Energy Efficiency and Conservation Authority
Te Tari Tiaki Pūngao

Summary of Maunsell Report "Costs and Benefits of Connecting Distributed Generation to Local Networks" Prepared for EECA

Date : February 2009

Prepared by : S. Torrens

Important note

Neither EECA nor the author accept any liability for loss or damage occurring as a consequence of reliance on any information and/or analysis contained in this report.

Executive Summary

Introduction

1. This paper provides a summary of the report "Costs and benefits of connecting distributed generation to local networks", prepared by Maunsell. EECA commissioned this work to help quantify the economic impacts of distributed generation (DG) on local distribution networks.

2. We note that the study was not intended to analyse the total net economic benefit that DG may provide to society. In some circumstances DG may not necessarily provide a net benefit to its local distribution network. It may *still* provide a net benefit to the economy though, once all other costs and benefits are taken into account. These include DG technology costs, avoided centralised generation costs, and benefits associated with increased competition, reduced environmental impacts (relative to centralised generation) and improved energy supply diversity.

3. The economic impacts of DG on the following two distribution networks were studied:

   - A hypothetical "optimised network". The components making up this network (e.g. cables, distribution transformers etc.) were selected so as to minimise total costs throughout the planning period to avoid any bias caused by 'over' or 'under' design that might occur in a real network. Other characteristics of the network were more or less typical of other networks in New Zealand; and,

   - A sample section of an existing network representative of a typical New Zealand urban distribution system.

4. For each network the net present value[1] for all major costs incurred over a 22 year planning period were estimated and compared for a range of DG scenarios. Estimated costs included capital costs, operating and maintenance costs and costs associated with supply reliability, power quality and network energy losses. The DG scenarios covered:

   - Different DG market growth rates;

   - DG connected at different network voltage levels; and,

   - Different proportions of intermittent DG (where output is variable and uncertain) and firm DG (where output can be relied upon to meet peaks in network demand).

Scenarios with firm DG

5. The effect of connecting firm DG at a growth rate of 10%, 25% and 50% of annual network demand growth was analysed for the optimised and sample distribution networks. For both networks it was shown that the addition of firm DG can **reduce** overall network costs (i.e. provide an overall benefit to the network). Higher DG growth rates result in proportionately higher cost reductions. The analysis was relatively insensitive to changes in the DG connection voltage level.

[1] Where all costs and benefits incurred in the future are converted to present values (or values in today's dollars) using an assumed discount rate.

6. The analysis excluded costs associated with DG installation and operation. This includes, in particular, the cost of network reinforcement that may be required to initially connect DG. This cost is typically considered a capital investment that should be borne by the DG developer and recovered through lines company charges. An estimate of DG connection costs was made for the optimised network and indicated that if these costs are included in the analysis, DG will **increase** overall network costs.

Scenarios with intermittent DG

7. The effect of intermittent DG, such as wind or solar photovoltaics, was analysed for the optimised network. It was shown that in comparison to firm DG, intermittent DG provides less benefits to the distribution network. With high DG growth rates there is a positive, though reduced, network benefit even for relatively high proportions of intermittent DG. For low DG growth rates, though, even a relatively small proportion of intermittent DG increased total distribution network costs.

Further work

8. The study high lights a number of areas for further work including:

   - Quantifying the typical magnitude of DG connection costs;
   - Assessing the economic impact of DG for a range of much more focussed scenarios that consider specific network locations with specific sizes and types of DG; and,
   - Investigating the impact of future technologies and whether there are any barriers to uptake for these technologies.

Introduction

1. The paper provides a summary of the report "Costs and benefits of connecting distributed generation to local networks", prepared by Maunsell[2]. EECA commissioned this work to help quantify the economic impacts of distributed generation (DG) on local distribution networks and the transmission grid. This will, in turn, improve understanding of the likely future role of DG in New Zealand. This work also contributes towards the NZEECS action "Raise awareness of the benefits and costs of distributed generation".

2. For the purposes of this study DG refers to electricity generation that is connected to a local distribution network rather than the transmission grid. DG encompasses a wide range of technologies and can range in size from 1 kW household systems through to 50 MW mid-sized commercial power stations.

Methodology

3. The economic impacts of DG on the following two distribution networks[3] were studied:

   - A hypothetical "optimised network"[4]. The components making up this network (e.g. cables, distribution transformers etc.) were optimised or selected to minimise the total costs throughout the planning period. Other characteristics of the network (such as the proportion of underground cables, system losses etc) were more or less typical of other networks in New Zealand.

   - A sample section of a existing distribution network[5] representative of a typical urban mixed overhead and underground network.

4. An optimised network was analysed to avoid bias caused by any 'over' or 'under' design that might occur in a real network and so provide a benchmark to compare the impact of DG on actual distribution networks in New Zealand. It also avoided the necessity of obtaining access to network information that may either be commercially sensitive or difficult to obtain. The sample distribution network was studied to validate the analysis of the optimised network.

5. For each network the net present value[6] of all major costs incurred over a 22 year planning period were estimated and compared for a range of DG scenarios. Estimated costs included capital costs, operating and maintenance costs and costs associated with supply reliability, power quality and network energy losses. Key assumptions used to estimate costs are described in Appendix 2. The DG scenarios covered:

---

[2] Maunsell. (2008). *Costs and Benefits of Connecting Distributed Generation to Local Networks*. Prepared for the Energy Efficiency and Conservation Authority.

[3] Key characteristics of these networks are described in Appendix 1.

[4] It was assumed that the optimised network had some existing DG, sufficient to provide 10% of total network demand.

[5] For the existing distribution network it was assumed for simplicity that the low voltage network had characteristics similar to those of the optimised network.

[6] Where all costs and benefits incurred in the future are converted to present values (or values in today's dollars) using an assumed discount rate.

- *Different DG growth rates*, including a base case with zero DG growth. The term ‘DG growth rate’ refers to the proportion of annual network demand growth meet by new DG installed capacity.

- *DG connected at different voltage levels*. Distribution networks are comprised of high voltage (HV), medium voltage (MV) and low voltage (LV) levels as required for the efficient transport of electricity and to serve a variety of different consumers.

- *Different proportions of intermittent and firm DG* (analysed for the optimised network only). Firm DG is able to reliably contribute to peak network demand while intermittent DG has a variable and uncertain output.

6. Distribution networks were modelled using the software package PSS-SINCAL, widely used in both New Zealand and overseas. This was supplemented by excel spreadsheets as necessary.

DG impacts on distribution networks

7. The analysis considered the following DG impacts[7]:

- *Reduced network energy losses*. DG can reduce network energy losses by reducing the distance that energy is transported.

- *Improved power reliability.* DG provides another source of electricity supply to the network and this can potentially improve the reliability and reduce the number and duration of supply outages.

- *Reduced network upgrades*. DG consisting of multiple plant using a mix of technologies will be able to provide a reliable off-set against demand. In so doing the need for network upgrades required to cope with demand growth will be deferred or avoided.

- *Reduced power quality*. DG can cause a number of power quality issues. These include reduced network power factor, lack of reactive support, increased fault current levels and network protection issues.

8. The analysis *did not* consider:

- *Voltage issues*. DG will change the voltage profile of the network. This may cause problems if this results in voltage levels at consumer’s premises that exceed acceptable limits. For the DG considered in this study there were no significant voltage issues identified.

- *Harmonics*. Some types of distributed generation can cause harmonics, or high frequency variations in system voltage, which can affect consumer electrical equipment. For the purposes of this study it was assumed that all new DG will use equipment designed to minimise harmonic distortion.

---

[7] For a more complete introduction to the impacts of DG on networks please refer to Econnect Consulting. (2006). *Accommodating Distributed Generation, Econnect Project No: 1672*. Prepared for the UK Department of Trade and Industry.

9. The analysis excluded costs associated with DG installation and operation. This includes, in particular, the cost of network reinforcement that may be required to initially connect DG. This cost is typically considered a capital investment that should be borne by the DG developer and recovered through lines company charges. An estimate of DG connection costs was made for the optimised network for the purpose of discussion and comparison (see below).

Key results

Optimised network with firm DG

10. The analysis first considered the impact of firm DG on total distribution network costs. Nine scenarios were analysed covering different DG growth rates and with DG at different network locations. These scenarios are outlined in Table 1.

Table 1: Firm DG scenarios

DG growth rate	DG location
10%	High MV
10%	High LV
10%	Uniform at all voltage levels
25%	High MV
25%	High LV
25%	Uniform at all voltage levels
50%	High MV
50%	High LV
50%	Uniform at all voltage levels

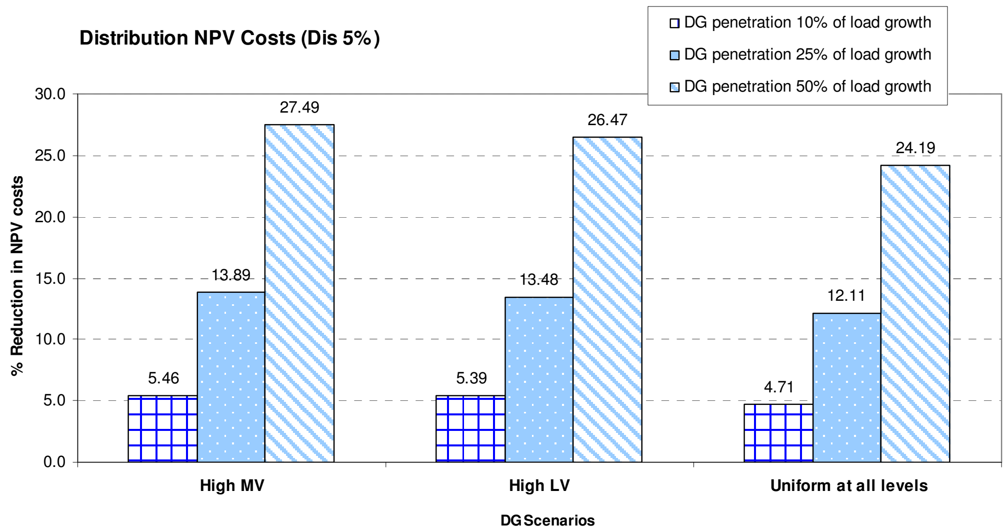
Notes to table:

1. DG growth rate is expressed as the percentage of annual network demand growth met by new DG capacity.
2. High MV: 60% of DG is connected at MV, 20% of DG is connected at LV and remainder is connected at HV.
3. High LV: 80% of DG is connected at LV and the remainder is connected at MV.
4. Uniform at all voltage levels: 30% of DG is connected at HV, 30% of DG is connected at MV and remainder is connected at LV.

11. The results of the analysis are shown in Figure 1 and show that firm DG can reduce (i.e. provide a benefit) total distribution network costs for a wide range of DG growth rates and with DG at different network locations.

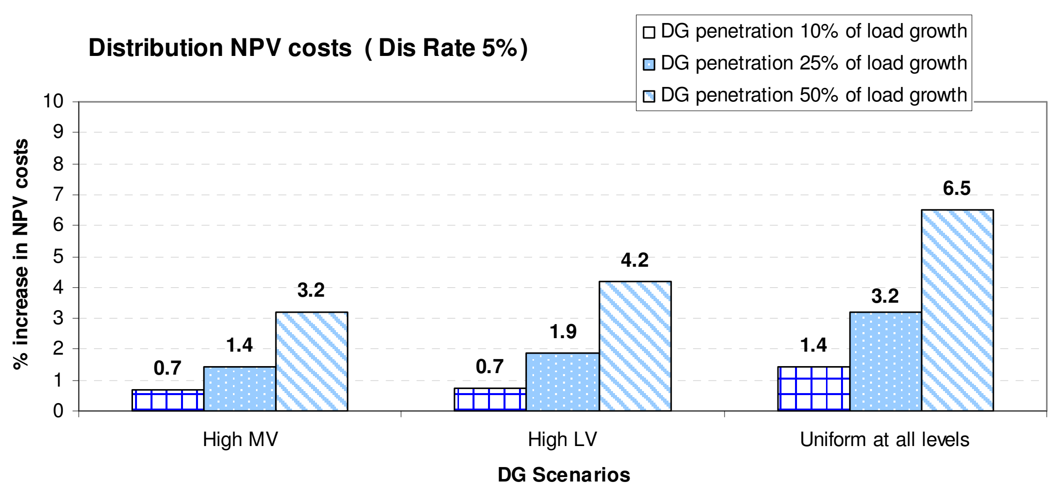
12. The reduction in total distribution network costs is roughly proportional to DG growth rate and is relatively insensitive to different DG network locations. The results shown in Figure 1 assume a 5% discount rate, although the *percentage* reduction in total distribution network costs is similar for a 10% discount rate.

Figure 1: Economic impacts of firm DG on the optimised network[8]



13. The analysis is confined to considering network losses, supply reliability, power quality and network upgrades required to meet demand growth. An indication of the effect of including DG connection costs in the analysis is shown in Figure 2. With these costs included total distribution network costs increase for all DG scenarios considered. This assumes the cost of connecting DG is roughly equal to the cost of meeting demand growth on a per MW basis. This assumption may not be correct in all circumstances and is likely to be conservative.

Figure 2: Economic impacts of firm DG on the optimised network - connection costs included[9]



[8] Maunsell. *op. cit.* p. 29.
[9] Maunsell. *op.cit.* p. 33.

Optimised network with intermittent generation

14. The impact of intermittent DG on the optimised network was also analysed, by considering different mixes of intermittent and firm generation, for different DG growth rates[10]. Twelve scenarios were considered as outlined in Table 2.

Table 2: Optimised DG scenarios

DG growth rate	Proportion of intermittent DG
10%	0%
10%	10%
10%	30%
10%	60%
25%	0%
25%	10%
25%	30%
25%	60%
50%	0%
50%	10%
50%	30%
50%	60%

Notes to table:

1. DG growth rate is expressed as the percentage of annual network demand growth meet by new DG capacity.

15. For each of three different DG growth rates the "equivalent" amount of firm DG capacity was kept constant with increasing amounts of intermittent DG. It was assumed that all intermittent DG would be able to contribute at least some firm generation, with the amount varying according to the type of energy resource used. For example, hydro is assumed in the analysis to reliably provide 55% of its installed capacity[11]. Under this assumption the total amount of *installed* DG capacity must increase with increasing proportions of intermittent DG if the equivalent amount of *firm* DG capacity is to remain constant.

16. Increasing the proportion of intermittent DG affects distribution network costs by:

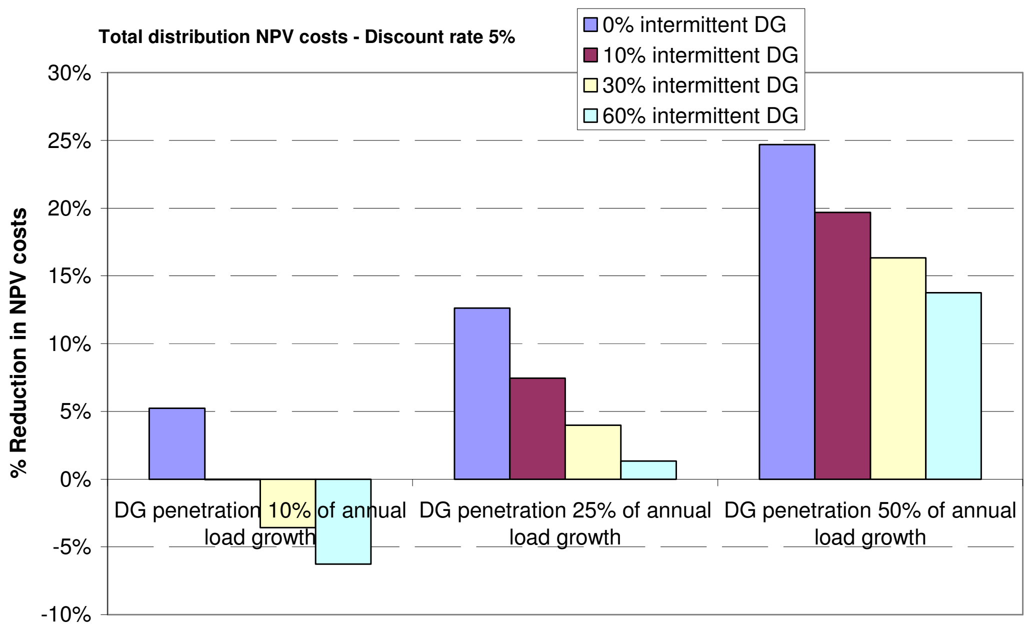
- Increasing network losses *relative* to a scenario where all DG is firm. The output from an intermittent generator will - due to its inherent variability - be out of sync with the load on the network. An intermittent generator is therefore less able to offset load and reduce network losses as compared to a firm generator; and

- Increasing DG connection costs. DG connection costs are proportional to the total amount of installed DG capacity which must increase with increasing proportions of intermittent DG (if the equivalent quantity of firm DG is to remain the same). The analysis below *excludes,* however, DG connection costs.

[10] DG network location was not varied.
[11] Maunsell. *op.cit.* p. 52.

17. The effect of different proportions of intermittent DG on total distribution network costs is shown in Figure 3. This indicates that increasing proportions of intermittent DG will reduce the economic benefit that DG can provide to a local network. With high DG growth rates there is a positive, though reduced, network benefit even for relatively high proportions of intermittent DG. For low DG growth rates only a relatively small proportion of intermittent DG increased total distribution network costs.

Figure 3: Economic impacts of intermittent DG on the optimised network[12]



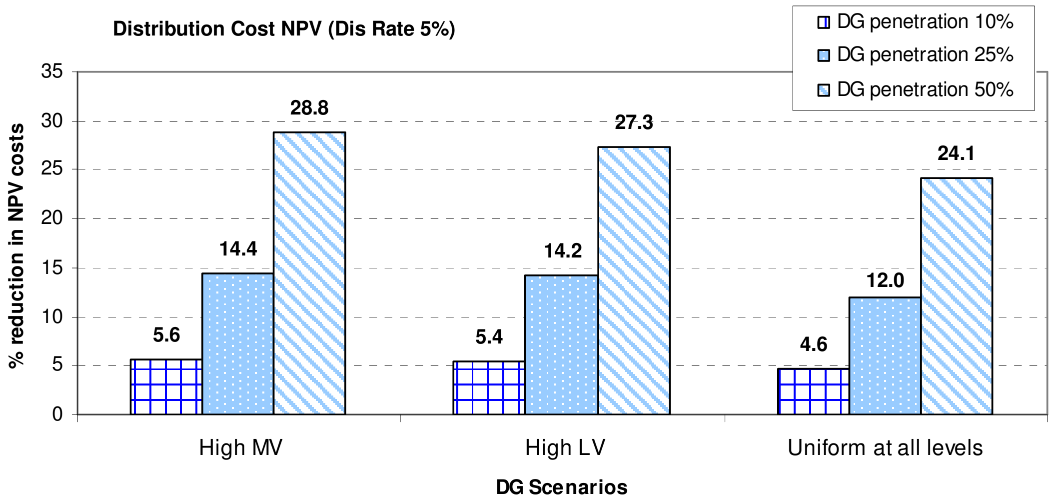
Existing network with firm distributed generation

18. To validate the results from the optimised network the impact of firm DG on a sample section of an existing urban distribution network has also been analysed. The same nine scenarios, covering a range of DG growth rates and network locations, were used as in the analysis of the optimised network (refer Table 1).

19. The analysis considered the impact of DG on the transmission grid as well as the distribution network[13]. The results of the analysis are shown in Figure 4 and indicate that the reduction in costs due to the connection of firm DG is similar in magnitude to the optimised network. While DG did reduce transmission costs the effect on the overall cost reduction shown in Figure 4 was relatively minor. This is because, in this instance, transmission costs were relatively small compared to distribution network costs over the planning period considered.

[12] Adapted from Table 8-2 in the Maunsell report
[13] DG connection costs were *excluded*.

Figure 4: Economic impacts of firm DG on an existing network[14]



EECA comments

Scope of the analysis

20. The study focuses on the economic impacts of DG on distribution networks. To understand the potential economic benefit that DG may provide in its entirety a broader range of costs and benefits would need to be considered, for example:

- DG installation and operation costs;
- Avoided large scale, centralised generation costs; and,
- Benefits associated with increased energy supply diversity, increased competition from new entrants and increased resilience of rural energy supply.

Cost of connecting DG

21. An estimate of the impact of the cost of connecting DG was only taken into account when considering the impact of firm generation on the optimised network. Given the potentially large magnitude of this cost further work in this area is required.

Aggregate vs. detailed analysis

22. Given the initial nature of this study the analysis was necessarily limited to considering a limited number of network configurations and focussed on the impacts of DG on aggregate. The impact of a specific DG installation, though, will vary considerably, with the size, location and type (firm or intermittent) of DG and characteristics of the network (e.g. urban vs. rural). Consider for example:

- DG on a long rural feeder. DG on long rural feeders can potentially defer the need for expensive upgrades due to demand growth. DG could consist of firm generation (e.g. diesel) or a combination of firm and intermittent generation (e.g. diesel and wind);

[14] Maunsell. *op.cit.* p. 42.

- DG on a industrial or commercial feeder with under-utilised standby generation (e.g. diesel gen-sets). With the right incentives this standby generation can be used to off-set peak demand and defer network investment or improve network reliability;

- Residential feeders with limited potential for DG (at least in the short term); and,

- New DG that requires a new feeder purpose built to connect to the distribution network.

23. For each of these scenarios the economic impact of DG will be different and there may be benefit in examining these specific situations in more detail. This would provide more useful information on the type of circumstances where the impacts of DG are either maximised or minimised.

Technology

24. For similar reasons the study also did not consider the impact of future changes in technology. For example, active network management or smart networks are a suite of new technologies that, among other benefits, can enable greater amounts of DG onto distribution networks. A recent study by the UK Centre for Distributed Generation and Sustainable Electricity Energy has shown that UK distribution networks with active network management will be able to accommodate about three times more DG than equivalent networks without active network management[15].

25. There are also other new technologies that will help “stretch” the capability of an existing distribution network. For example, solid state and superconducting current limiting devices will be able to limit severe faults, allowing greater amounts of DG without significantly increasing network energy losses[16].

Conclusions

26. The following major conclusions can be drawn from the study:

    - Firm DG reduced total network distribution costs for both networks analysed for a wide range of DG growth rates and different DG network locations. This result ignores DG connection costs, as they are typically regarded as a cost to be borne by the DG developer. If these costs are included DG may increase total distribution network costs; and

    - Intermittent DG reduces the network benefit provided by DG. For the optimised network with high DG growth rates there is a positive, though reduced, network benefit even for relatively high proportions of intermittent DG. For low DG growth rates, though, even a relatively small proportion of intermittent DG increased total distribution network costs.

27. Areas for further work include assessing:

    - Quantifying the typical magnitude of DG connection costs;

[15] McDonald. (2008). Adaptive intelligent power systems: Active distribution networks. *Energy Policy* 36 (2008) 4346 – 4351.
[16] Refer Econnect Report, page 77.

- Assessing the economic impact of DG for a range of much more focussed scenarios that consider specific network locations with specific sizes and types of DG; and,
- Investigating the impact of future technologies and whether there are any barriers to the uptake for these technologies.

Appendix 1 : Key Characteristics of the optimised and existing network[17]

	Optimised Network	Section of an existing network
Grid Exit Points	Two no. with connection at 33 kV sub-transmission level	One with connection at 33 kV sub-transmission level
Planning Horizon	From 2008 to 2030	From 2008 to 2030
OHL Feeders	• 100% at 33 kV • 70% at 11 kV • None at 0.4 kV	• 100% at 33 kV • 70% at 11 kV • None at 0.4 kV
Cable Feeders (underground)	• None at 33 kV • 30% at 11 kV • 100% 0.4 kV	• None at 33 kV • 30% at 11 kV • 100% 0.4 kV
Transformers (OLTC)	• 33 kV/11 kV – Zone substations • 11 kV/0.4 kV – Distribution Transformers (DT)	• 33 kV/11 kV – Zone substations • 11 kV/0.4 kV Distribution Transformers(DT)
Load Power Factor	0.95 lag	0.95 lag
Total System Load	111.4 MW	19.674 MW
LV Load *Residential*	50%	50%
MV Load *Commercial* *Industrial*	30% 20%	40% None
Voltage Tolerance	1.05 pu to 0.95 pu	1.05 pu to 0.95 pu
Existing Generation	None	None
LV Networks	Two networks with 0.28 MW load each. The load is unbalanced due to single phase supply to residential customers	All Distribution Transformers 11/0.4 kV supply LV networks
Total System Losses	7.5% of total load (typical to New Zealand DNOs)	7.17% of Total Load
Network Structure *Sub-Transmission* *MV Level* *LV Level*	• Ring configuration • Radial Feeder • Mains and lateral with an external standby tie feeder	• Ring configuration • Radial Feeder • Main and Lateral with an external standby tie feeder
Security criterion	n-1/n based on: • Thermal load limits • Power quality limits	n-1/n based on: • Thermal load limits • Power quality limits
Existing DGs	10% of total demand	None

[17] Maunsell. *op.cit.* p. 14 and 40.

Appendix 2 : Key assumptions for cost benefit analysis[18]

General Parameters		Value	Units
O&M and Admin Cost		10%	of CAPEX
Energy Loss Value		90	$/MWhr
Cost of Energy Not Supplied (ENS)	Financial Analysis	80	$/MWhr
	Economic Analysis	20,000	$/MWhr
Discount Rate		10%, 5%	
Capex		1420	k$/MW
Connected Load PF		0.95	Lag
Annual LF		0.6	LF
Annual Load Growth		2.0	%
Planning Period		22	Year
Loss Factor		0.41	LLF
Parameters for Substation Service Area			
Total Demand		125	MVA
HV Circuit Density		1.4	Km/sq. km
MV Circuit Density		3.0	Km/sq. km
Area		250	Sq.km
Average Load Density		0.5	MVA/Sq.km

[18] Maunsell. *op.cit.* p. 23.