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Optimization of photovoltaic system integration for an Australian educational institute

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Abstract

The energy system optimization in internet of things era is a critical task considering high number of active participant and their cyber security and privacy. In this paper, optimization of an energy system is discussed that can be expanded to include other characteristics of a smart grids such as communication systems and the constraints of consumers. This paper investigates the cost viability of installing photovoltaic and battery systems at an Australian educational institute to offset the peak demand and reduce total electricity price. The results from this cost benefit analysis shows that considerable savings in energy purchased will be achieved when panels are installed on North facing rooftops only for a large scale photovoltaic system. It has also been shown that batteries are not economically feasible for this case as their costs are high.

Keywords: PV, battery, educational institute, cost benefit analysis, optimization, HOMER, net present cost

1. Introduction

Sustainability in all areas of the economy specifically in the energy sector has been an area experiencing growing demand worldwide. This combined with the depletion of energy resources globally has necessitated the exploration of alternate energy so as to meet the energy needs both current and future. Significant investment has been made in recent years in alternative sources of energy more so in naturally replenish- able energy produced from natural renewable energy resources. These sources of energy could be biofuels, geothermal, hydro, wind, biomass and solar [1]. Renewable energy sources are environmentally friendly due to lack of pollution, are available readily, are sustainable but are highly variable (solar and wind) and may produce odour (biomass) [2]. In this paper, the cost/benefit of solar energy has been investigated in terms of storage, installation and photovoltaics (PV) at an Australian educational institute. A cost/benefit analysis is important so as to determine the economic feasibility of solar installations in the institution by performing a comparison of the project costs with the quantified benefits before the actual installation is done [3].

Solar energy is an inexhaustible, readily available and clean energy with PV implementation being modular allowing for expansion of the system in case of an increase in demand and due to the global presence of sunlight, power generation is decentralized. It however is highly variable a feature that affects quantity of power generation and the cost of electricity produced from it is comparatively higher than the cost of electricity generated from conventional energy sources [4]. Due to these advantages, the field of solar energy has received considerable investment in terms of research, development and installations from major companies and economies amounting to a total of 227 GW of global installed solar capacity [5] with Australia having a total solar installed capacity of 5.4 GW as at June 2016 [6].

Schools in Australia such as the Amaroo School in Canberra, Bundaberg Christian College in Southern

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Queensland and the University of Queensland have undertaken large scale solar installations in collaboration with industry players Solar Choice, GEM energy and Trina Solar Panels/Power One respectively. The installation at The Amaroo school is an on-grid installation that has a generation capacity of 600 kW made up of 2000 -310 W solar panels installed on roof tops [7]. At Bundaberg Christian College, the installation was a hybrid system made up of 740 panels with 200 kW production capacity, LED lights and a 250 kWh battery storage [8]. For the University of Queensland, the installation was an on-grid system comprising 5000 panels connected to inverters and has a 1.22 MW generation capacity [9].

Various types of optimization algorithms and tools are available based on mathematical, heuristic or enumeration approaches. Some tools like GAMS and Gurobi can provide mathematical-based optimization, while particle swarm [10], ant colony and simulated annealing [11], honey bee [12], optimizations, etc. are representing the heuristic approaches. Hybrid optimisation of multiple energy resources (HOMER) assesses the search space of an optimization problem for an energy system by enumeration thoroughly. This software provides a complete analysis of different configuration of energy system including statistical analysis, which gives a good insight for decision makers. Various studies have been done in various parts of the world to determine the viability of a solar installation. Examples include a study in Abu Dhabi, United Arab Emirates [13] and another study done in Southern India using HOMER [14]. In these studies, methods of estimation of the quantity of energy generated by a PV system, methods of determining financial viability, methods to estimate costs of installation and maintenance of a large scale solar PV system as well as techniques of using HOMER to perform cost benefit analysis including calculations and their explanations are discussed. This paper provides an optimized configuration of PV and battery integration within an educational institute in Perth, Australia [15] to reduce the total cost of electricity.

2. Methods

The costs of interest during this cost analysis for solar systems include cost of hardware, cost of installation, soft costs and the levelized cost of electricity (LCOE). LCOE is the price per kWh of energy generated. Cost of hardware includes raking, safety and security costs, cabling costs, PV module costs (accounting for a third to a half of the total cost) [16], battery and inverter costs and mounting and grid connection costs (assumed to be $ 100,000 in this analysis). The costs of PV used in this project is assumed to be $1,520 per kW summarised in Table 1 below with inverter installation costs assumed to be $ 10,000 with the converter having a 98.8 % efficiency and a 60 kW capacity.

Table 1. Estimated cost ($)/kW installation

Costs related to 5 Kw rated PV system	Cost (**$**)
PV panels	**$** 2,000
Racking	**$** 2,000
Design & Consulting	**$** 700
Materials	**$** 400
protection & commissioning	**$** 500
Labour	**$** 2,000
Total Cost ($)	**$** 7,600
Total Cost/kW Installed($)	**$** 1,520

Since the costs of solar PV has been on a decline trend and is expected to continue reducing significantly [17], the cost of power from solar PV therefore is expected to decrease further [18]. Large scale battery (LSB) of 600 kWh capacity from Redflow whose capital cost for a single unit is US $550,000 [19] was the battery selected for this project. Installation costs include costs of mechanical and electrical installations as well as inspection and soft costs. The soft costs include costs associated with acquiring a permit, customers, system design, application for incentives, operation and maintenance costs and margin and financial costs [20].

The payback period of the solar PV system is also an important factor that was considered during this cost analysis study. Payback period depends on the cost of electricity and therefore areas with lower electricity costs would have longer payback periods. The HOMER software is used for simulation of the solar installations in this Australian educational institute in this study. HOMER was used for determining the optimum PV and battery size required at the educational institute.

3. Load Analysis and Irradiation Potential

Load analysis is conducted to evaluate the total energy consumption of the power system at the institute, and to determine the peak load demand. The load data is collected by energy management system through the installed meters at the institute. This analysis can be done hourly, daily, monthly or annually. Fig. 1 shows the total energy consumption for the Australian educational institute for the year 2015. The highest energy was consumed during the hot months of February and March. January and December are also hot months but the consumption is lower due to the fact that the educational institute is operating at a lower capacity because of the holiday season. The main component of energy consumption during winter months of June, July and August is for heating of homes because of the cold weather. Fig. 2 shows that the highest peak demand for the year 2015 was 5.6 MW in the summer month of February with the lowest peak demand occurring in the winter month of July. Load factor for this Australian educational institute is between 44% and 52%, which is defined as the ratio of average energy consumption to the maximum demand over a particular duration.

Perth, the city where the educational institution is located receives an annual solar irradiation of around 2000 kWh/m^2 [21]. The monthly average radiation incident at the Australian educational institute at a latitude angle of 32^0 South is shown in Fig. 3 below. From the figure, it can be seen that an average of above 7 kWh/m^2 of radiation was incident on a plate angle of 32^0 during the summer months of December, January and February than during any other season. Winter month of June was observed to have the lowest radiation of 3.75 kWh/m^2.

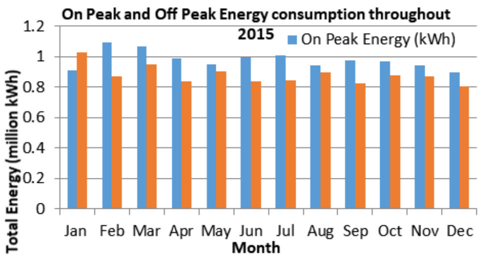

Fig. 1. On peak and Off-peak energy consumption

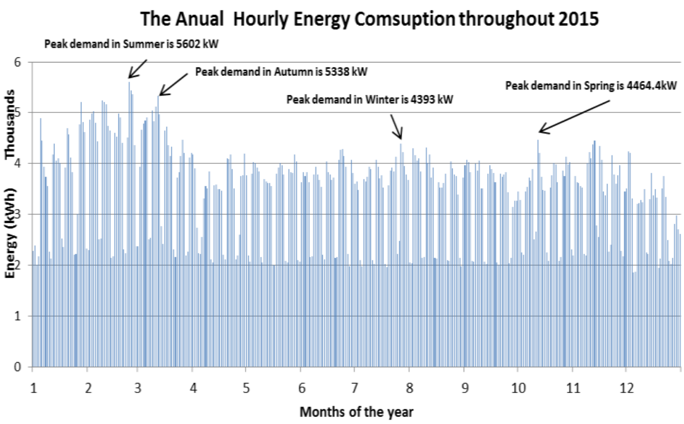

Fig. 2. Peak demand for each season

4. Simulation Results

Four simulations are conducted using HOMER, which covers the major cases of system configurations in this institute. In Simulation 1, there is not any limit on the size of component nor any penalty on unmet load. Therefore, the Simulation 2 is designed to apply a penalty for unmet load, which shows there is a trade-off between the grid capacity and unmet load. Then, the Simulations 3 and 4 are conducted with different level of grid capacity to find out the optimum system configuration while satisfying the unmet load constraints. Therefore, the proposed simulation cases would cover majority of various configurations, so a valid recommendation can be produced using the outcome of these simulations. Based on these results, the optimum system size is found in the simulation 4 for a project lifetime of 20 years. These optimum values were obtained using the installation of only North facing PV, as they produce the major solar generation due to sun movement in that location (West and East facing PV are neglected).

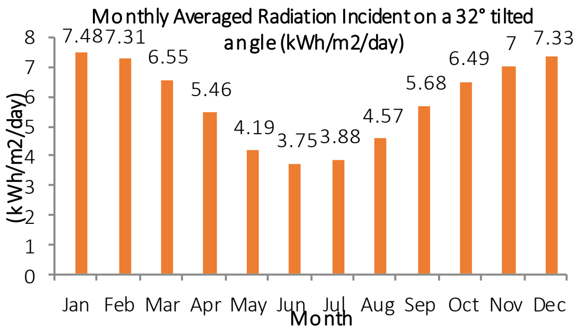

Fig. 3. Average monthly radiation at MU [20]

4.1. Simulation 1: Unlimited component size

Table 2 shows the component selection for the simulation 1. The results obtained from this simulation are shown in Table 3 and 4. As seen, the system is optimum for the 20-year project lifetime with a \$31.2m for the net present cost (NPC), \$0.143 for the cost of electricity (COE) and a grid purchase capacity of 3500 kW. By decreasing the project lifetime to 15 years, there would be a decrease in NPC by \$ 3.7m to \$ 28.7m and an increase in the COE by % 0.001.

Table 2. Component size consideration for simulation 1

Component	**value**	
	Min	**Max**
Grid purchase capacity (kW)	1000	7000
PV North (kW)	0	2000
PV West (kW)	0	500
PV East (kW)	0	600
Converter (kW)	0	3100
Battery (Quantity)	0	2

Table 3. Optimum system component sizing for simulation 1

Project Lifetime	**PV North (kW)**	**PV West (kW)**	**PV East (kW)**	**Battery (No.)**	**Grid (kW)**	**Converter (kW)**	**Dispatch**	**Ren Fraction (%)**
10 years	2000	500	400	1	3500	2066.67	CC	21.55
15 years	2000	333.33	600	0	3500	2066.67	CC	21.44
20 years	2000	333.33	600	0	3500	2066.67	CC	21.44

Table 4. Optimum system costing for simulation 1

Project Lifetime	**COE (\$)**	**NPC (\$)**	**Operating cost (\$)**	**Initial cost (\$)**
10 years	\$0.15191	\$22,699,580.00	\$2,549,861.00	\$5,589,809.00
15 years	\$0.14441	\$27,525,570.00	\$2,642,972.00	\$4,903,111.00
20 years	\$0.14265	\$31,189,420.00	\$2,677,318.00	\$4,903,111.00

The battery was chosen by HOMER only for the 10-year project lifetime, which results in a significant increase in the initial capital cost. The cycle charging (CC) dispatch controller was the one selected for all optimum simulations and 2066.67 kW selected as the converter size for all the simulations. There was an increase in the west facing PV and a decrease in the east facing PV size for the 10-year project lifetime compared to the 15 and 20-year lifetime.

A total of 22 cases of 140 kWh/year of unmet electrical loads was present in all systems with some days experiencing up to 894 kW of unmet load. This was because the purchase capacity from the grid was limited to 3500 kW during this simulation and this restricted the purchase of more than 3500 kW from the grid by the primary load as illustrated in Fig. 4.

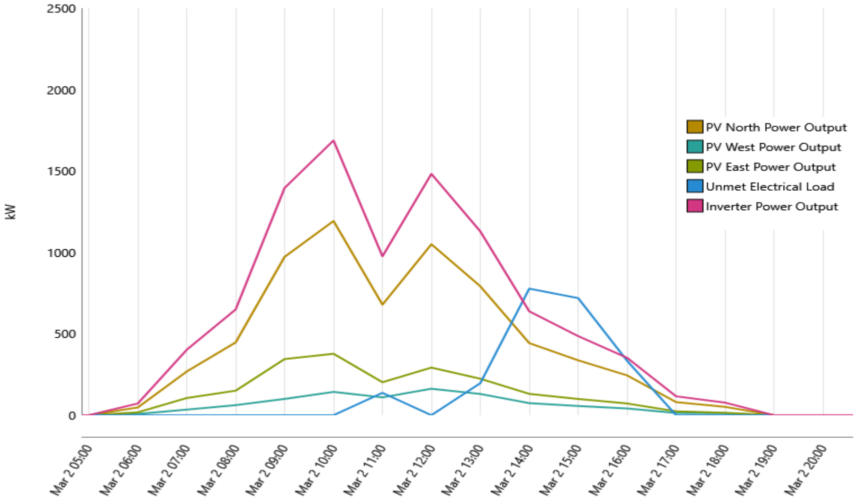

Fig. 4. Unmet electrical loads

4.2. Simulation 2: Unlimited component size with unmet load penalty introduction

A penalty is introduced in this simulation on all unmet loads with all parameters from simulation 1 kept the same. Tables 5 and 6 shows the results of the simulation. In this simulation, batteries as well as East and West facing PV panels were not considered for any system. The energy output from the system was therefore smaller. It can be seen that the operating costs and COE increased for all systems since the energy output from the system was reduced due to omission of east and West facing PV. HOMER oversized the purchase capacity from the grid due to the penalty introduced for unmet load.

Table 5. Component sizing for simulation 2

Project Lifetime	PV North (kW)	PV West (kW)	PV East (kW)	Battery (No.)	Grid (kW)	Converter (kW)	Dispatch	Ren Fraction (%)
10 years	1333.33	0	0	0	5900	1033.33	LF	10.25
15 years	1500	0	0	0	5900	1291.67	CC	11.72
20 years	2000	0	0	0	5900	1550	CC	15.37

Table 6. System costing for simulation 2

Project Lifetime	COE ($)	NPC ($)	Operating cost ($)	Initial cost ($)
10 years	0.15267	22,800,000.00	3,060,719.00	2,298,889.00
15 years	0.15119	28,800,000.00	3,067,039.00	2,595,278.00
20 years	0.15003	32,800,000.00	2,998,271.00	3,398,333.00

4.3. Simulation 3: Grid purchase capacity limited to 4800 kW

The parameters selected for the Simulation 3 is similar to Table 2 except grid purchase capacity that is set to 4800 kW. Tables 7 and 8 show the results obtained from this simulation. From the results, it is found that all electrical loads were met by the grid purchase capacity. It is also found that the larger components are used for the 15 and 20-year project lifetime while smaller components were used in the 10-year project lifetime, however, there are some unmet load in this case as well.

Table 7. Component sizing for simulation 3

Project Lifetime	PV North (kW)	Grid (kW)	converter (kW)	Dispatch	Ren Fraction (%)
10 years	1166.67	4800	962.5	CC	9.07
15 years	1758.81	4800	1414.47	CC	13.62
20 years	2000	4800	1618.75	CC	15.50

Table 8. System costing for simulation 3

Project Lifetime	COE ($)	NPC ($)	Operating cost ($)	Initial cost ($)
10 years	0.15260	22,825,410.00	3,098,571.00	2,033,750.00
15 years	0.15115	28,839,450.00	3,017,744.00	3,009,143.00
20 years	0.15002	32,833,930.00	2,996,914.00	3,409,792.00

4.4. Simulation 4: Grid purchase capacity limited to 5300 kW

In order to limit the unmet load, in this simulation, the grid purchase capacity is limited to 5.3 MW, which is 0.5 MW bigger than the value for the simulation 3. This is also based on the internal regulation of the institute to overdesign the network capacity for addressing unexpected problems. The results of the simulations are shown in Tables 9 and 10. These simulations shows an optimum case for PV/battery integration including minimizing unmet load during a year. Table 11 shows the obtained optimum system sizes. The electrical performance of the optimum system has been summarized in Table 12. Since the selected converter size is small, the converter does not convert all the energy produced by the PV thus the excess electricity that can be observed from Table 12. Table 13 shows the NPCs for different component for the optimum system. Based on the NPC data in Table 13 and subsidies from the Government, the payback period is calculated which is about 4.5 year, as shown in Fig. 5.

It is important to mention that these simulations are for overall cost benefit analysis of energy system, which does not include internal distribution network of the institute. Further study for the long-term planning of this network will be conducted based on the method detailed in [22, 23].

Table 9. Component sizing for simulation 4

Project Lifetime	PV North (kW)	Grid (kW)	Converter (kW)	Dispatch	Ren Fraction (%)
10 years	962.5809	5300	770.6629	CC	7.45
15 years	1777.778	5300	1420.833	CC	13.75
20 years	2000	5300	1614.583	CC	15.49

Table 10. System costing for simulation 4

Project Lifetime	COE ($)	NPC ($)	Operating cost ($)	Initial cost ($)
10 years	$0.15256	$22,819,290.00	$3,148,654.00	$1,691,567.00
15 years	$0.15115	$28,839,450.00	$3,014,252.00	$3,039,028.00
20 years	$0.15002	$32,833,890.00	$2,996,981.00	$3,409,097.00

Table 11. Optimum system size

Component	Size
Grid	5300 kW
PV North facing	2000 kW
Converter	1620 kW*

Table 12. Optimum system size

Electrical Summary	Total Consumption	Grid purchase	Renewable	Excess Electricity
kWh/yr	22,291,353	18,837,843	3,558,344	52,242
%	100	84.1	15.9	0.233

Table 13. NPC cost summary for optimum system

Cost Summary NPC	System	PV North	Converter	Grid
Capital	$3,409,097	$3,040,000	$269,097	$100,000
Replace	$124,644	$0.00	$124,644	$0.00
O&M	$29,385,971	$202,253	$1,387	$29,182,330
Salvage	-$85,819	-$85,819	$0.00	$0.00
Total	$32,833,893	$3,156,434	$395,128	$29,282,330

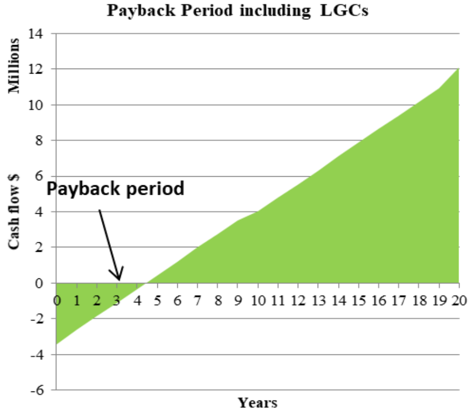

Fig. 5. Payback period of the optimum system

5. Conclusion

This paper studies the optimization of energy system for an Australian institute for PV and battery integration. The optimization tool can be expanded to include communication systems and the constraints of load such as cyber security and comfort level. The results clearly show that a large-scale PV generation system is economically viable at the Australian educational institute as it would reduce the purchase of energy from the grid. The results further prove that installation of North facing PV modules only is more economical than installation of West and East together with the North facing PV panels. Also, it is illustrated that batteries are not feasible for use in the proposed solar system due to the high investment costs of them and also due to the good correlation of PV generation and the institute’s demand.

Future work includes integration of the cost of communication for control system of PV inverter, demand response and possible battery and diesel generator. In this study, the tradeoff between the cost of communication system and the achieved flexibility is studied. Also, the participation of the institute in the wholesale market will be investigated to reduce the total cost of electricity by demand response and battery injection during higher cost of energy periods.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Sami Alhusainy conducted the research, analyzed the data, and wrote the first draft of the paper. Ali Arefi conducted supervision and project management, reviewed the paper, and conceptualized the aims of the paper. Andrew Haning provided the required data reviewed the paper. All authors had approved the final version.

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References

[1] Sorensen B. *Renewable Energy: Physics, Engineering, Environmental Impacts, Economics & Planning*, Fourth Edition, Burlington: Elsevier Ltd, 2011.

[2] Nelson V. *Introduction to Renewable Energy*, Florida: Taylor and Francis Group LLC, 2011.

[3] WebFinance Inc, "Cost benefit analysis (CBA)," 23 November 2016. [Online]. Available: www.businessdictionary.com/definition/cost-benefit-analysis-CBA.html.

[4] Solanki CS, Solar Photovoltaic Technology and Systems: A Manual for TEchnicians, Trainers and Engineers, Delhi: PHI Learning Private Limited, 2013.

[5] IEA-PVPS, "A Snapshot of global PV 4th Edition," IEA Photovoltaic System Programme, 2016.

[6] Australian PV Institute (APVI) Solar Map, "Australian PV market since April 2001," 21 November 2016. [Online]. Available: pv-map.apvi.org.au.

[7] Kelly E. Amaroo School to gleam under ACT's largest rooftop solar system. 25 September 2015. [Online]. Available: http://www.canberratimes.com.au/act-news/amaroo-school-to-gleam-under-acts-largest-rooftop-solar-system-20150924-gjujsf.html.

[8] Wetering JVD. Australia's largest hybrid solar installation goes live at Bundaberg school. 18 March 2016. [Online]. Available: http://www.abc.net.au/news/2016-03-18/austalias-largest-hybrid-solar-installation-bundaberg-school/7259054.

[9] Trina S. University of Queensland: Queensland Australia. 28 December 2016. [Online]. Available: http:www.trinasolar.com/us/resources/success-stories/university-queensland.

[10] Arefi A, Haghifam MR. A modified particle swarm optimization for correlated phenomena. *Applied Soft Computing*, 2011;11, (8): 4640-4654,

[11] Olamei J, Niknam T, Arefi A, and Mazinan AH. A novel hybrid evolutionary algorithm based on ACO and SA for distribution feeder reconfiguration with regard to DGs. 2011 IEEE GCC Conference and Exhibition (GCC), Dubai, 2011, pp. 259-262.

[12] Arefi A, Haghifam MR, Fathi SH, Niknam T and Olamaei J. A novel algorithm based on Honey Bee Mating Optimization for distribution harmonic state estimation including distributed generators. 2009 IEEE Bucharest PowerTech, Bucharest, 2009: 1-7.

[13] Harder EJM. The costs and benefits of large scale solar photovoltaic power production. *Renewable energy an International Journal*, 2011: 789-796.

[14] Amutha MWVR. Cost benefit and technical analysis of rural electrification alternatives in Southern India using HOMER. *Renewable and Sustainable Energy*, 2016; 236-246,.

[15] Alhusayni S. "Cost benefit analysis of PV and storage installation at murdoch university. Honours thesis, Murdoch University, Supervisor: Dr Ali Arefi, 2017.

[16] International Renewable Energy Agency, "Solar photovolaics," *Renewable Energy Technologies: Cost Analysis Series Volume 1: Power Sector Issue 4/5*, June 2012.

[17] Asplund RW. Profiting from Clean Energy: A complete Guide to Trading Green in Solar, Wind, Ethanol, Fuel Cell, Power Efficiency, Carbon Credit Industries and More, New Jersey: John Wiley & Sons, 2008.

[18] Fraunhofer ISE, "Current and future cost of photovolatics. Long-term scenarios for market development, system prices and LCOE of utility scale PV systems. Study on behalf of agora energiewende," Agora Energiewende, Freiburg, 2015.

[19] Redflow, "Understanding the RedFlow battery," Redflow, March 2015. [Online]. Available: http://redflow.com/wp-content/uploads/2015/03/redflow-Understanding-the-Redflow-Battery.pdf.

[20] International Renewable Energy Agency, "the power to change: Solar and wind cost reduction potential to 2025," *2 Solar Photovoltages/Balance of System Costs*, pp. 29-33, June 2016.

[21] Australian Energy Council, "Solar Report," Australian Energy Council, Melbourne, 2016.

[22] Arefi A, Abeygunawardana A and Ledwich G. A new risk-managed planning of electric distribution network incorporating customer engagement and temporary solutions. in IEEE Transactions on Sustainable Energy, Oct. 2016; 7(4): 1646-1661.

[23] Rahman MM, Arefi A, Shafiullah GM, and Hettiwatte S. A new approach to voltage management in unbalanced low voltage networks using demand response and OLTC considering consumer preference. *International Journal of Electrical Power & Energy Systems*, 2018/07/01/ 2018; 99: 11-27.