IMPACTS OF DISTRIBUTED GENERATION ON TRANSMISSION AND DISTRIBUTION LOSSES IN SRI LANKAN POWER SYSTEM

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September 2015

DECLARATION

I declare that this is my own work and this dissertation does not incorporate without acknowledgement any material previously submitted for a Degree or Diploma in any other University or institute of higher learning and to the best of my knowledge and belief it does not contain any material previously published or written by another person except where the acknowledgement is made in the text.

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……………………..

Dr. H.M. Wijekoon Banda Date: ……………………….

ABSTRACT

According to the National Energy Policy and Strategies of Sri Lanka [1], the Government will endeavour to reach a minimum level of 10% of electrical energy supplied to the grid to be from Non- Conventional Renewable Energy sources by year 2015. Further, Government of Sri Lanka has revised the target to reach 20% of electricity supply is expected to be generated by renewable energy by year 2020.

Main Non Conventional Renewable Energy Sources available in Sri Lanka are Wind, Small hydro, Solar and Biomass. They are also called as Distributed Generation (DG) units which are located especially close to load centers of the distribution network.

When driven for such a national target as a utility, impacts of these technologies should be evaluated to maintain power quality and the stability of the power system. There are considerable impacts of DG units to utility as well as to consumers.

While improving power quality and stability, DG is a financial benefit to the utility and to the country. One of the main impacts of the DG for the utility is reduction of losses. The objective of this study is to estimate the impact of distributed generation on transmission and distribution losses in Sri Lanka power system. Transmission network and the part of the distribution network were separately studied and used to calculate the losses by using PSSE software and SynerGEE software. Badulla, Kiribathkumbura, Rathnapura and Ukuwela, grid substations with the feeders which are connected to considerable amount of DGs are selected for analysis.

According to the results, transmission network always gives a loss reduction by introducing DGs. But in distribution network, only some feeders give a positive value for the loss reduction when DGs are present.

The study shows that, when total network is considered, always there is a loss reduction and a financial benefit from DGs added to the system.

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Chapter 1

1. INTRODUCTION

1.1 Distributed Generation

Distributed Generation (DG) is the use of small generating units installed in strategic points of the power system, and specially close to load centers [2]. There are many technologies applied for the DG in the world such as,

- Combined Cycle Gas Turbine
- Combustion Engine
- Combustion Turbine
- Fuel Cells
- Small Hydro
- Wind Turbine
- Solar
- Biomass
- Ocean Energy
- Battery Storage

DG systems provide many benefits to the utility [3]. They may level the load curve, improve the voltage profile across the feeders, may reduce the loading level of branches and substation transformers and provide environment benefits by offsetting the pollutant emissions.

At the same time utility economic benefits also include loss reduction, avoided cost of energy production, generation capacity, distribution and transmission capacity investment deferral, reducing risk from uncertain fuel prices, green pricing benefits, etc.

DG causes an impact on losses in the power system due to its proximity to the load centers. DG units should be allocated in places where they provide a higher reduction of losses. This process of DG allocation is similar to capacitor allocation to minimize losses. The main difference is that the DG units cause impact on both active and reactive power, while capacitor banks only have impact in the reactive power flow.

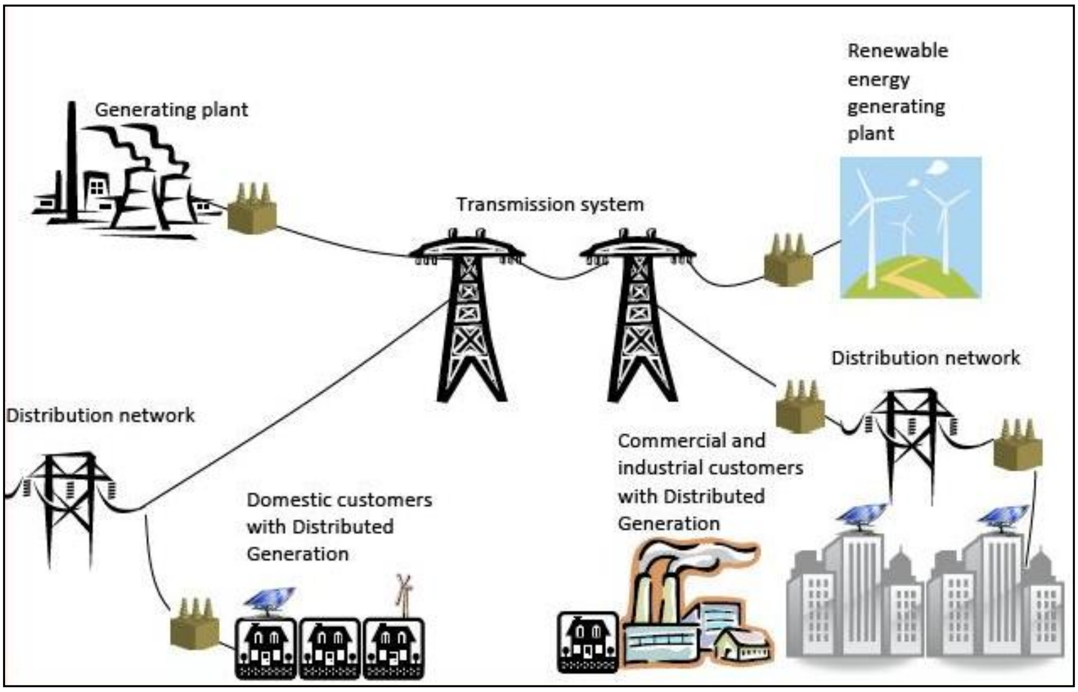

Figure 1.1 : Dynamic Diagram of how DG connected to the Power System.

1.2 Objective of the project

To estimate the impact of Distributed Generation on transmission and distribution losses in Sri Lanka power system.

1.3 Methodology

The methodology followed in this study is listed below.

- Study the Sri Lanka power system to identify the areas where the DG is commonly used in the power system.
- Study the transmission network and calculate the transmission losses due to DGs by using PSSE software.
- Study the distribution network and select most suitable feeders from the distribution network and calculate the loss figures by using SynerGEE software.
- Analyze the loss data and estimate the cost saving due to the DGs in the System.

1.4 Sri Lanka Power System with DG

Due to the geo-climatic conditions, Sri Lanka is blessed with several forms of energy sources. As an island, Sri Lanka receives rain from two monsoonal wind regimes. It is characterized by a central highland, lowland mountain ranges, flat terrains and plateaus. The annual mean rainfall ranges from 750 to 5000 mm, which in turn sources a perennial river system as well as has yielded a high plant density in the island. It receives a year round supply of solar radiation. The tropical temperature and the islands location in the ocean have resulted in distinct wind regimes. These settings have endowed the country with an ample renewable energy resource base.

So, main renewable energy resources available in Sri Lanka to generate electricity are hydro power, solar, wind and biomass. These power generating projects are mainly at resource locations and connected to the power system as distributed generating units, island wide.

1.4.1 Small Hydro Power Plants

The small hydro industry is typically characterized by hydro power projects with a capacity less than 10 MW. The economically feasible small hydro potential in Sri Lanka is estimated to be 400 MW [4].

As at January 2015, 142 small hydro power projects have been connected to the national grid with a total capacity of 293 MW [5]. All these plants are connected to the distribution network as DGs.

1.4.2 Wind Power Plants

Wind Energy Resource Atlas compiled by the National Renewable Energy Laboratory (NREL) of USA in year 2003, has identified three major wind resource regions such as North-western coastal region, Central highlands in the interior of the country and parts of Sabaragamuwa and Uva provinces [4]. The meteorological potential of all wind sites in Sri Lanka is 25,000 MW. But due to system absorption limitations only 200 MW of this is feasible to be developed according to the present system parameters.

There are 15 wind power plants which have been connected to the Sri Lanka power system with a total capacity of 123.8 MW, as at January 2015 [5]. Out of that, eight power plants with each 10 MW capacity are connected to the transmission network and the rest is connected to the distribution network. So, out of the total wind capacity of 123.8 MW, 53.85 MW is connected to the distribution network.

1.4.3 Solar Power Plants

Sri Lanka is situated close to the equator, therefore receives an abundant supply of solar radiation year around and a substantial potential exists in the dry zone of Sri Lanka for harnessing solar energy.

Four solar power plants with the total capacity of 1.4 MW are connected to the distribution network, as at January 2015 [5]. At the same time many solar power plants under the net metering concept are also connected to the system. Technically, any renewable resource like hydro, wind, solar and biomass can be net-metered. But at household level, solar PV systems are the preferred option, owing to resource availability, smaller space requirements and ease of operation and maintenance.

1.4.4 Biomass Power Plants

Biomass is the most common source of energy supply in the country, with the majority usage coming from the domestic sector for cooking purposes. Due to the abundant availability, only a limited portion of the total biomass usage is channeled through a market and hence the value of the energy sourced by biomass is not properly accounted. Biomass resource from energy plantation (specially from Gliricidiasepium) could prove to be the most vital component in meeting non-conventional renewable energy targets.

There are six biomass power plants from both agricultural waste and dendro power, with a total capacity of 23.5 MW which are connected to the power system as at January 2015 [5].

The capacities of each DG technology connected to the Sri Lanka power system, mentioned above can be summarized as shown in Table 1.1 below.

Table 1.1:Summary of DGs connected to Sri Lanka power system(January 2015)

Technology	**No. of Plants**	**Added capacity to the System (MW)**
Small Hydro	142	293.269
Wind	15	123.850
Solar	4	1.378
Biomass	6	23.500
Total	**167**	**441.997**

According to the Table 1.1, 167 power plants have contributed to generate 441.667 MW from renewable energy sources as at January 2015.It is a contribution of 9.8% from the annual energy generation.

Chapter 2

2. TRANSMISSION LOSS CALCULATION

Sri Lanka transmission network of year 2013 was used for the calculation and analyzing purposes in the project. The transmission network diagram for year 2013 is shown in Annex A - 1 and Annex B - 1. This network was used in PSSE software in different calculation scenarios for the study.

2.1 Calculation Scenarios

Different calculation scenarios were used for the data calculation and purpose of analyzing. The two main basis for the different scenarios were used are time basis and the load basis.

2.1.1 Time Basis

The daily load curve of 9th April 2013, shown in Figure 2.1 was considered for the time basis scenario. This is the day which is having the highest night peak value in year 2013.

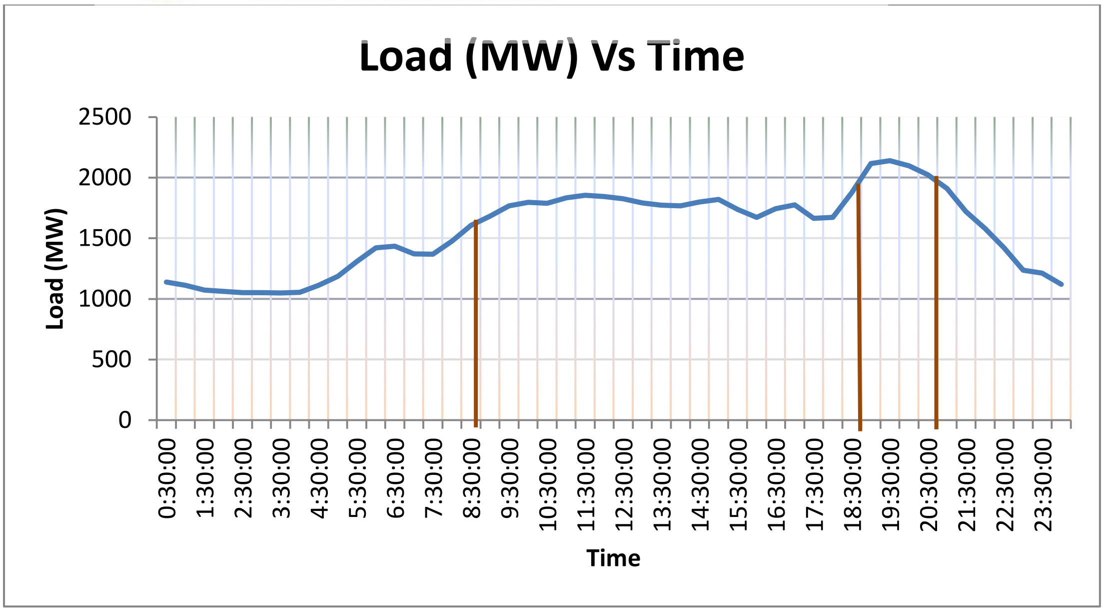

Figure 2.1: Load curve of 9th April 2013

To get an extreme end calculation, this day was considered rather than using an average load profile. Considering the load profile of the selected day, the day is divided into three main peak values as Night Peak, Day Peak and Off Peak as below.

- Night Peak of 2140.9 MW for 2 hours (from 18.30 hrs to 20.30 hrs)
- Day Peak of 1853.5 MW for 12 hours (from 08.30 hrs to 18.30 hrs)
- Off Peak of 1048.7 for 10 hours (from 20.30 hrs to 08.30 hrs)

2.1.2 Load Basis

The loading percentage of the DGs in the system can be varied time to time due to so many reasons. As the main objective is to determine the loss figures related to the DGs added to the system, the main two load basis was selected as 100% loading of DGs and 0% loading of DGs. Simply it is with the full loading of DGs and with no loading of DGs. And one scenario was taken in to consideration by evaluating the past generation data of the mini hydro power plants. As the majority of the DGs are consisting of mini hydro, monthly generation data of past 3 years was considered for this basis. When analyze the past data, it was revealed that even the installed capacity is having a higher value, normal loading percentage was around 40% from the installed capacity. Hence three load basis scenarios was taken as,

- Full Loading of DGs – DGs are fully loaded.
- 40% Loading of DGs – As the DGs are loaded only up to 40% of installed capacity.
- Without Loading DGs – When DGs are not operated.

The transmission loss was calculated by using PSSE software for the transmission network of year 2013. The loss figures are shown in Table 2.1. The network diagram while running the PSSE software is shown in Annex C - 1.

Table 2.1: Transmission loss figures calculated by using PSSE software.

Scenario	Transmission Loss (MW)		
	Night Peak	Day Peak	Off Peak
With Full DG (100%)	70.9	43.5	16.0
With 40% Loaded DG	82.4	44.8	16.1
Without DG (0%)	87.6	47.7	16.3

2.2 Data Analysis for Transmission Loss calculation

The calculated losses can be presented as a percentage of the relevant peak value as below.

<u>With full DG</u>

Night Peak loss percentage = (70.9 / 2140.9) x 100 = 3.31%
Day Peak loss percentage = (43.5 / 1853.5) x 100 = 2.35%
Off Peak loss percentage = (16.0 / 1048.7) x 100 = 1.52%

The calculated percentage losses for all scenarios can be summarized as in Table 2.2.

Table 2.2: Transmission Loss

Scenario	Transmission Loss (% from peak demand)		
	Night Peak	Day Peak	Off Peak
With Full DG	3.31	2.35	1.52
With 40% Loaded DG	3.85	2.42	1.53
Without DG	4.09	2.57	1.55

The energy loss of transmission network can be estimated from the loss factor method as given below [6].

$$\text{Loss factor} = a \times (\text{Load Factor}) + b \times (\text{Load Factor})^2$$

Where a = 0.2 and b = 0.8 for the transmission network [6] and Load Factor for transmission network at selected day can be calculated as below.

$$\text{Load Factor} = \frac{\text{Average Load of the System}}{\text{Peak Load of the System}}$$

Average load of the System = 1561.27 MW
Peak load of the System = 2140.9 MW
Load Factor of the system = 1561.27 / 2140.9
= 0.7293

Accordingly Loss Factor for the system can be calculated as,
Loss Factor of the system = 0.2 x (0.7293) + 0.8 x $(0.7293)^2$
= 0.5714

Then,
Transmission Energy Loss (kWh) = Peak Power Loss (kW) x Time (hrs) x Loss Factor

Accordingly, annual transmission energy loss can be calculated as below.

With full DG
Transmission energy loss per day = 70.9 x 24 x 0.5714
= 972.29 MWh
Annual transmission energy loss = 972.29 x 365 MWh
= 354.89 GWh

Further this figure can be shown as a percentage value from the annual generation of that year.

Annual generation for year 2013 [7] is 11, 962 GWh.
Therefore, Annual Loss in % = (354.89 / 11, 962) x 100
= 2.97 %

Table 2.3 shows the summary of annual transmission energy loss and the percentage of the loss from the annual generation.

Table 2.3 : Annual Transmission Energy Loss and Percentage Loss

Scenario	**Annual Transmission Energy Loss (GWh)**	**Energy Loss Percentage from Annual Generation (%)**
With 100% loaded DG	354.89	2.97
With 40% Loaded DG	412.45	3.45
Without DG	438.48	3.67

When comparing the loss percentages, it is clear that there is a percentage reduction of 0.70% when the DGs are fully loaded and 0.22% when the DGs are loaded for 40% of installed capacity.

2.3 Comparison of Transmission Energy Loss Reduction

According to the loss figures mentioned in Table 2.1, it can be compared with the difference of the loss figures at different loading. It is proven that, when the DGs are connected to the system, the transmission loss has been reduced by a significant level.

2.3.1 Energy Loss reduction with 40% loading of DG

Daily energy loss with 40% loading	= 1,130.00 MWh
Annual energy loss with 40% loading	= 412.45 GWh
Daily energy loss with 0% loading	= 1,201.31 MWh
Annual energy loss with 0% loading	= 438.48 GWh

Daily energy loss reduction with 40% loading = (1,201.31 – 1,130.00) MWh
= 71.31 MWh

Annual energy loss reduction with 40% loading = (438.48 – 412.45) GWh
= 26.03 GWh

2.3.2 Energy Loss reduction with full DG

Daily energy loss with 100% loading = 972.29 MWh

Annual energy loss with 100% loading = 354.89 GWh

Annual energy loss with 0% loading = 438.48 GWh

Daily energy loss reduction with 100% loading = (1,201.31 – 972.29) MWh
= 229.02 MWh

Annual energy loss reduction with 100% loading = (438.48 – 354.89) GWh
= 83.59 GWh

Summarized energy loss reduction can be tabulated as in Table 2.4.

Table 2.4 : Summary of Energy Loss Reduction in Transmission Network.

Scenario	Daily Energy Loss Reduction (MWh)	Annual Energy Loss Reduction (GWh)
With 40% DG	71.31	26.03
With 100% DG	229.02	83.59

Chapter 3

3. DISTRIBUTION LOSS CALCULATION

In Sri Lanka power system, DGs are connected to the distribution network island wide depending on the resource location. Study and apply the SynerGEE software for each and every feeder in Sri Lanka distribution network is a very time consuming task which cannot be successfully completed during a restricted time frame.

Therefore, the distribution loss calculation was done for selected few feeders. They were selected considering the DG capacity addition to the network and grid load. While selecting the feeders for data calculation, total number of feeders in the grid substation was selected rather than selecting the feeders individually. Then it was used to apply the demand of the grid substation which is the demand at the grid used in transmission network calculation.

To get an accurate output relevant to the DGs, four grid substations were selected which are having a higher contribution of DGs out of the total DG capacity. The selected grid substations for the detailed study are Badulla, Rathnapura, Kiribathkumbura and Ukuwela. Out of the total capacity of DGs which is around 293 MW, these four grid substations are contributed to add 80 MW of DG capacity to the distribution network. This is a percentage of around 27 from the total mini hydro capacity in Sri Lanka network. The details of the selected grid substations can be summarized as in Table 3.1 below.

Table 3.1: Selected Grid Substations for the Distribution Loss Calculation

Grid Substation	Night Peak Load of the Grid (MW)	Added Capacity of DGs to the Distribution Feeder (MW)
Badulla	46.7	14.6
Kiribathkumbura	71.0	16.7
Rathnapura	22.7	38.0
Ukuwela	58.2	10.0
Total	198.6	79.3

The distribution network diagrams of the selected grid substations were used for the calculation. They were used in SynerGEE software in different calculation scenarios for the study.

3.1 Calculation Scenarios

The calculation scenarios for the calculation are same as the scenarios used in transmission loss calculation with some additional load basis. Time basis is same as the Night Peak, Day Peak and Off Peak mentioned in transmission loss calculation. Even three load basis scenarios were used in transmission loss calculation, to get a smooth variation of the loss figures it was used more load basis scenarios for distribution loss calculations. It is starting from 0% to 100% loading with 5% step increments in the loading value. Then it gives 20 loss figures, corresponding to those loading steps.

Distribution loss calculation was done by using the individual grid substation in the SynerGEE software.

3.2 Loss Calculation – Ukuwela Grid Substation

Ukuwela grid substation supplies around 52.8 MW of night peak demand and a capacity of 10.0 MW of DGs is connected to the distribution network. An overview of SynerGEE software for Ukuwela grid substation is shown in Figure No.3.1. Peak load values of Ukuwela grid substation on 9th April 2013 are,

- Night Peak – 58,250 kW
- Day Peak – 37,150 kW
- Off Peak – 28,540 kW

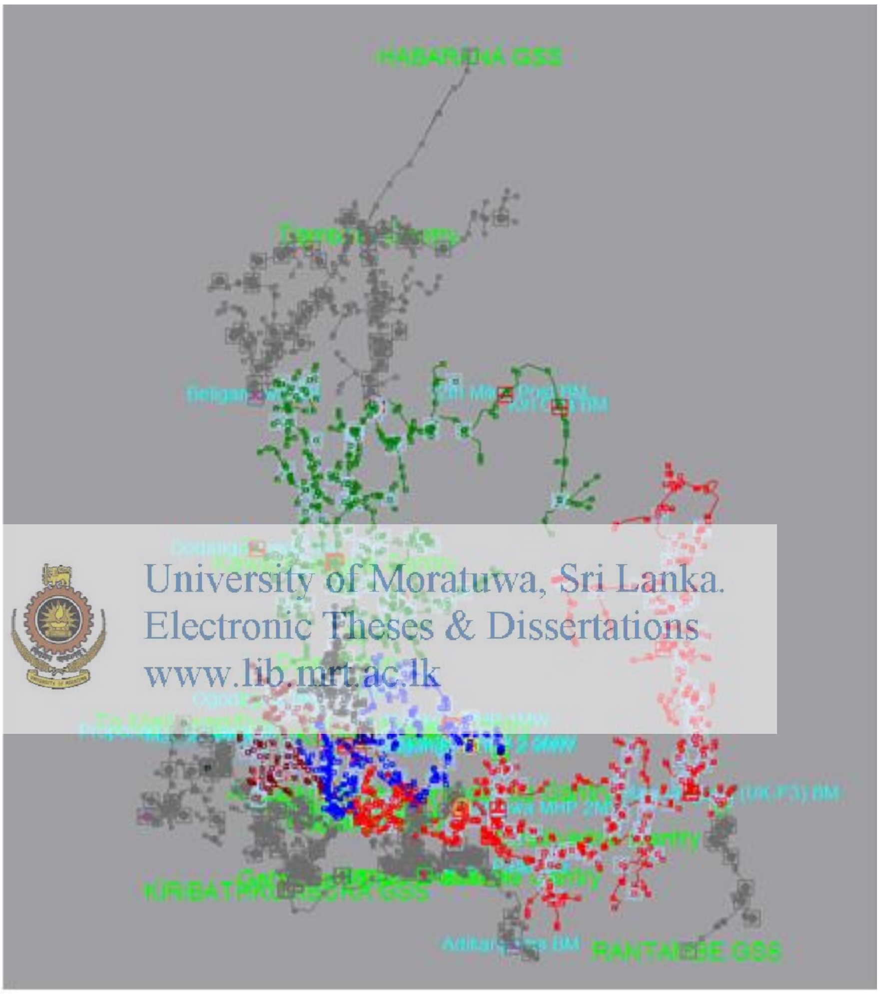

Figure 3.1: Overview of Ukuwela Grid Substation Feeders in SynerGEE software.

The calculated power loss figures by using SynerGEE software of Ukuwela grid substation are shown in Table 3.2 below.

Table 3.2: Power Loss Figures of Ukuwela Grid Substation

DG%	Power Loss (kW)		
	Night Peak	Day Peak	Off Peak
0	2,663	1,038	603
5	2,591	995	571
10	2,525	957	544
15	2,465	925	523
20	2,411	898	506
25	2,362	876	495
30	2,319	859	488
35	2,280	846	486
40	2,247	838	488
45	2,218	835	494
50	2,194	836	504
55	2,175	841	519
60	2,160	850	537
65	2,149	862	559
70	2,143	879	585
75	2,141	900	614
80	2,142	924	647
85	2,147	951	684
90	2,156	983	723
95	2,169	1,017	766
100	2,186	1,055	813

Graphical view of the loss data can be shown as in Figure 3.2.

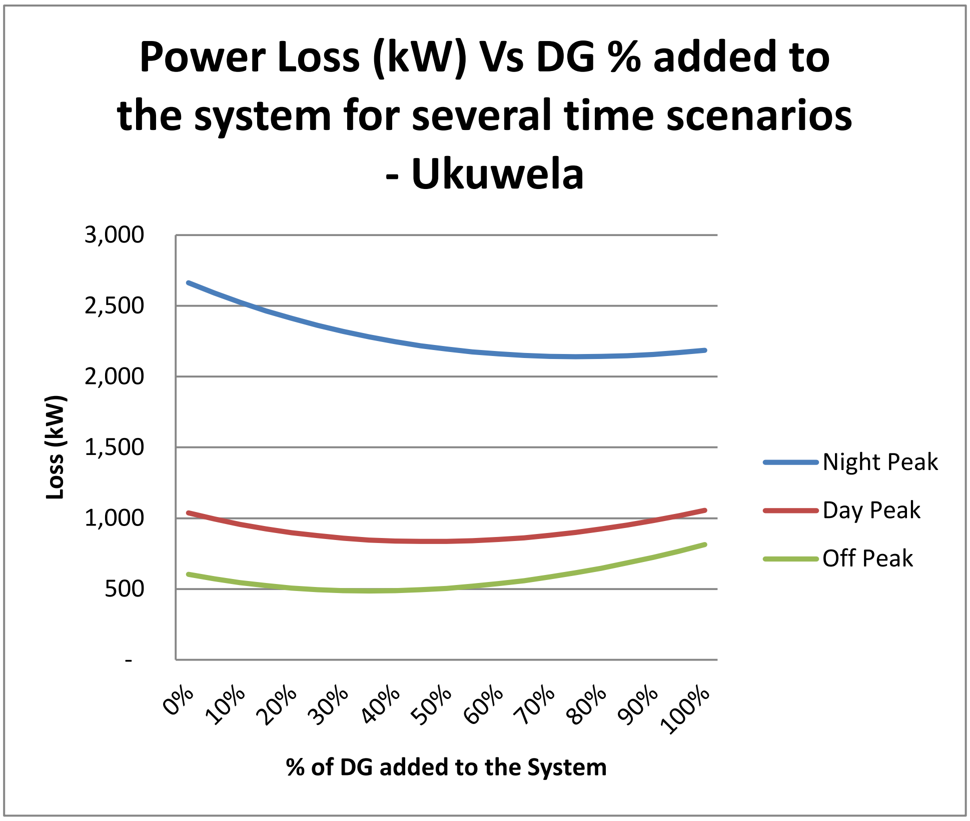

Figure 3.2: Power Loss (kW) Vs DG% added to the system

According to the Figure 3.2, it can be seen that, the loss has gradually reduced and has increased when the DG is gradually added to the system. Night Peak loss is much higher than the Off Peak loss.

Accordingly the annual energy loss can be calculated as mentioned below.

The empirical formula, known as Jungs's formula has been used for evaluation of Utilization time of losses (UTL) [7].

$$UTL = \frac{e^2(2+e^2) \text{ x } 8760}{(1 + 2e)} \text{ hrs/ year}$$

Where, e is the load factor of the system.

e = 0.555 for Ukuwela Area [7].

$$\text{Then, } UTL_{\text{Ukuwela}} = \frac{[(0.555)^2 \text{ x } (2 + (0.555)^2)] \text{ x } 8760}{(1 + 2 \text{ x } 0.555)} \text{ hrs / year}$$

$$= 2{,}952 \text{ hrs /year}$$

If the peak power loss of the system is $P_{loss-pk}$, then the energy loss E_{loss} is,

$$E_{loss} = P_{loss-pk} \text{ x UTL per year}$$

Where $P_{loss-pk}$ is derived from load flow studies by using SynerGEE software.

For 0% of DG in Table 3.2,

Annual energy loss = 2,663 x 2,952 kWh

= 7.861GWh

Annual energy loss for each loading scenario of Ukuwela grid substation is tabulated in Table 3.3.

Table 3.3: Annual Energy Loss at Ukuwela Grid Substation.

DG%	DG (MW)	$P_{loss-pk}$ (kW)	Annual Energy Loss (GWh)
0	0.0	2,663	7.861
5	0.5	2,591	7.649
10	1.0	2,525	7.454
15	1.5	2,465	7.277
20	2.0	2,411	7.117
25	2.5	2,362	6.973
30	3.0	2,319	6.846
35	3.5	2,280	6.731
40	4.0	2,247	6.633
45	4.5	2,218	6.548
50	5.0	2,194	6.477
55	5.5	2,175	6.421
60	6.0	2,160	6.376
65	6.5	2,149	6.344
70	7.0	2,143	6.326
75	7.5	2,141	6.320
80	8.0	2,142	\6.323
85	8.5	2,147	6.338
90	9.0	2,156	6.365
95	9.5	2,169	6.403
100	10.0	2,186	6.453

The graphical view of the Annual Energy Loss data shown in Table 3.3 can be shown as in Figure 3.3.

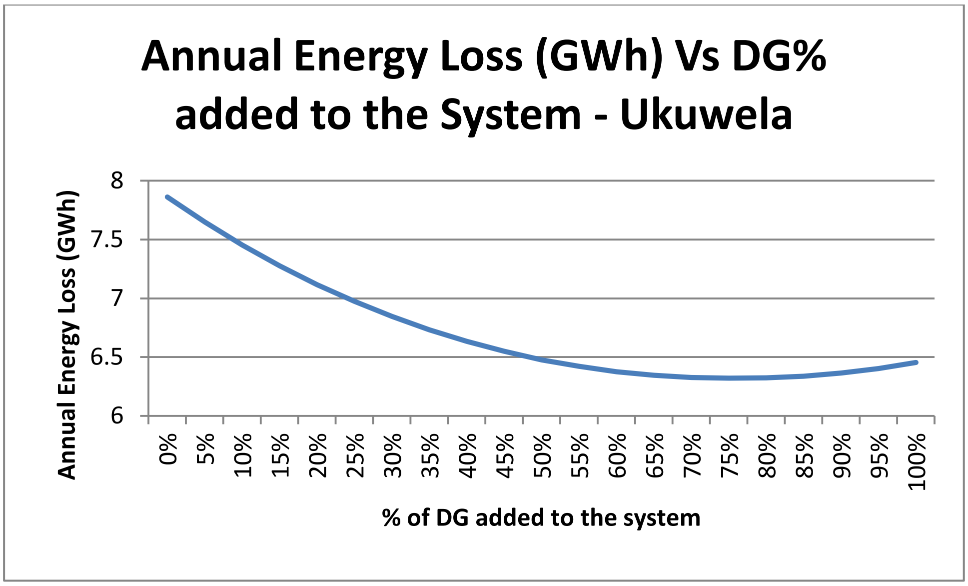

Figure 3.3: Annual Energy Loss (GWh) Vs DG% added to the System for Ukuwela Grid Substation.

According to the Figure 3.3, minimum annual energy loss is visible when the DGs are loaded at 75 percent from the installed capacity.

3.3 Loss Calculation – Badulla Grid Substation

Badulla grid substation has a 46.7 MW of Night Peak load and a total capacity of 14.6 MW of DGs is connected to the system. An overview of SynerGEE software for Badulla grid substation is shown in Figure 3.4. Peak load values of the Badulla grid substation on 9th April 2013 are,

- Night Peak – 46,750 kW
- Day Peak – 30,090 kW
- Off Peak – 22,910 kW

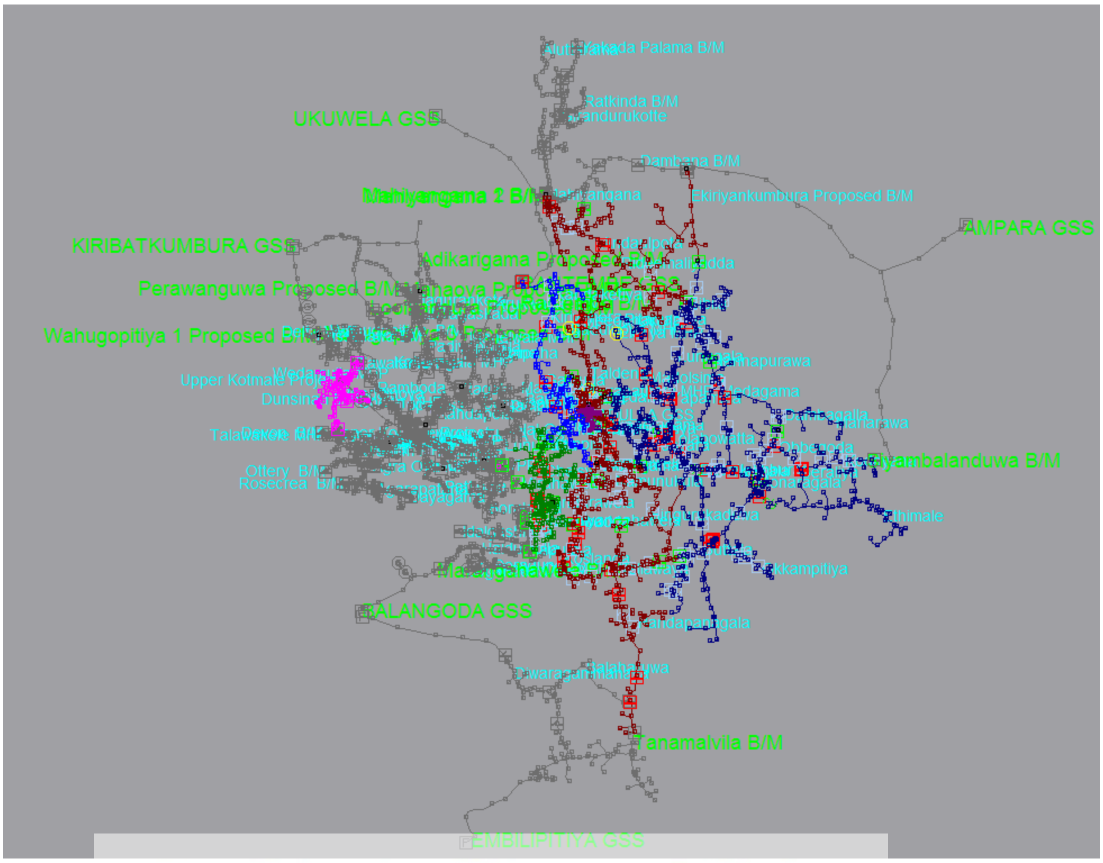

Figure 3.4: Overview of Badulla Grid Substation feeders in SynerGEE software.

The calculated power loss figures by using SynerGEE software of the Badulla grid substation are shown in Table 3.4 below.

Table 3.4: Power Loss at Badulla Grid Substation

DG%	Power Loss (kW)		
	Night Peak	Day Peak	Off Peak
0	3,398	1,328	766
5	3,282	1,265	721
10	3,174	1,209	682
15	3,075	1,159	649
20	2,985	1,116	622
25	2,902	1,078	600
30	2,826	1,047	583
35	2,758	1,021	572
40	2,696	1,000	566
45	2,641	985	565
50	2,593	975	568
55	2,550	970	576

60	2,514	970	589
65	2,483	975	606
70	2,458	984	627
75	2,438	998	653
80	2,424	1,016	682
85	2,414	1,038	716
90	2,409	1,065	754
95	2,409	1,095	795
100	2,414	1,129	840

Graphical view of the loss data can be shown as in Figure 3.5.

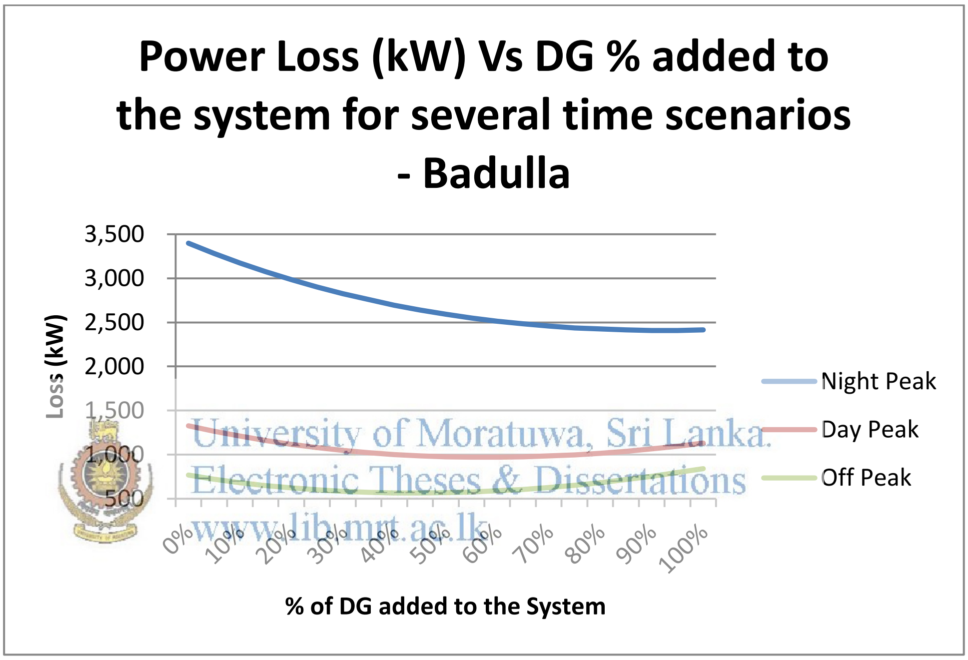

Figure 3.5: Power Loss (kW) Vs DG% added to the system

Here also, it is clear that the loss has gradually decreased and increased again with the loading of the DGs gradually.

Accordingly the annual energy loss can be calculated as mentioned below.

Load Factor for Badulla Area [7],

$e_{badulla} = 0.555$

Then, $UTL_{Badulla} = \frac{[(0.555)^2 \times (2 + (0.555)^2)] \times 8760}{(1 + 2 \times 0.555)}$ hrs / year

$= 2{,}952$ hrs /year

For 0% of DG in Table 3.4,

Annual energy loss = 3,398 x 2,952 kWh

= 10.031 GWh

Annual energy loss for each loading scenarios are calculated and tabulated as in Table 3.5.

Table 3.5: Annual Energy Loss at Badulla Grid Substation.

DG%	DG (MW)	$P_{loss-pk}$ (kW)	Annual Energy Loss (GWh)
0	0.0	3,398	10.031
5	0.7	3,282	9.688
10	1.5	3,174	9.370
15	2.2	3,075	9.077
20	2.9	2,985	8.812
25	3.7	2,902	8.567
30	4.4	2,826	8.342
35	5.1	2,758	8.142
40	5.9	2,696	7.959
45	6.6	2,641	7.796
50	7.3	2,593	7.655
55	8.1	2,550	7.528
60	8.8	2,514	7.421
65	9.5	2,483	7.330
70	10.2	2,458	7.256
75	11.0	2,438	7.197
80	11.7	2,424	7.156
85	12.4	2,414	7.126
90	13.2	2,409	7.111
95	13.9	2,409	7.111
100	14.6	2,414	7.126

The graphical view of the annual energy loss data shown in Table 3.5 can be shown as in Figure 3.6.

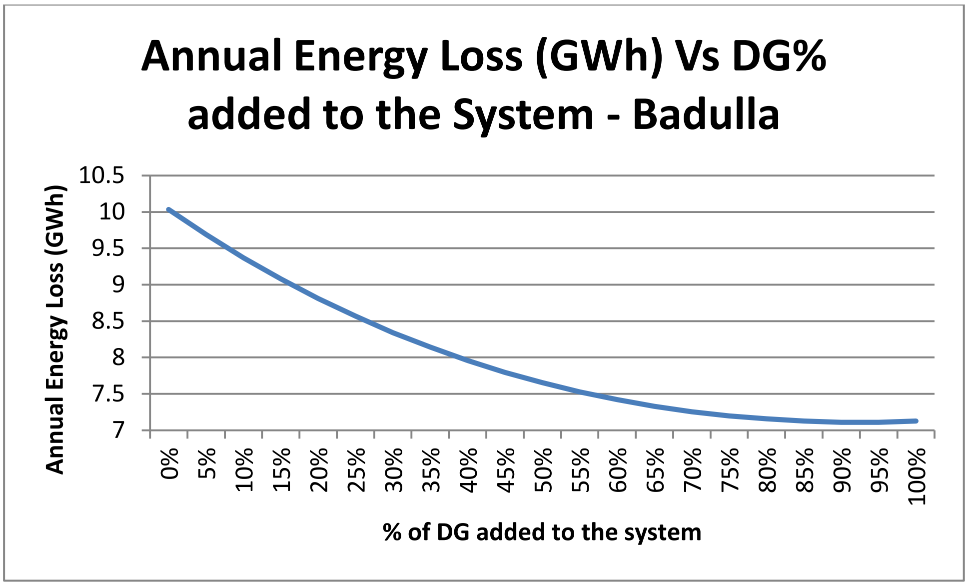

Figure 3.6: Annual Energy Loss (GWh) Vs DG% added to the System for Badulla Grid Substation.

According to the Figure 3.6, minimum annual energy loss is visible when the DGs are loaded at 90 and 95 percent from the installed capacity.

3.4 Loss Calculation – Kiribathkumbura Grid Substation

Kiribathkumbura grid substation is consisting of 71.0 MW of Night Peak load and a capacity of 16.7 MW of DGs is connected to the system. An overview of SynerGEE software for Kiribathkumbura grid substation is shown in Figure 3.7. Peak load values of the Kiribathkumbura grid substation on 9th April 2013 are,

- Night Peak – 71,010 kW
- Day Peak – 43,090 kW
- Off Peak – 34,780 kW

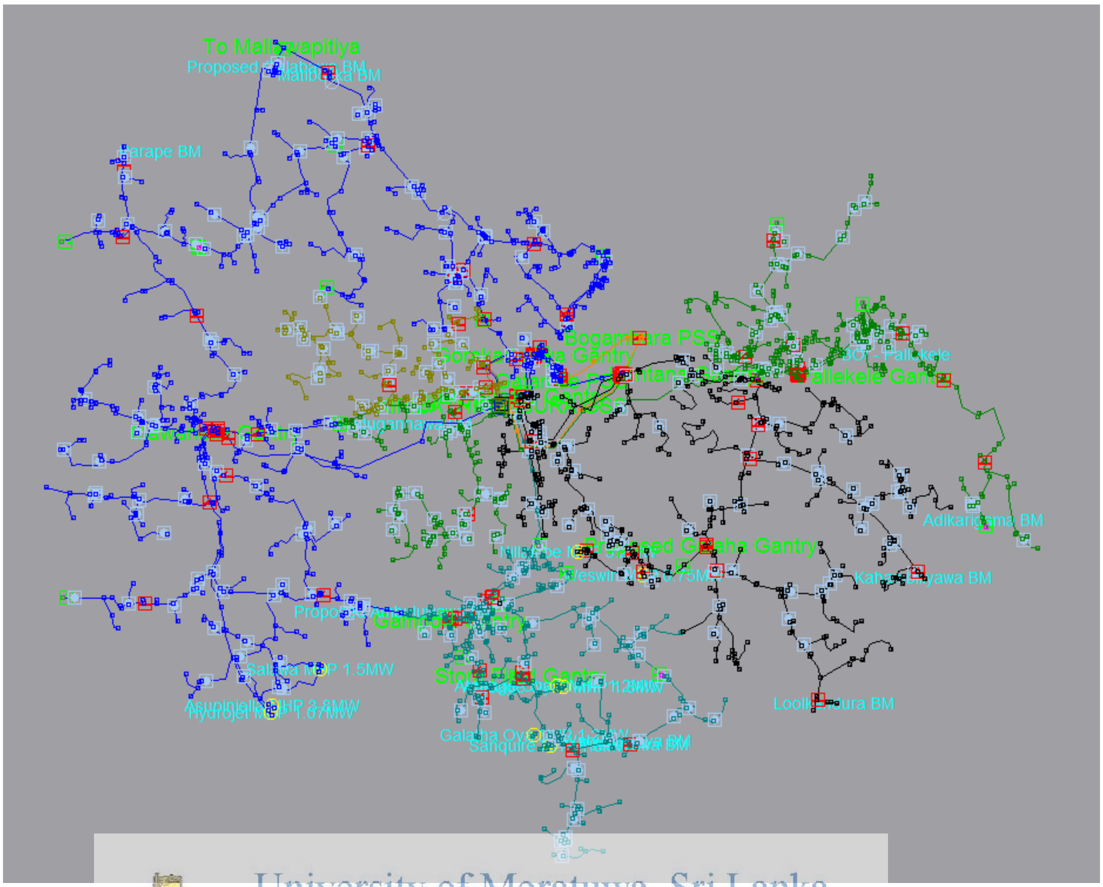

Figure 3.7: Overview of Kiribathkumbura Grid Substation feeders in SynerGEE software.

The calculated power loss values by using SynerGEE software of the Kiribathkumbura grid substation are shown in Table 3.6 below.

Table 3.6: Power Loss at Kiribathkumbura Grid Substation

DG%	Power Loss (kW)		
	Night Peak	Day Peak	Off Peak
0	2,051	754	488
5	2,006	728	468
10	1,967	706	451
15	1,925	684	435
20	1,889	666	423
25	1,856	651	413
30	1,826	639	406
35	1,798	629	402

40	1,774	622	400
45	1,752	618	401
50	1,733	616	404
55	1,717	617	410
60	1,703	620	418
65	1,692	626	429
70	1,684	634	442
75	1,678	645	457
80	1,674	657	475
85	1,673	673	495
90	1,675	690	517
95	1,678	710	542
100	1,685	732	569

Graphical view of the loss data can be shown as in Figure 3.8.

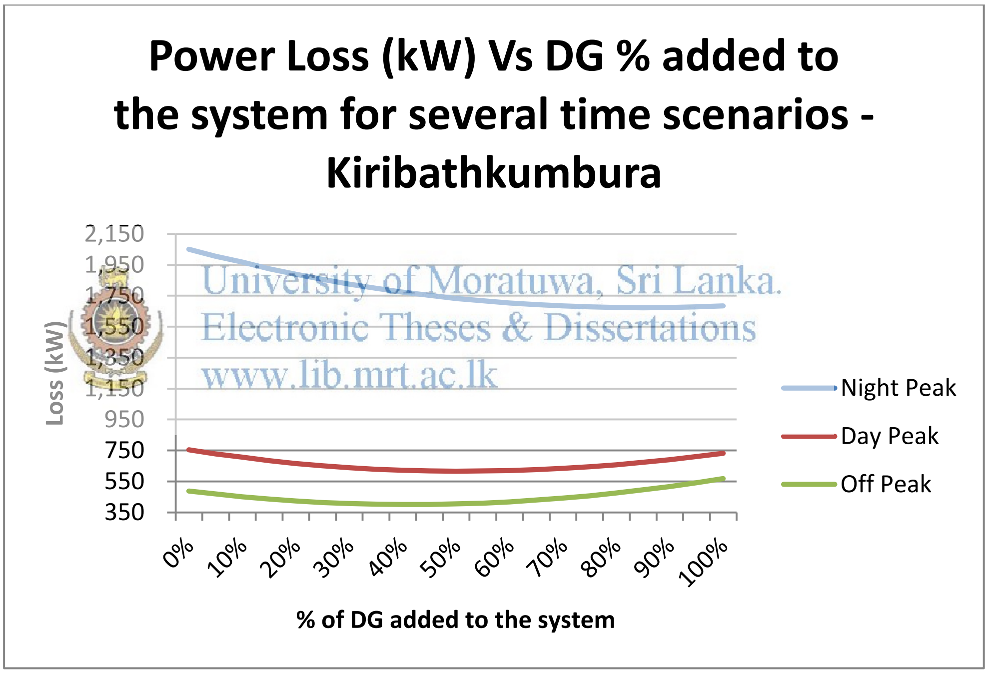

Figure 3.8: Loss (kW) Vs DG% added to the system

Here also, it is clear that the loss has gradually decreased and increased again with the loading of the DGs gradually.

Accordingly the annual energy loss can be calculated as shown below.

Load Factor for Kiribathkumbura area [7],

$e_{\text{Kiribathkumbura}} = 0.555$

Then, $\text{UTL}_{\text{Kiribathkumbura}}$

$$= \frac{[(0.555)^2 \text{ x } (2 + (0.555)^2)] \text{ x } 8760}{(1 + 2 \text{ x } 0.555)} \text{ hrs / year}$$

$$= 2{,}952 \text{ hrs /year}$$

For 0% of DG in Table 3.6,

Annual energy loss = 2,051 x 2,952 kWh

= 6.055 GWh

Annual energy loss for each loading scenarios are calculated and tabulated as in Table 3.7.

Table 3.7: Annual Energy Loss at Kiribathkumbura Grid Substation.

DG%	DG (MW)	$P_{loss-pk}$ (kW)	Annual Energy Loss (GWh)
0	0.0	2,051	6.055
5	0.8	2,006	5.922
10	1.7	1,967	5.807
15	2.5	1,925	5.683
20	3.3	1,889	5.576
25	4.2	1,856	5.479
30	5.0	1,826	5.390
35	5.8	1,798	5.308
40	6.7	1,774	5.237
45	7.5	1,752	5.172
50	8.3	1,733	5.116
55	9.2	1,717	5.069
60	10.0	1,703	5.027
65	10.9	1,692	4.995
70	11.7	1,684	4.971
75	12.5	1,678	4.953
80	13.4	1,674	4.942
85	14.2	1,673	4.939
90	15.0	1,675	4.945
95	15.9	1,678	4.953
100	16.7	1,685	4.974

The graphical view of the annual energy loss data shown in Table 3.7 can be shown as in Figure 3.9.

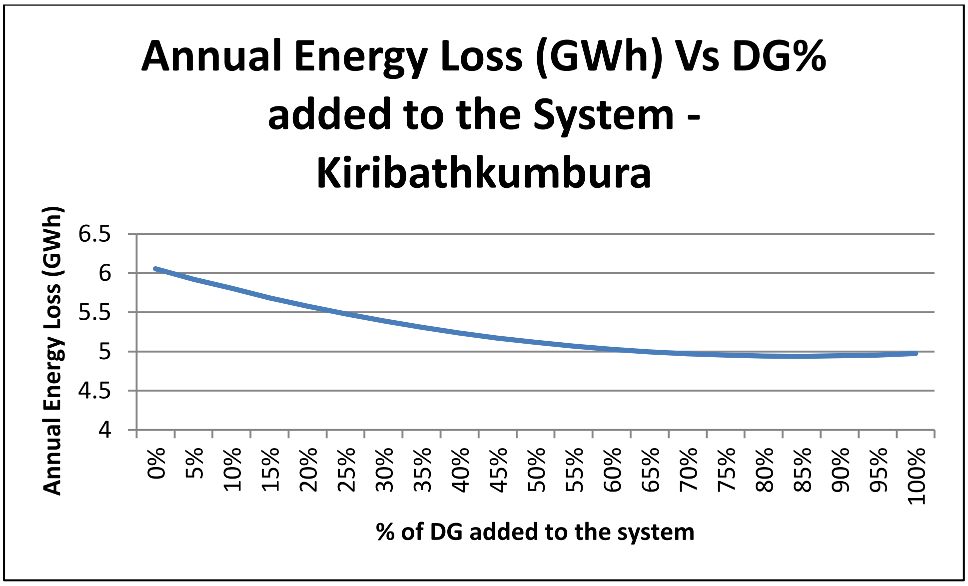

Figure 3.9: Annual Energy Loss (GWh) Vs DG% added to the System for Kiribathkumbura Grid Substation.

According to the Figure 3.9, minimum annual energy loss can be seen when the DGs are loaded at 85 percent from the installed capacity.

3.5 Loss Calculation – Rathnapura Grid Substation

Rathnapura grid substation is consisting of 22.7 MW of Night Peak load and a capacity of 38 MW of DGs is added to the system. An overview of SynerGEE software for Rathnapura grid substation is shown in Figure 3.10. Peak Load values of the Rathnapura grid substation on 9th April 2013 are,

- Night Peak – 22,710 kW
- Day Peak – 11,510 kW
- Off Peak – 11,130 kW

The calculated power loss figures of the Rathnapura grid substation by using SynerGEE software are shown in Table 3.8.

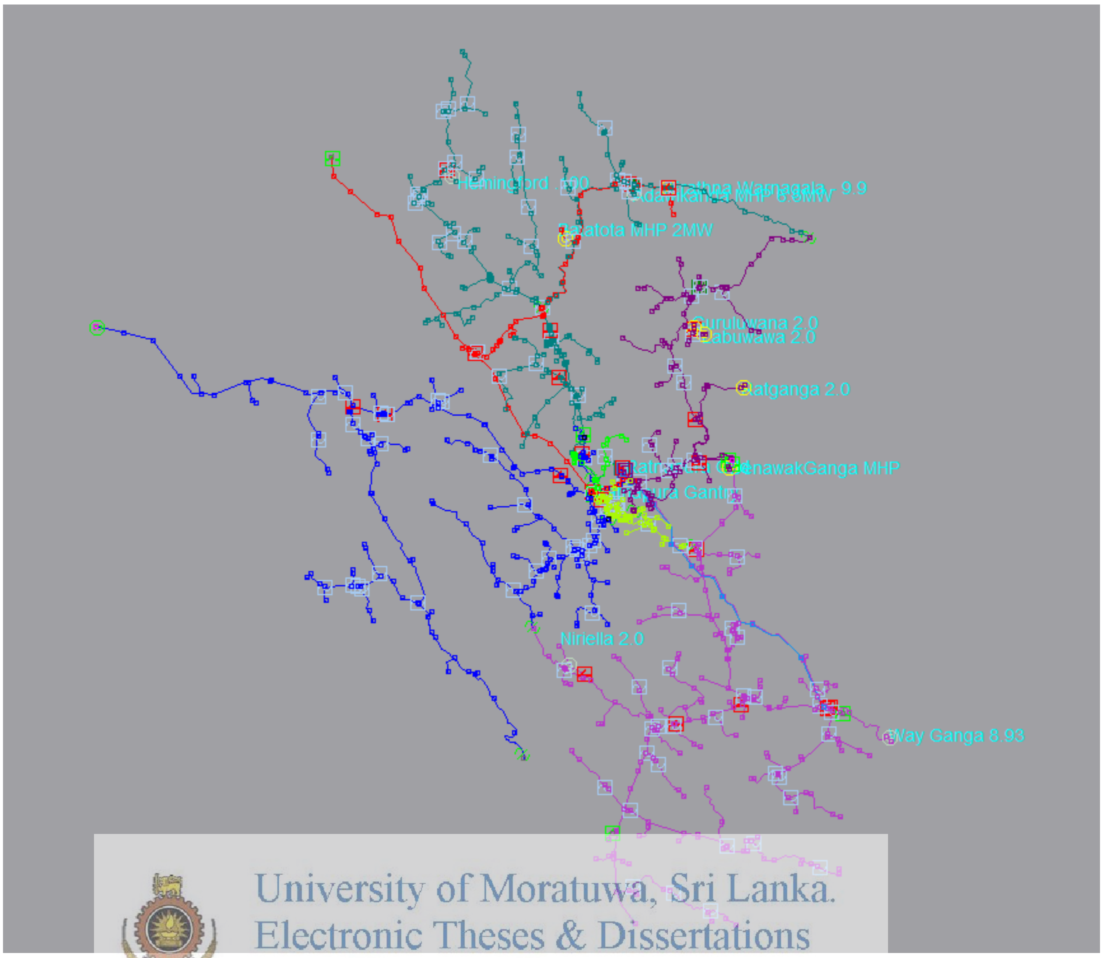

Figure 3.10: Overview of Rathnapura Grid Substation feeders in SynerGEE software.

Table 3.8: Power Loss at Rathnapura Grid Substation

DG%	Power Loss (kW)		
	Night Peak	Day Peak	Off Peak
0	459	131	123
5	418	112	106
10	387	104	98
15	367	106	101
20	356	118	114
25	356	140	136
30	366	171	168
35	385	212	210
40	414	262	260
45	452	321	320
50	500	388	388
55	556	465	465

60	621	549	551
65	694	643	644
70	776	744	746
75	859	853	856
80	958	971	974
85	1,066	1,096	1,100
90	1,182	1,229	1,234
95	1,305	1,369	1,375
100	1,436	1,517	1,524

Graphical view of the loss data can be shown as in Figure 3.11.

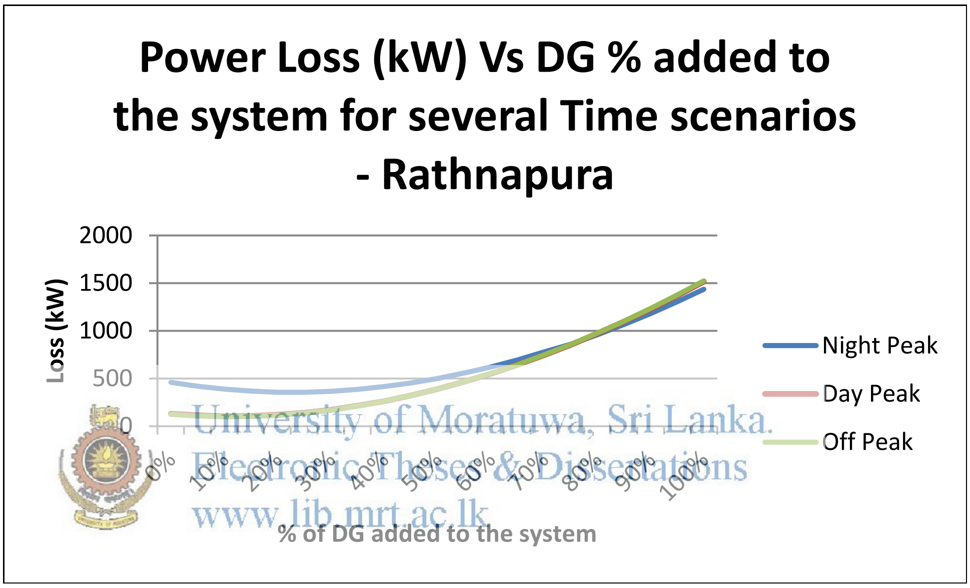

Figure 3.11: Loss (kW) Vs DG% added to the system

The situation in Rathnapura grid substation is totally different compared to other grid substations. Here when the DGs are gradually added to the system, the power loss figure is gradually increased rather than decreasing. As the DG capacity added to the system is higher than the peak demand of the grid substation feeders, the balance or the excess power generation should be transferred to the transmission network. For that the power flow from the generation point should come to the grid substation. Hence, loss in that case is higher than if the generation of energy is utilized in that load center, when considering the distribution network. But when it comes to transmission network it is a loss reduction factor.

Accordingly the annual energy loss can be calculated as shown below.

Load Factor for Rathnapura area [9],

$e_{\text{Rathnapura}} = 0.450$

Then, $UTL_{\text{Rathnapura}}$ $$= \frac{[(0.450)^2 \times (2 + (0.450)^2)] \times 8760}{(1 + 2 \times 0.450)} \text{ hrs / year}$$

$= 2{,}056$ hrs /year

For 0% of DG in Table 3.8,

Annual energy loss $= 459 \times 2{,}056$ kWh

$= 0.944$GWh

Annual energy loss for each loading scenarios are calculated and tabulated as in Table 3.9.

Table 3.9: Daily Power Loss Figures of Rathnapura Grid Substation.

DG%	DG (MW)	$P_{loss-pk}$ (kW)	Annual Energy Loss (GWh)
0	0.0	459	0.944
5	1.9	418	0.859
10	3.8	387	0.796
15	5.7	367	0.755
20	7.6	356	0.732
25	9.5	356	0.732
30	11.4	366	0.752
35	13.3	385	0.792
40	15.2	414	0.851
45	17.1	452	0.929
50	19.0	500	1.028
55	20.9	556	1.143
60	22.8	621	1.277
65	24.7	694	1.427
70	26.6	776	1.595
75	28.5	859	1.766
80	30.4	958	1.970
85	32.3	1,066	2.192
90	34.2	1,182	2.430
95	36.1	1,305	2.683
100	38.0	1,436	2.952

The graphical view of the annual energy loss data shown in Table 3.9 can be shown as in Figure 3.12.

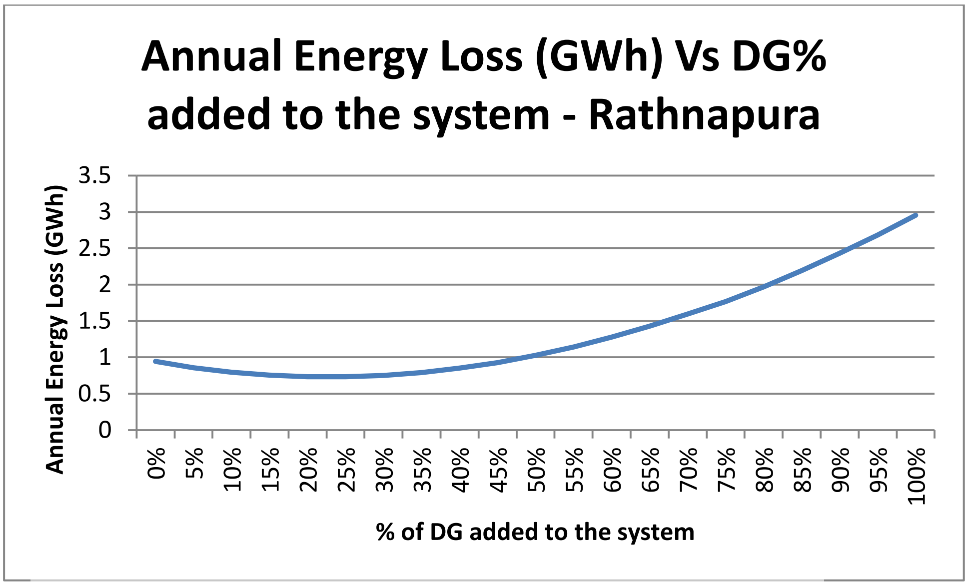

Figure 3.12: Annual Energy Loss (GWh) Vs DG% added to the System for Rathnapura Grid Substation.

Figure 3.12 shows that, addition of DGs results in an increase of distribution losses. The reason for this is in Rathnapura grid substation where added capacity of DGs is higher than the demand of the grid substation. Hence power flows from DG to transmission network via grid substation. It will result in increase of distribution loss while decreasing the transmission loss. However loading DGs less than the demand of the grid substation is more economical.

Chapter 4

4. ECONOMIC ANALYSIS OF LOSS REDUCTION

4.1 Cost Saving due to Transmission Loss Reduction

4.1.1 Energy Cost Saving due to reduction of Transmission Loss

Energy cost saving due to transmission loss reduction can be calculated by referring the Table 2.4 and the marginal generation cost shown in Table 4.1 below. Marginal generation cost is the unit generation cost of the next power plant to be dispatched according to the merit order dispatch of CEB. This is mainly based on thermal power plants.

Table 4.1: Marginal Generation Costs in year 2013.

Time	**Unit Cost (LKR/kWh)**
Night Peak	24.16
Day Peak	23.85
Off Peak	21.77

Weighted average of the marginal generation costs was calculated for the costing of transmission energy loss calculation.

Weighted average of marginal generation cost = (24.16 x 2 + 23.85 x 12 + 21.77 x 10) / 24

= 23.01 LKR / kWh

Accordingly, cost of transmission energy loss can be calculated as below.

With Full DG (100%)

Cost of loss per day = LKR 70.9 x 24 x 0.5714 x 23.01

= LKR Million 22.372

Annual cost of losses = LKR (22.372 x 365)

= LKR Million 8,165.8

With 40% DG

Cost of loss per day = LKR 82.4 x 24 x 0.5714 x 23.01

= LKR Million 26.001

Annual Cost of losses = LKR (26.001 x 365)

= LKR Million 9,490.4

With 0% DG

Cost of loss per day = LKR 87.6 x 24 x 0.5714 x 23.01

= LKR Million 27.642

Annual Cost of losses = LKR (27.642 x 365)

= LKR Million 10,089.3

The energy cost saving in transmission network due to the DGs, can be summarized as in Table 4.2.

Table 4.2: Energy Cost Saving of transmission network due to DGs

Scenario	**Annual Cost of Transmission Energy Loss(LKR Million)**	**Energy Cost Saving due to DG (LKR Million)**
Without DG	10,089.3	-
With 40% DG	9,490.4	598.9
With 100% DG	8,165.8	1,923.5

4.1.2 Capacity Cost Saving due to reduction of Transmission Loss

For the calculation of capacity cost saving, average capacity charge of Independent Power Producers (IPP) for year 2013 was considered. It is 2.95 LKR per kWh.

Referring the Table 2.4 and the average capacity charge of IPPs, annual capacity cost saving due to reduction of transmission loss was calculated and tabulated in Table 4.3.

Annual Capacity Cost Reduction = Annual Energy Loss reduction x Average Capacity Charge of IPP

Table 4.3: Capacity Cost saving of Transmission network due to DGs.

Scenario	Daily Energy Loss Reduction (MWh)	Annual Energy Loss Reduction (GWh)	Annual Capacity Cost saving (LKR Million)
With 40% DG	71.31	26.03	76.8
With 100% DG	229.02	83.59	246.6

4.2 Cost saving due to Distribution Loss Reduction

The cost saving figures of the selected four grid substations are added and taken for the cost analysis considerations. For the cost calculations, energy charge and the capacity charge were taken from the Medium Voltage Distribution System Development Plan 2013 – 2022, CEB – Region 2 [7].

C_e= Cost of Energy =LKR 24.66 / kWh

C_c = Capacity Cost = LKR 18,679 / kW / Year

Total cost of losses = Capacity Cost + Energy Cost

i.e. Annual Cost of Losses = $C_c \times P_{loss-pk} + C_e \times E_{loss}$

4.2.1 Energy Cost Saving due to reduction of Distribution Loss

The summary of energy cost saving due to reduction of distribution losses was tabulated in Table 4.4.

Table 4.4: Energy Cost saving in Distribution network

DG %	Annual Energy Loss (GWh)				Total Annual Energy Loss (GWh)	Annual Cost of Energy Loss (LKR Million)	Annual Cost Saving of Energy Losses due to DGs (LKR Million)
	Badulla	Kiribathkumbura	Rathnapura	Ukuwela			
0	10.03	6.06	0.94	7.86	24.89	613.81	0.00
5	9.69	5.92	0.86	7.65	24.12	594.75	19.06
10	9.37	5.81	0.80	7.45	23.43	577.71	36.10
15	9.08	5.68	0.76	7.28	22.79	562.05	51.76
20	8.81	5.58	0.73	7.12	22.24	548.36	65.45
25	8.57	5.48	0.73	6.97	21.75	536.38	77.43
30	8.34	5.39	0.75	6.85	21.33	526.00	87.81
35	8.14	5.31	0.79	6.73	20.97	517.19	96.62
40	7.96	5.24	0.85	6.63	20.68	509.97	103.84
45	7.80	5.17	0.93	6.55	20.45	504.17	109.64
50	7.66	5.12	1.03	6.48	20.28	500.01	113.80
55	7.53	5.07	1.14	6.42	20.16	497.17	116.64
60	7.42	5.03	1.28	6.38	20.10	495.69	118.12
65	7.33	5.00	1.43	6.34	20.10	495.57	118.24
70	7.26	4.97	1.60	6.33	20.15	496.85	116.96
75	7.20	4.95	1.77	6.32	20.24	499.02	114.79
80	7.16	4.94	1.97	6.32	20.39	502.84	110.97
85	7.13	4.94	2.19	6.34	20.60	507.87	105.94
90	7.11	4.95	2.43	6.37	20.85	514.19	99.62
95	7.11	4.95	2.68	6.40	21.15	521.56	92.25
100	7.13	4.97	2.95	6.45	21.51	530.31	83.50

4.2.2 Capacity Cost Saving due to reduction of Distribution Loss

The summary of capacity cost saving due to reduction of distribution losses was tabulated in Table 4.5.

Table 4.5 : Capacity Cost Saving due to reduction of Distribution Losses.

DG %	Annual Capacity cost of Losses (LKR Million)				Total Annual Capacity Cost (LKR Million)	Annual Cost saving in Capacity Cost (LKR Million)
	Badulla	Kiribathkumbura	Rathnapura	Ukuwela		
0	63.47	38.31	8.57	49.74	160.09	00.0
5	61.30	37.47	7.81	48.40	154.98	5.11
10	59.29	36.74	7.23	47.16	150.42	9.67
15	57.44	35.96	6.86	46.04	146.30	13.79
20	55.76	35.28	6.65	45.04	142.73	17.36
25	54.21	34.67	6.65	44.12	139.65	20.44
30	52.79	34.11	6.84	43.32	137.06	23.03
35	51.52	33.58	7.19	42.59	134.88	25.21
40	50.36	33.14	7.73	41.97	133.20	26.89
45	49.33	32.73	8.44	41.43	131.93	28.16
50	48.43	32.37	9.34	40.98	131.12	28.97
55	47.63	32.07	10.39	40.63	130.72	29.37
60	46.96	31.81	11.60	40.35	130.72	29.37
65	46.38	31.60	12.96	40.14	131.08	29.01
70	45.91	31.46	14.49	40.03	131.89	28.20
75	45.54	31.34	16.05	39.99	132.92	27.17
80	45.28	31.27	17.89	40.01	134.45	25.64
85	45.09	31.25	19.91	40.10	136.35	23.74
90	45.00	31.29	22.08	40.27	138.64	21.45
95	45.00	31.34	24.38	40.51	141.23	18.86
100	45.09	31.47	26.82	40.83	144.21	15.88

Chapter 5

5. CONCLUTIONS

Cost saving of both transmission and distribution network due to DGs added to the system can be summarized as in Table 5.1.

Table 5.1: Summary of Transmission and Distribution Loss Reduction.

Scenario	Transmission Loss Reduction (LKR Million)		Distribution Loss Reduction (LKR Million)		Total Loss Reduction per year (LKR Million)
	Energy Cost	Capacity Cost	Energy Cost	Capacity Cost	
Loss Reduction with 40% Loading	599	77	104	27	807
Loss Reduction with full DG	1,924	247	84	16	2,271

This is the total loss reduction per year due to the DGs added to Sri Lanka power system. In the other words this is the additional annual cost that should be added to the system expenditure, if the DGs were not connected to the power system.

However for the distribution loss analysis, only four grid substations were considered due to difficulty of collecting data within limited time duration. The result can be optimized if all DG connected grid substations are considered.

According to Table 5.1, annual loss reduction due to DGs connected to the system, with 40% loading and full loading both contribute to loss reduction in a significant level. When both scenarios are compared, transmission loss reduction is much less in 40% loading scenario than the 100% loading scenario. But in distribution side, it is the opposite of that. Distribution loss reduction is higher in 40% loading scenario. The main reason for that is the loss of Rathnapura grid substation. There, generation from DGs is much higher than the demand in that grid. So the excess generation is transferred to the transmission network after a long power transmission distance in the distribution network. But when it comes to the transmission network, loss reduction is given a much higher positive value.

Finally, it can be concluded that the study shows, when total Sri Lanka power network is considered, always there is a loss reduction and a significant financial benefit from the DGs added to the system.

However, it can be suggested to extend this study further to find out the optimum DG capacity that can be connected to a particular grid substation to have the maximum loss reduction, as it is proven that there is a positive benefit.

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ANNEXES