DC-connected solar plus storage modeling and analysis for front-of-the-meter systems

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ABSTRACT

The deployment of high-power dc equipment is increasing in solar photovoltaic (PV) plants, but very few studies have quantified dc arc-flash risks. Currently, PV plant owners and operators rely on theoretical, simplified models, such as those in NFPA-70E and other publications for the assessment of risk associated with dc arc-flash. This paper presents an overview of arc-flash risks in a PV system based on a series of field experiments based on IEEE-1584 in two large-scale ground mounted PV plants. The experiments include various high-power dc equipment of a PV plant such as central inverters, combiner boxes, recombiner boxes, string inverters, and multiple configurations of electrodes in a 20-inch calibration cube. The study reveals the none of the available dc arc-flash models are applicable for a PV plant. This work is an important first step towards developing an improved model that more accurately assesses dc arc-flash risk in a PV plant.

The primary objective of this research is to develop advanced photovoltaic (PV) battery storage systems that maximize energy retention while ensuring the complete utilization of self-generated solar power, without restricting consumer energy usage or disrupting power supply reliability. To achieve this, various system topologies are explored with the aim of minimizing energy losses and optimizing the consumption of PV-generated electricity. A key focus of the study is identifying the most efficient dispatch strategies under both alternating current (AC) and direct current (DC) configurations, ultimately aiming to reduce dependence on the conventional.

Keyword: photovoltaic (PV), Maximum Power Point Tracking (MPPT), Solar Advisor Model(SAM), Levelized Cost of Energy (LCOE),

1.1 Introduction

The global shift towards renewable energy is transforming electricity production, offering a sustainable alternative to conventional sources. This transition involves complex global activities, laws, and technologies aimed at mitigating climate change. Developing low-carbon, sustainable energy systems requires the use of renewable energy sources. The cost of wind and solar photovoltaics has dropped dramatically in recent years, improving the world's energy balance. Photovoltaic cells, which capture solar energy, offer a plentiful and clean power source. Additionally, geothermal and biomass energy diversify the renewable portfolio by offering sustainable fossil fuel substitutes. With carbon-based fuels rapidly depleting and accounting for 80% of the world's energy consumption (IRENA, 2019a), researching sustainable and clean energy alternatives is essential. Solar energy's share of the world's power output is still quite small, at 3.6%, but it has made a name for itself in the field of clean energy, 31.4% of all set-up of green energy range in 2022. Following hydroelectric technology of 1392 GW, which is the most installed renewable energy technology in 2022, solar energy has an installed capacity of 1053 GW (IRENA, 2023).

By 2050, various energy sources will contribute significantly to installed power capacity and electricity production. In 2016, renewable sources accounted for a quarter of global power generation and around 30% of installed capacity. Solar power contributed about 8% of this renewable electricity. Solar PV technology is expected to supply approximately 25% of global energy consumption by 2050, ranking second in importance after wind power, with an anticipated installed capacity of 8,519 GW (MNRE, 2024).

This Paper covers the introduction to green energy concept to integrate the renewable energy scenario in the world and India. Further it introduces the motivation behind this research and respective problem and research objectives to tackle the identified problems. Finally, the thesis layout is given.

Natural reservoirs provide clean energy as they replenish faster than they're consumed, unlike carbon-based fuels which take centuries to form. Renewable sources like wind and sunlight are abundant and continuously renewed. Many people are unaware of our energy supply limitations. Burning carbon-based fuels for power emits over two billion tons of carbon dioxide annually, contributing to greenhouse gases. The Earth receives solar radiation at a rate about ten thousand times greater than human energy consumption. The sun, a natural gift, provides the most widely available energy source. Solar technologies, using photovoltaic panels to concentrate sunlight, are used for power generation and natural lighting. Every country can incorporate significant amounts of solar energy into its energy mix, although sun exposure varies by location.

3 METHODOLOGY

This chapter examines the advantages of installing a solar photovoltaic (PV) array coupled with front-the-meter storage for solar and weather data of Lucknow, U.P., India. It explores various dispatch strategies, such as automated peak-shaving and manual scheduling, to identify the most effective method for enhancing the system's value and reducing demand charges. The analysis leverages recent electric tariffs, as well as site-specific load and load data, using the publicly available SAM to provide an accurate evaluation.

The development, research, demonstration, and deployment of the SAM by the NREL is supported by an integration of several weather data resources and component parameter databases contributed by key organizations. These include NREL, Sandia National Laboratories, the UW, the CEC, and the U.S. DOE (SAM Version 2018.9.5, 2017). SAM, developed by NREL, is a versatile software tool that comprises multiple models to estimate the power output of advanced renewable technologies such as PV, CPV, and CSP systems. It also includes financial models for calculating key economic metrics such asNPV, payback period, and levelized cost of electricity (Blair et al., 2014). Numerous researchers have contributed to the development and validation of the software and its underlying models (Dobos et al., 2014).

SAM has undergone multiple updates, and the current study utilizes the latest release, Version 2021.12.2 (64-bit) (Solar PV FactBook, 2017). Initially named the "Solar Advisor Model," SAM has evolved into a comprehensive tool to support stakeholders in evaluating the cost and performance of solar energy systems, including both PV and CSP technologies. It also supports the assessment of other renewable energy resources. The software integrates design modules that estimate system performance based on a variety of parameters, as well as weather data inputs such as irradiance, temperature, and humidity specific to a given location. SAM is accessible through the official website:https://www.nrel.gov/analysis/sem/

The software includes detailed modeling capabilities for various CSP configurations, including power towers, parabolic troughs, linear Fresnel systems, and engine/dish systems. SAM also features algorithms for calculating LCOE, incorporating user-defined assumptions regarding financial structure, incentives, and operational and installation costs.

Within the PV industry, multiple photovoltaic technologies are available, each with different efficiency characteristics. These consist of cadmium telluride (CdTe), monocrystalline silicon (Mono-Si or SC-Si), and other materials (Solar PV FactBook, 2017). Mono-Si cell technology, a well-established and extensively used PV technology frequently utilized in large-scale, grid-connected solar power projects, is the subject of the analysis in this article.

SAM requires a number of user-provided inputs in order to run simulations. Hourly weather information, technical requirements for PV modules, inverters, and array design, the impact of soiling on module performance, possible shading losses, and electrical losses related to AC/DC power conversion are a few of these. It is assumed in this study that the tracking structures, inverters, and modules continue to operate at their best throughout the simulation time.

3.3 DESIGN PERFORMANCE

Based on the strictures and tariff rates provided in Tables 3.1 and 3.2, the performance analysis was conducted using the SAM simulation tool. The rated short-circuit current (I_{SC}) of the selected solar module, Sun Power SPR-X21-335, is recorded as 6.2 A. Under open-circuit conditions—when the load is disconnected—the current output drops to zero, while the open-circuit voltage (V_{OC}) reaches approximately 70 V. The resulting I-V curve, shown in Figure 3.5, aligns with the module specifications defined in Table 3.1, validating the module's performance characteristics.

This study evaluates a behind-the-meter system, either AC- or DC-coupled, within a techno-economic analysis framework. The primary power source is the photovoltaic module. Following the solar module, the inverter module is integrated into the system. The inverter's percentage efficiency, illustrated in Figure 3.6, is evaluated based on the percentage of its rated output power. The analysis reveals that the inverter operates with an efficiency ranging from 98% to 100% when functioning within 10% to 50% of its rated output. This high efficiency within the partial load range demonstrates that the selected inverter is appropriately matched to the DC output of the solar module, including the regulated output managed by the Maximum Power Point Tracking (MPPT) controlled DC-DC converters.

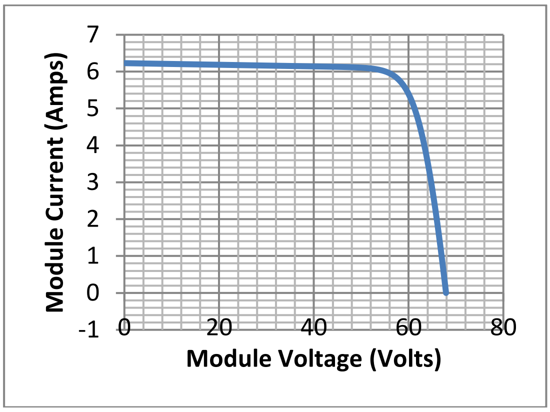

Figure 3.5: I-V curve for performance analysis of solar module (SunPower SPR-X21-335)

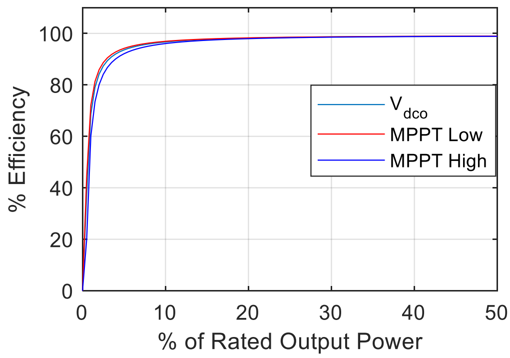

Figure 3.6: Percentage efficiency with respect to rated power for inverter (SE6000HUS)

The power output from the inverter module is directly used to supply residential or commercial electrical loads, while simultaneously being routed to the battery storage system through an AC-DC converter, depending on the specific system connection configuration. This arrangement allows for flexible power distribution, ensuring that excess energy can be stored for later use based on the system's operational design. As illustrated in Figure 3.4, both AC- and DC-coupled behind-the-meter (BTM) system configurations are considered. When solar generation exceeds the immediate load demand, the surplus power is directed to the battery for storage. Various power dispatch strategies are proposed to manage the flow of electricity to the battery, with flexible control schemes tailored to solar irradiance levels and real-time energy consumption patterns.

Building upon this foundation, the following chapter presents a comprehensive techno-economic analysis of FOM photovoltaic (PV) systems, exploring system performance, economic viability, and optimization strategies under different operational scenarios, focusing on (i) the impact of different battery storage types, (ii) various dispatch schemes, and (iii) the profitability of AC versus DC connected systems from a techno-economic perspective. The analysis uses grid-level battery energy storage technology, tailored to the weather data and electric tariff rates specific to Lucknow, U.P., India. Conducted over a one-year period using the SAM tool, the analysis demonstrates that FOM systems offer greater techno-economic benefits compared to traditional transmission-level services.

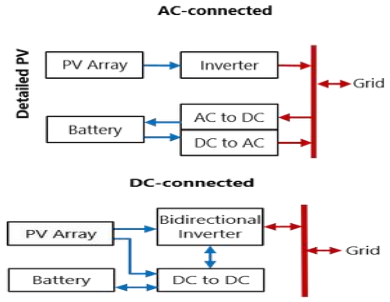

Figure 3.7: Front-of- meter Battery Configurations

Conservational concerns, rapid technological progress, and increasing consumer demand are collectively driving the transformation of the electric power supply sector. To meet the global objective of reducing greenhouse gas emissions, there is an urgent need to incorporate renewable energy sources into the power grid. Historically, electricity generation and distribution have been managed by government-regulated, centralized systems designed to deliver consistent and affordable power. However, the continuous surge in electricity consumption across residential, commercial, and industrial domains is straining these traditional infrastructures. As a result, power systems are facing significant financial burdens and technical complexities that demand innovative solutions and policy reforms.

3.4 FRONT- OF -METER SYSTEM

An emerging alternative to traditional electricity supply is the *behind-the-meter* system, which integrates photovoltaic (PV) connections for households and businesses, aiming to reduce dependence on conventional energy sources and lower electricity costs. Another widely adopted option is the *front-of-the-meter* configuration, where locally generated energy is fed directly into the grid.

However, the gradual decline in feed-in tariffs has made it increasingly difficult for solar users to receive fair compensation for home-generated electricity. At the same time, power supply network operators face challenges in managing the technical impacts of integrating variable renewable sources like wind and solar PV within existing business models.

In this context, microgrids combining solar PV and battery storage present promising opportunities for mitigating these challenges. Access to wholesale electricity prices and more advantageous retail tariffs are two possible advantages for consumers. Demand-side management and local energy control, particularly by lowering peak loads, may result in further cost savings. However, the front-of-the-meter system necessitates a thorough comprehension of the technology and the basic ideas underlying the supply and demand for power. As shown in Figure 3.7, the battery can be linked to the inverter's AC or DC side and is usually utilized in this arrangement to optimize energy generation revenue.

4 RESULTS AND DISCUSSIONS

4.1 FRONT OF METER DC CONNECTED SYSTEM

The simulation results for the Front-of-the-Meter (FOM) system with a DC-connected design architecture are shown in Table 4.1a. Year 1 Annual AC Energy, DC Capacity Factor, Energy Yield, Battery Round-Trip Efficiency, LCOE, IRR, and NPV are among the performance metrics that are being assessed. These performance metrics are reported across various dispatch strategies for different battery chemistries. Notably, the best-performing values under each dispatch mode are highlighted for comparison.

The analysis shows that the NCA/Graphite battery consistently achieves the highest values in technical metrics such as AC Energy Output, DC Capacity Factor, Energy Yield, and Round-Trip Efficiency. In contrast, the LFP/Graphite battery delivers superior economic performance, reflected by the highest values of LCOE, IRR, and NPV, especially in the "charge from system" and "manual dispatch" scenarios. However, under the "charge from system and grid" mode, the LMO/LTO battery configuration exhibits better financial outcomes.

Table 4.1b displays the corresponding results for the AC-connected FOM system. A similar trend is observed: the NCA/Graphite battery leads in technical output metrics, while the LFP/Graphite battery provides the most favorable economic returns under most dispatch modes—except in the combined system and grid charging mode, where LMO/LTO proves more effective. Finally, Table 4.2 offers a comparative summary of AC- and DC-coupled architectures, helping to identify the optimal battery type and dispatch configuration for maximizing system performance and cost-effectiveness.

Table 4.1a: Front - of - Meter (DC Connected) Manual Dispatch

	LMO/GRAPHIT	LFP/GRAPHIT	LCO/GRAPHIT	LMO/LTO	NMC/GRAPHIT	NCA/GRAPHIT
Metric	Value	Value	Value	Value	Value	Value
Annual AC energy in Year 1	7,581	7,578	7,573	7,571	7,562	7,584
DC capacity factor in Year 1	18.40	18.40	18.40	18.40	18.40	18.40
Energy yield in Year 1	1,615	1,615	1,614	1,613	1,611	1,616
Performance ratio in Year 1	0.79	0.79	0.79	0.79	0.79	0.79
Battery roundtrip efficiency	95.55	94.60	93.93	93.53	91.20	96.17
% Battery charge energy from	100	100	100	100	100	100
PPA Price in Year 1 (	10	10	10	10	10	10
PPA Price escalation	1	1	1	1	1	1
LPPA price nominal (	17.77	17.78	17.78	17.74	17.74	17.78
LPPA price real (c/kWh)	13.49	13.49	13.49	13.46	13.47	13.49
LCOE nominal (c/kWh)	11.21	11.04	12.08	11.24	11.43	11.47
LCOE real (c/kWh)	8.51	8.38	9.17	8.53	8.68	8.7
NPV Net Present Value ($)	5,234	5,375	4,548	5,183	5,027	5,039
IRR Internal Rate of Return	13.03	13.46	12.62	12.99	12.54	13.05
Year IRR is achieved	12	12	12	12	12	12
IRR at End of Project (%)	16.90	17.22	16.18	16.85	16.51	16.86
Net capital cost ($)	7,786	7,672	7,911	7,791	7,908	7,786
Equity ($)	7,786	7,672	7,911	7,791	7,908	7,786
Size of Debt ($)	0	0	0	0	0	$0
Minimum DSCR	Inf	Inf	Inf	Inf	Inf	Inf

In this Table 4.1a we had discussed about the **Front - of - Meter** system with DC Connected configuration using **Manual** dispatch mode. We have shown six columns of different types of batteries namely- LMO/Graphite, LFP/Graphite, LCO/Graphite, LMO/LTO, NMC/Graphite and NCA/Graphite. The performance is expressed in terms of different metrics. It has been observed that the metrics of NCA/Graphite battery is showing best result for Annual Energy, DC Capacity factor, Energy Yield. However LFP/Graphite shows best result for LPPA, LCOE, IRR, Net capital cost among all batteries.

In this Table 4.1b we had discussed about the **Front - of - Meter** system with DC Connected configuration using **Automated Dispatch: Perfect Look Ahead Battery can charge from system** dispatch mode. We have shown six columns of different types of batteries namely- LMO/Graphite, LFP/Graphite, LCO/Graphite, LMO/LTO, NMC/Graphite and NCA/Graphite. The performance is expressed in terms of different metrics. It has been observed that the metrics of NCA/Graphite battery is showing best result for Annual AC Energy, DC Capacity factor, Energy Yield and Battery roundtrip efficiency metrics. However LFP/ Graphite shows best for LCOE,NPV and IRR metrics among all batteries.

Table 4.1b: Front - of -Meter (DC Connected) Automated Dispatch: Perfect Look Ahead

Battery can charge from system

Metric	LMO/ GRAPHIT	LFP/ GRAPHIT	LCO/ GRAPHIT	LMO/ LTO	NMC/ GRAPHIT
	Value	Value	Value	Value	Value
Annual AC energy in Year 1 (kWh)	7593	7,591	7,591	7,590	7,591
DC capacity factor in Year 1 (%)	18.50	18.50	18.50	18.50	18.50
Energy yield in Year 1 (kWh/kW)	1,618	1,618	1,617	1,617	1,618
Performance ratio in Year 1	0.79	0.79	0.79	0.79	0.79
Battery roundtrip efficiency (%)	96.13	95.21	94.69	94.77	94.51
% Battery charge energy from	100	100	100	100	100
PPA Price in Year 1 (c/kWh)	10	10	10	10	10
PPA Price escalation (%/year)	1	1	1	1	1
LPPA price nominal (c/kWh)	18.23	18.22	18.23	18.22	18.22
LPPA price real (c/kWh)	13.83	13.83	13.83	13.83	13.83
LCOE nominal (c/kWh)	11.2	11.02	11.39	11.21	11.39
LCOE real (c/kWh)	8.5	8.37	8.65	8.51	8.64
NPV Net Present Value ($)	5,625	5,755	5,465	5,611	5,468
IRR Internal Rate of Return (%)	13.79	14.17	13.36	13.76	13.37
Year IRR is achieved	12	12	12	12	12
IRR at End of Project (%)	17.48	17.78	17.13	17.45	17.14
Net capital cost ($)	7,786	7,672	7,911	7,791	7,908
Equity ($)	7,786	7,672	7,911	7,791	7,908
Size of Debt ($)	0	0	0	0	0
Minimum DSCR	Inf	Inf	Inf	Inf	Inf

Table 4.1c: Front - of -Meter (DC Connected) Automated Dispatch: Perfect Look Ahead

Battery Can Charge From Grid & Battery Can Charge From System

Metric	LMO/ GRAPH	LFP/ GRAPH	LCO/ GRAPH	LMO/ LTO	NMC/ GRAPH	N GR
Annual AC energy in Year 1 (kWh)	7,514	7,502	7,514	7,438	7,364	7,
DC capacity factor in Year 1 (%)	18.30	18.20	18.30	18.10	17.90	1
Energy yield in Year 1 (kWh/kW)	1,601	1,599	1,601	1,585	1,569	1,
Performance ratio in Year 1	0.79	0.78	0.79	0.78	0.77	0
Battery roundtrip efficiency (%)	94.94	93.23	92.09	90.85	87.19	9
% Battery charge energy from system	1.40	4.30	1.30	3.30	4.60	1
PPA Price in Year 1 (c/kWh)	10	10	10	10	10	
PPA Price escalation (%/year)	1	1	1	1	1	
LPPA price nominal (c/kWh)	18.37	18.36	18.08	18.22	18.21	1
LPPA price real (c/kWh)	13.98	13.92	13.83	13.84	13.89	1
LCOE nominal (c/kWh)	10.59	9.84	11.97	9.73	10.03	
LCOE real (c/kWh)	8.06	7.46	9.16	7.39	7.65	8
NPV Net Present Value ($)	6,880	7,635	5,149	7,828	7,437	6,
IRR Internal Rate of Return (%)	17.12	17.48	13.22	17.61	17.14	1
Year IRR is achieved	12	12	12	12	12	
IRR at End of Project (%)	19.89	20.45	17.27	20.55	20.09	1
Net capital cost ($)	7,786	7,672	7,911	7,791	7,908	7,
Equity ($)	7,786	7,672	7,911	7,791	7,908	7,
Size of Debt ($)	0	0	0	0	0	
Minimum DSCR	Inf	Inf	Inf	Inf	Inf	

We covered the Front-of-Meter system with AC Connected setup utilizing Automated Dispatch in Table 4.1j. In the future, the battery can be charged both from the grid and from system dispatch mode. Six columns of various battery types—LMO/Graphite, LFP/Graphite, LCO/Graphite, LMO/LTO, NMC/Graphite, and NCA/Graphite—are displayed. Various measures are used to express the performance. It has been noted that LMO/LTO batteries perform best for Net Present Value, LCOE, and IRR metrics, whereas NCA/Graphite batteries perform best for Annual AC Energy, DC Capacity Factor, Energy Yield, and Battery Roundtrip Efficiency metrics.

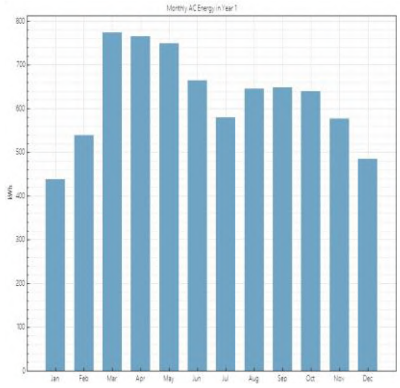

Figure 4.1a: Monthly Energy Production Graph - (LFP/GRAPHITE) - DC Connected – Perfect Look Ahead-Battery can charge from Grid and system

Figure 4.2a Monthly Energy Production Graph - (LFP/GRAPHITE) - DC Connected – Perfect Look Ahead-Battery can charge from Grid and system. It shows the variation between Monthly AC Energy in year 1 in (kWh) on Y-axis and Months on X-axis. The range of Y-axis varies up to 800 kWh and the highest value is 780 kWh approximately in the month of March. The lowest value of AC Energy is attained 440 kWh approximately in the month of January.

Figure 4.2b Monthly AC Power and Demand in Year 1 (LFP/GRAPHITE) - DC Linked - Ideal ProspectsGrid and system power can be used to charge batteries. Months on the X-axis and Monthly AC Energy and Load in Year 1 in (kWh) on the Y-axis are displayed. The Y-axis ranges up to 1800 kWh, with the maximum AC energy value of 780 kWh occurring in March and the highest electric load value of 1600 kWh, roughly, occurring in July. The lowest AC energy value, around 420 kWh, is reached in January, and the lowest electric load value, approximately 650 kWh, is reached in November and February.

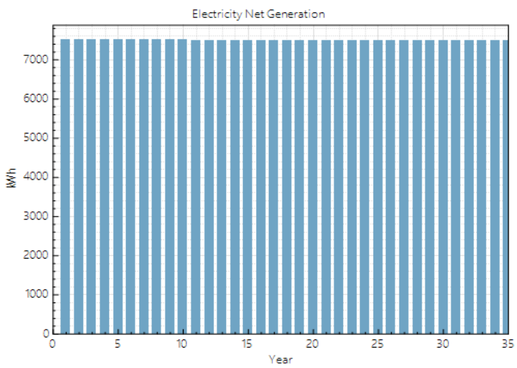

Figure 4.1b: Monthly AC Energy and Load in Year1 (LFP/GRAPHITE) - (DC Connected - Perfect Look Ahead-Battery can charge from Grid and system

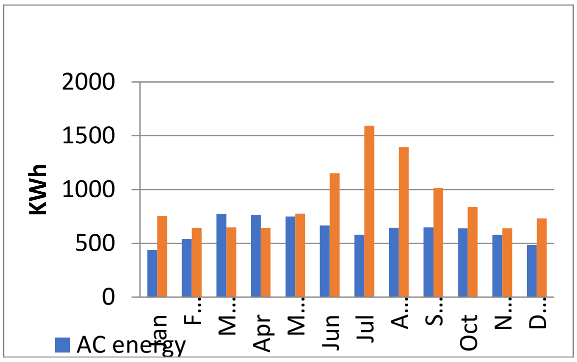

Figure 4.1c: Electricity Net Generation - (LFP/GRAPHITE) - DC Connected- Perfect Look Ahead-Battery can charge from Grid and system

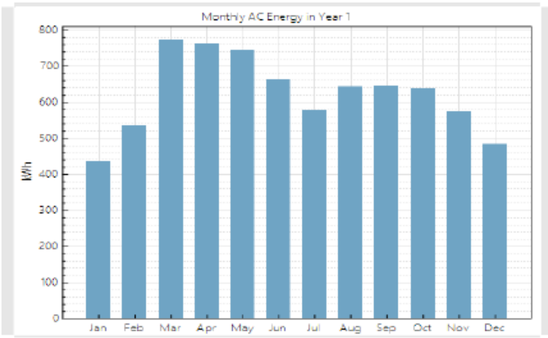

Figure 4.1 d: Monthly Energy Production Graph - (LFP/GRAPHITE) - AC Connected – Perfect Look Ahead-Battery can charge from Grid and system

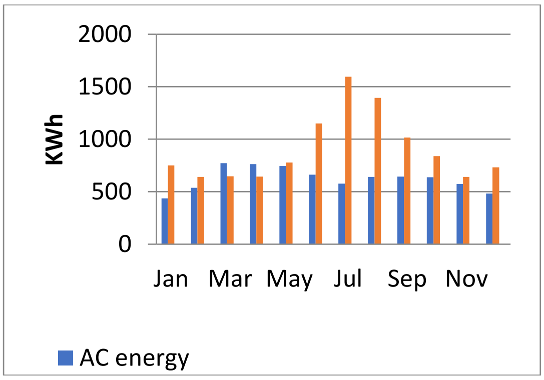

Figure 4.1 e: Monthly AC Energy and Load in Year1 (LFP/GRAPHITE) - (AC Connected - Perfect Look Ahead-Battery can charge from Grid and system

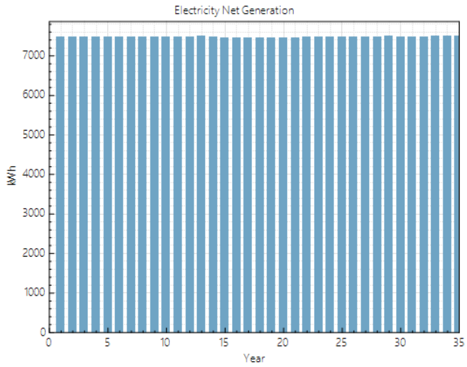

Figure 4.1f: Electricity Net Generation - (LFP/GRAPHITE) - AC Connected- Perfect Look Ahead-Battery can charge from Grid and system

With an emphasis on both DC and AC linked systems, this chapter investigates the techno-economic analysis of front-of-the-meter photovoltaic (PV) systems using the SAM program. The investigation looks at several types and ways of battery power dispatch. Under the Perfect Look Ahead scenario, in which the battery can be charged from both the grid and the PV system, the LMO/LTO battery type provides the best values for metrics like Levelized Cost of Energy (LCOE), Internal Rate of Return (IRR), and Net Present Value (NPV) for the DC connected system. The largest annual energy yield is likewise provided by this method. However, the NCA/Graphite lithium-ion battery performs best under the Perfect Look Ahead scenario, where the battery charges from the PV system, for metrics such as Annual AC Energy (Year 1), DC Capacity Factor (Year 1), Energy Yield (Year 1), and Battery Round-Trip Efficiency. The DC-connected system performs better overall than the AC-connected system.

5.1 CONCLUSION

Using the SAM software, a thorough model of a PV system with battery storage is created in this thesis. This model offers a comprehensive simulation environment to illustrate how different AC and DC coupled battery storage system configurations behave. One key motivation drawn from literature survey in chapter 2 behind the research is that in AC coupled systems, energy output is subject to clipping due to inverter capacity limitations. This clipping leads to reduced energy output. In contrast, DC coupled battery storage systems mitigate this issue, resulting in improved energy output. The proposed system design, which integrates battery storage, is shown to lead to a reduction in electricity bills compared to systems that do not utilize battery storage.

The techno-economic viability of behind-the-meter photovoltaic systems is the main topic of the thesis. The analysis contrasts DC and AC-connected systems using SAM software to identify the optimal setup. The study finds that the price signal forecast mode of battery dispatch is the most advantageous, providing the best values across all metrics. This mode achieves the highest annual energy yield and the shortest payback period for both DC and AC connected behind-the-meter systems. The analysis identifies the NCA/Graphite lithium-ion battery as the optimal choice overall, delivering the best results for most metrics except for battery round-trip efficiency. Furthermore, the performance of the DC connected system is slightly superior to that of the AC connected system concerning annual AC energy and net present value.

Chapter 4 extends the analysis to front-of-the-meter (FOM) PV systems, evaluating both DC and AC connected configurations. The research utilizes SAM software to perform a techno-economic analysis, assessing various battery dispatch modes and types. For the DC connected system, the LMO/LTO battery type demonstrates superior performance in terms of LCOE, IRR, and NPV under the Perfect Look Ahead scenario, where the battery can charge from both the grid and the PV system. Over a 12-year period, this mode produces the most energy for both DC and AC-connected FOM systems. However, the NCA/Graphite lithium-ion battery performs best under the Perfect Look Ahead scenario, where the battery charges only from the PV system, for metrics like Annual AC Energy (Year 1), DC Capacity Factor (Year 1), Energy Yield (Year 1), and Battery Round-Trip Efficiency. Overall, the DC connected system exhibits better performance than the AC connected system across the evaluated metrics.

This detailed analysis underscores the significant benefits of integrating battery storage with PV systems, highlighting the advantages of both DC and AC configurations depending on the specific application and metrics of interest. The findings suggest that careful consideration of dispatch modes and battery types can lead to optimized performance and economic benefits for both behind-the-meter and front-of-the-meter PV systems.

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