considered because it will impact the power losses and voltage profile in the respective area. Current and future growth is crucial in design and planning adequately so that DGs can optimize throughout the years. However, most research is not tested and simulated the impact of the integration of massive solar DGs with a practical radial 11kV distribution system. Thus, the effect of appearances solar DGs not analyse and details out in terms of power losses and voltage profile [9]. The impact of connection solar DGs on voltage profile and system stability has become very important to the distribution system. Rising issues such as voltage stability and voltage profile need to be studied, analysed, and closely monitored to avoid the failure of the distribution system, especially during peak demand or contingencies events in the power system. The fluctuation in voltage stability can affect the integration of DGs to the distribution system depending on the power system operation. Currently, most DGs operate by injecting active power with a unity power factor so that the voltage regulation complies with the allowable value [10-11]. Optimization of the location of DGs in the distribution system can mitigate network congestion and improve the voltage profile in respective busses of the network. Many DGs are used in the distribution system, such as solar PV, fossil fuel power plants, wind, and other new DG types [12-13].

Therefore, this research focused on optimizing the massive solar DGs allocation and sizing to minimize power losses and improve the voltage profile. Moreover, the profile of load is based on a practical distribution system at Malaysia utility. This research will also examine the effectiveness of metaheuristic techniques in determining the most reliable solution. Thus, considerations are required to find the best sizing and locations, such as the influence of randomness and the increment of future load growth. This article organised into five sections. The first section discusses the significance of DG and current research focus. Section 2 specifies in detail the fundamental parameters modelling such as distribution system, DG and load characteristic. Next, section 3 directed on the methodology in determining the optimal sizing and placement based on the recommended metaheuristic method. In section 4, focus on results and the discussion on the results. Ultimately, the research conclusion manifested in Section 5.

2. System Modelling

These sections will concentrate on modelling the distribution system, DG and load profile. Next, to focus on the appropriate formula to determine power loss, voltage profile and load growth. Lastly focus on metaheuristic technique used in this research.

2.1. Distribution system modelling

The distribution system is modelled based on typical load and DGs operation. The network is modelled based on the practical distribution system from Malaysia utility with a typical load of mixed residents, commercials, and industries area. In line with the connection of solar DGs to the distribution system, this research preferred to use and model 11kV 69-bus of the radial distribution system as presented in Figure 1. The practical distribution system normally has more branches due to customer request and distance from nearest bus. The load and line data presented at Table 1 and Table 2. The highest load recorded at bus 46 consume 2.732 MW and 1.693 MVAr while the longest lines between bus 45 to 54. The load data is based on peak load during afternoon.

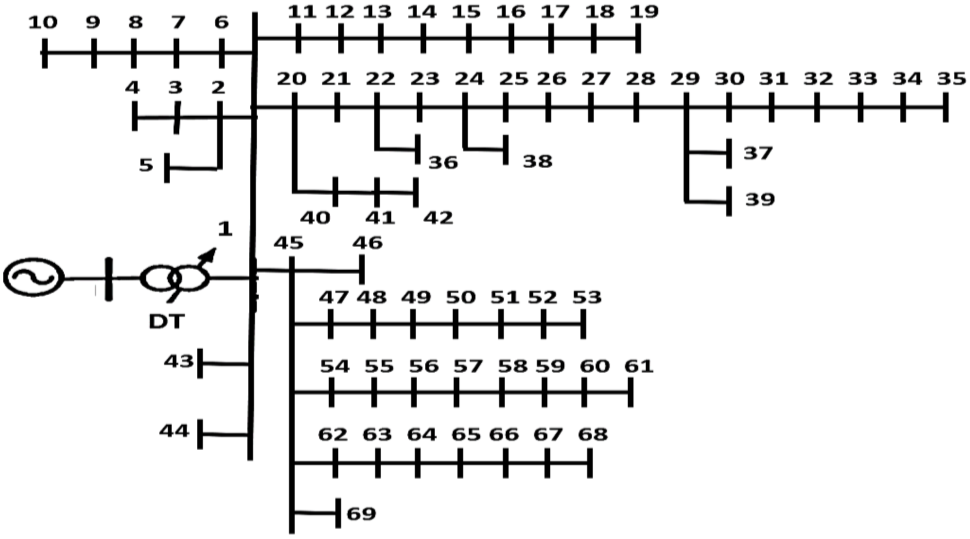

Figure 1. 11 kV practical 69-bus radial distribution system

Table 1. Load data for 69-bus radial distribution system

Bus No.	Load (MW)	Load (MVAr)	Bus No.	Load (MW)	Load (MVAr)	Bus No.	Load (MW)	Load (MVAr)	Bus No.	Load (MW)	Load (MVAr)
1	-	-	**19**	0.135	0.084	**36**	0.157	0.092	**53**	0.260	0.161
2	0.688	0.426	**20**	0.00	0.00	**37**	0.079	0.049	**54**	0.315	0.195
3	0.000	0.000	**21**	0.185	0.092	**38**	0.012	0.007	**55**	0.121	0.075
4	0.211	0.131	**22**	0.020	0.012	**39**	0.012	0.007	**56**	0.073	0.045
5	0.315	0.195	**23**	0.037	0.023	**40**	0.185	0.092	**57**	0.121	0.075
6	0.101	0.063	**24**	0.004	0.002	**41**	0.163	0.101	**58**	0.121	0.075
7	0.016	0.010	**25**	0.004	0.002	**42**	0.157	0.097	**59**	0.035	0.022
8	0.004	0.002	**26**	0.079	0.049	**43**	2.018	1.050	**60**	0.150	0.093
9	0.006	0.004	**27**	0.151	0.094	**44**	0.220	0.110	**61**	0.150	0.093
10	0.004	0.002	**28**	0.079	0.049	**45**	0.000	0.000	**62**	0.177	0.053
11	0.163	0.101	**29**	0.020	0.012	**46**	2.732	1.693	**63**	0.000	0.000
12	0.082	0.051	**30**	0.092	0.057	**47**	0.151	0.093	**64**	0.056	0.035
13	0.429	0.215	**31**	0.185	0.092	**48**	0.052	0.032	**65**	0.079	0.039
14	0.138	0.085	**32**	0.031	0.019	**49**	0.130	0.080	**66**	0.075	0.046
15	0.245	0.152	**33**	0.024	0.015	**50**	0.208	0.109	**67**	0.026	0.016
16	0.742	0.460	**34**	0.052	0.032	**51**	0.087	0.054	**68**	0.045	0.028
17	0.036	0.022	**35**	0.153	0.095	**52**	0.366	0.183	**69**	0.000	0.000
18	0.109	0.067									

Table 2. Line data for 69-bus radial distribution system

Form Bus	To Bus	R (ohm)	X (ohm)	Form Bus	To Bus	R (ohm)	X (ohm)	Form Bus	To Bus	R (ohm)	X (ohm)
1	**2**	0.4080	0.4840	**24**	**25**	0.2381	0.1443	**47**	**48**	0.0579	0.0549
2	**3**	0.2513	0.1523	**25**	**26**	0.3968	0.2405	**48**	**49**	0.0265	0.0160
3	**4**	0.0975	0.0415	**26**	**27**	0.2116	0.1282	**49**	**50**	0.0265	0.0160
2	**5**	0.0053	0.0032	**27**	**28**	0.3915	0.2372	**50**	**51**	0.1323	0.0802
1	**6**	0.4344	0.4115	**28**	**29**	0.2169	0.1314	**51**	**52**	0.1137	0.0689
6	**7**	0.0837	0.0792	**29**	**30**	0.1931	0.1170	**52**	**53**	0.2195	0.1330
7	**8**	0.1416	0.1341	**30**	**31**	0.2195	0.1330	**45**	**54**	0.7328	0.8693
8	**9**	0.0434	0.0411	**31**	**32**	0.2037	0.1234	**54**	**55**	0.2574	0.2438
9	**10**	0.1287	0.1219	**32**	**33**	0.0661	0.0401	**55**	**56**	0.4473	0.4237
1	**11**	0.4827	0.4572	**33**	**34**	0.2301	0.1395	**56**	**57**	0.0644	0.0610
11	**12**	0.1448	0.1372	**34**	**35**	0.5078	0.3078	**57**	**58**	0.1657	0.1570
12	**13**	0.1448	0.1372	**22**	**36**	0.6454	0.3911	**58**	**59**	0.1271	0.1204

13	**14**	0.2381	0.1443	**29**	**37**	0.2513	0.1523	**54**	**60**	0.0322	0.0305
14	**15**	0.1243	0.0753	**24**	**38**	0.0878	0.0373	**60**	**61**	0.0097	0.0091
15	**16**	0.2619	0.1587	**29**	**39**	1.8602	0.3330	**45**	**62**	0.3315	0.3139
16	**17**	0.2650	0.1060	**20**	**40**	0.1979	0.1875	**62**	**63**	0.0692	0.0655
17	**18**	0.1638	0.0696	**40**	**41**	0.0451	0.0427	**63**	**64**	0.0386	0.0366
18	**19**	0.2094	0.0837	**41**	**42**	0.0547	0.0518	**64**	**65**	0.1303	0.1234
1	**20**	0.7328	0.8693	**1**	**43**	0.0724	0.0686	**65**	**66**	0.0933	0.0884
20	**21**	0.3041	0.2880	**1**	**44**	0.3878	0.3673	**66**	**67**	0.0805	0.0762
21	**22**	0.3105	0.2941	**1**	**45**	0.0016	0.0019	**67**	**68**	0.1287	0.1219
22	**23**	0.1209	0.0514	**45**	**46**	0.0560	0.0664	**45**	**69**	0.1287	0.1219
23	**24**	0.1014	0.0431	**45**	**47**	0.5632	0.5334				

2.2. DG modelling

The impacts of installing solar DGs on the active and reactive power losses depend on its numbers and the ratings of the output powers pattern. The characteristic of every solar DGs is determined by the technology used to build up the plant and the design of both active and reactive power generating to the distribution system. Modelling the solar DGs produced either active or reactive power according to its technological characteristics. Since this research focuses only on power loss and voltage profile, every DG will produce only active power and assume to have unity power factor. The placement and sizing of DG will be based on optimization result.

2.3. Power Loss and Voltage Profile

There are two objective functions involve in this research which are power loss and voltage profile. Generally, in distribution system, cable or overhead line is connected with two buses. The power loss presented mathematically as in equation (1) or (2) [14-15].

$$P_{loss} = \left(\frac{P_{ij}^2+Q_{ij}^2}{V_i}\right)R_{ij} \tag{1}$$

$$P_{loss} = \sum_{i=1}^{n_n} I_{rel,ij}^2 \, R_{ij} \tag{2}$$

where;

n_n - total number of busses
R_{ij} - the resistance at the line
$I_{rel,ij}$ - real current at the line

Voltage profile at all busses can be determine by using equation explained details in [16]. This equation is presented in equation (3). The second optimization constraint is that all bus voltages must be within the permitted range [17]. The voltage acceptance range is between 0.95 pu to 1.05 pu.

$$V_{profile} = \sum_{i=1}^{n} |V_i - V_{nom}| \tag{3}$$

where;

V_i - the bus voltage *i* in pu
V_{nom} - the nominal voltage in the pu
n - the number of buses

2.4. Metaheuristic Techniques

This research will focus on two metaheuristic techniques which are LSA and MLSA. The LSA basically inspired by lightning phenomenon which formulated in mathematical equation while MLSA is extended of LSA with focus in improving existing searching method. Chosen of these techniques are based on capability of this techniques from past research. Moreover, MLSA was designed based on the enhancements made to the original LSA [18] which share the same fundamental based on lightning characteristic. The detail on four enhancements made at the original LSA to produce MLSA are at [19-22].

3. Methodology

This section will focus on presenting the research structure that describes the overall process of this research. MATLAB software is used in this research to set up the process and execute the simulation. The extensive research structure is segregated into three parts, as shown in flowchart Figure 2. First part focus on modelling the practical 69-bus radial distribution system with the typical load. Next, the backwards-forward load flow analysis was used to determine the voltage and current at all buses and lines. Then, the second part focuses on DG placement and sizing that will affect the load side of the distribution system. Lastly, the third part will focus on metaheuristic techniques LSA and MLSA to find the optimal placement and sizing of all DGs. Moreover, the multi-objective using the weight summation approach was used for the third part to simplify the fitness equation.

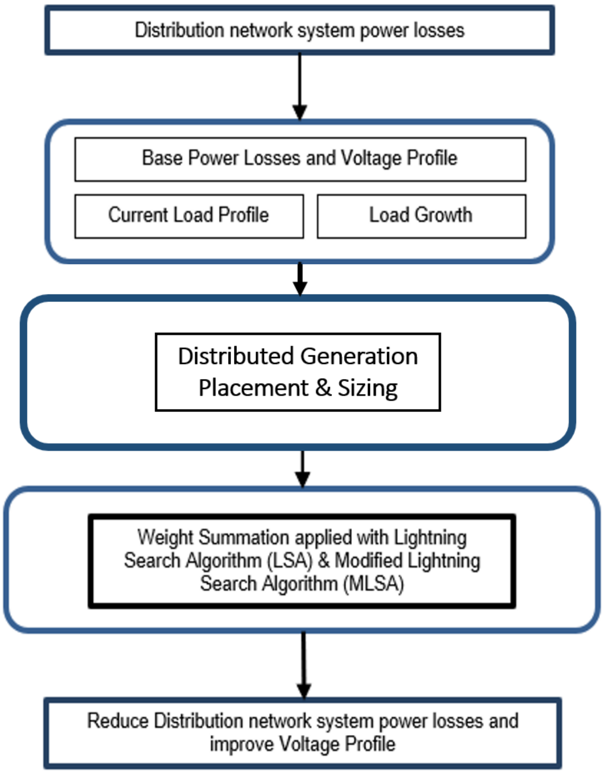

Figure 2. Research Flowchart

However, the number of DGs install must be established beforehand to ensure the system benefits from the proposed method. Therefore, the DG number will be determined based on the typical sizing range of solar installed in Malaysia. The total variables for this research are 10, which are 5 placement and 5 sizes. All these parameters will have its own constraints that needs to fulfil. The DGs will be place at any bus based on minimum power loss and improve voltage profile. Since it involves two objective function, multi-objective using weight summation approach will be adopted. The important formulas for multi-objective are as follow: -

$$OBJ = \omega_1 Losses_{rel} + \omega_2 V_{profile} \tag{4}$$

$$\omega_1 = \omega_2 = 0.5 \tag{5}$$

where,

OBJ - multi-objective function
$\omega_1$and ω_2 - weighted coefficient
$Losses_{real}$ - active power losses of distribution system

4. Result and discussion

The initial simulation is to determine the range size of solar DGs connected to the distribution system to minimize the distribution system active power losses. The DGs numbers is set at 5 units for every chosen bus. Based on existing simulation, the power loss is registered at 148.236KW for system without DGs. Therefore, an initial simulation as per Table 3 shows 5 range size of DG that is chosen based on typical size installed in Malaysia. The result shows that the range of solar size is best at 0.5 MW to 2 MW.

Table 3. Initial simulation to determine the best numbers and range size of DG

No.	Total of solar DGs (Units)	Range size of solar DGs (MW)	Initial Real Power Losses (kW)
1.	5	0.100-0.250	105.467
2.	5	0.250-1.000	69.475
3.	5	0.500-2.000	56.420
4.	5	1.000-5.000	185.488
5.	5	5.000-10.000	653.033

For first scenario, this research was carried out assuming that the load remains constant in the existing distribution system. Next, LSA and MLSA with multi-objective functions were used and simulated randomly with a practical 69-bus radial distribution system to find and then optimize the five placement and sizes of the solar DGs. Then, simulation began with 50 populations with 100 iterations for all optimization strategies to find the minimum fitness value. The channel time of LSA was set to 10, but MLSA did not use the channel time approach. The learning factor for MLSA has been set to 2.0 in this simulation, included with the five locations buses and five units of solar DGs sizes.

Based on the convergence curve for both methods at Figure 3, MLSA optimization can reach the minimum fitness value compared to LSA. In addition, the detailed results found that MLSA showed better performance in giving the best minimum, median and average values compared to LSA. Looking at the convergence curve, MLSA can identify the best fitness with the minimum of iterations. In this analysis, the MLSA method has presented remarkable results in locating five units of solar DGs at busses 16, 21, 31, 52 and 54 for the proposed distribution system.

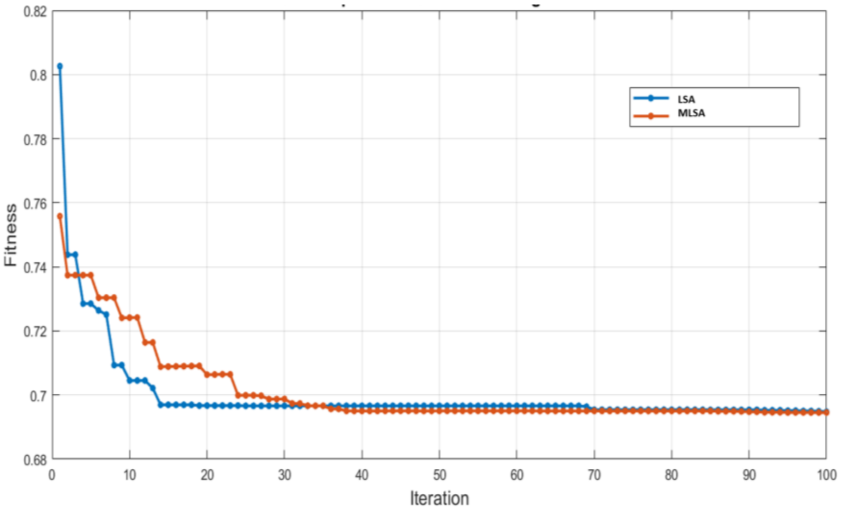

Figure 3. LSA and MLSA convergence curve

The comparison results between LSA and MLSA show at Table 4. Based on Table 4, the optimal size and location of the solar DGs simulated by the LSA method were placed at the 16, 21, 31, 52, and 54 buses with penetration of solar DGs were 1.6300 MW, 0.8685 MW, 0.7965 MW, 1.1227 MW and 1.0752 MW. However, with the MLSA optimization, the minimum fitness shows at the exact bus placement as LSA with the sizing of solar DGs are 1.6592MW, 0.9638MW, 0.7752MW, 1.0680MW and 1.0889MW. Therefore, the losses produced in the practical 69-bus radial distribution system for LSA optimization is 62.180kW and for MLSA optimization is 56.026kW, significantly decreased compared to the existing real power losses recorded at 148.236kW after the installation of solar DGs sources.

Other than that, the voltage variance at each bus should have been within the upper and lower limits to guarantee voltage stability and power quality. Therefore, within ±5% of the rated voltage for the load buses in the distribution system, voltage limits are acknowledged. Using LSA and MLSA optimization improved the voltage profile in all terminal buses, including the voltage where the solar DGs connected at five buses. As a result, the voltage value at these buses had improved to the satisfied values of 10.888kV, 10.885kV, 10.810kV, 10.953kV and 10.943kV. The voltage profile comparison before and after shows in Figure 4.

Table 4. Simulation result using LSA and MLSA

Solar DGs No.	**Existing network**	**Existing network with Solar DGs using LSA**		**Existing network with Solar DGs using MLSA**	
		Bus No.	**Size (MW)**	**Bus No.**	**Size (MW)**
Solar DG1	without Solar DGs	16	1.6300	16	1.6592
Solar DG2		21	0.8685	21	0.9638
Solar DG3		31	0.7965	31	0.7752
Solar DG4		52	1.1227	52	1.0680
Solar DG5		54	1.0752	54	1.0899
Losses (kW)	148.236 kW	56.063 kW		**56.026 kW**	
% Losses reduction	-	-62.180%		-62.205	
Voltage Profile	1.3179	0.5658		**0.5589**	

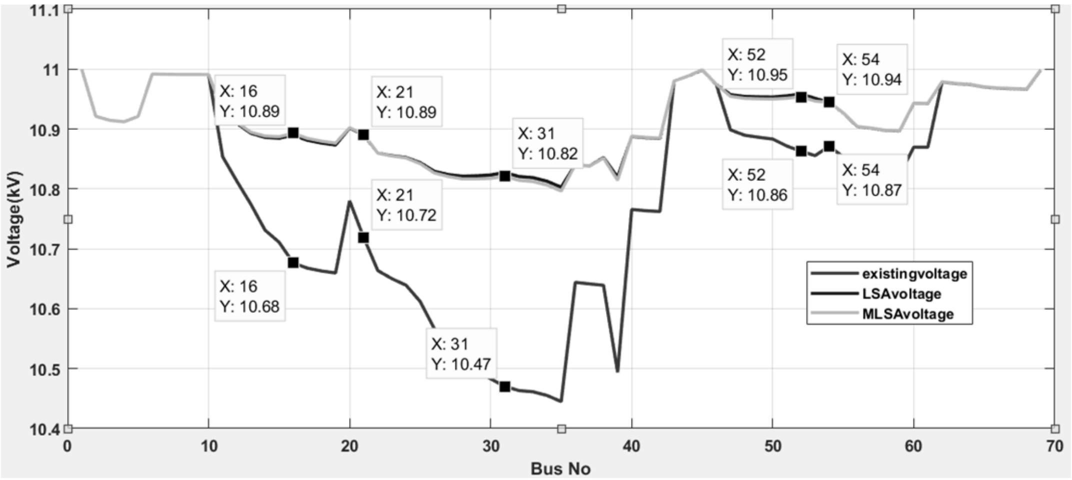

Figure 4. Voltage Profile before and after connected with solar DGs

5. Conclusion

The optimization of placement and sizing of solar DGs is addressed in this research. The proposed optimal solar DGs method can reduce power loss as well as improving voltage profile. Next, LSA and MLSA methods were adopted to solve this optimization problem, and multi-objective using the weight summation approach was used to identify the best fitness value. According to the result obtained from the extensive analysis, MLSA produced better results compare to LSA and significantly resolved power losses minimization in the existing distribution system. From the view of voltage profile, LSA and MLSA did not show much difference in voltage profile, but these two methods created high voltage profile improvement compared with the existing distribution system.

Acknowledgments

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