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REVIEW OF THE FEASIBILITY STUDY OF MARNEULI SOLAR POWER PLANT AND RECOMMENDATIONS ON THE CONNECTION TO THE GEORGIAN TRANSMISSION SYSTEM

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ACRONYMS

EnCT	Energy Community Treaty
EU	European Union
USAID	United States Agency for International Development
LLP	Limited Liability Partnership
GoG	Government of Georgia
MoESD	Ministry of Economy and Sustainable Development of Georgia
VRE	Variable Renewable Energy
SPP	Solar Power Project
CAPEX	capital expenditure
GSE	JSC Georgian State Electrosystem
ENTSO-E	European Network of Transmission System Operators for Electricity
O&M	Operation and Maintenance
MW	Megawatt
BESS	Battery Energy Storage System
km	Kilometers
kV	kilovolt
$ / USD	United States Dollar
GEL	Georgian Lari
kW	Kilowatt
min	Minute
%	Percentage
RSR	Lowry Range Solar Station
DOE	U.S. Department of Energy
NREL	National Renewable Energy Laboratory
GHI	Global Horizontal Solar Irradiance
DHI	Defuse Horizontal Solar Irradiance
DNI	Direct Normal Solar Irradiance

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1. INTRODUCTION

In October 2016, Georgia signed the Energy Community Treaty (EnCT) signaling the country's commitment to direct future energy planning and market development towards approximation with the European Union (EU). This step commits Georgia to enhance the security of energy supply by promoting the development of relevant infrastructure, increasing market integration and gradual regulatory approximation towards key elements of the EnCT, and promoting the use of renewable energy sources. In order for Georgia to meeting its strategic commitments in the energy sector, the United States Agency for International Development (USAID) is providing technical assistance and policy advice on legal, regulatory and institutional reform issues, including facilitating investment and deal structuring, engineering and environmental analyses, financial planning, and outreach, and other consulting. This technical assistance, ("USAID Energy Program") is being rendered by Deloitte Consulting LLP, under a USAID contract, AID-OAA-I-13-00018.

The objective of USAID Energy Program is to support Georgia's efforts to facilitate increased investment in power generation capacity as a means to increase national energy security, facilitate economic growth, and enhance national security. The project will have a significant impact on energy market reform efforts of the Government of Georgia (GoG) to comply with the country's obligations under the EnCT. The investment objective will be achieved through the provision of technical assistance to a variety of stakeholders in the energy sector.

The purpose of USAID Energy Program is to: (1) support Georgia in energy market development per Georgia's obligations under the EnCT, (2) build the capacity of the GoG and relevant institution(s) to evaluate the fiscal and long-term impacts of regulatory changes, (3) promote energy investments, primarily in variable renewable energy development, (4) to support the integration of non-hydro renewable energy into the power system, and (5) provide strategic advisory services to the GoG to increase Georgia's energy security.

The ultimate goal of this Program is to enhance Georgia's energy security through an improved legal and regulatory framework and increased investments in the energy sector. The ultimate expected outcome of this Program is an energy market legal and regulatory framework that complies with European requirements and encourages competitive energy trade and private sector investments.

USAID Energy Program is tasked under its contract, AID-OAA-I-13-00018, to assist the Ministry of Economy and Sustainable Development of Georgia (MoESD) in developing a support scheme for encouraging investment in electricity generation infrastructure to promote the development of energy generation from a diversified source of native resources.

To facilitate making energy projects eligible for financing, USAID Energy Program is providing technical assistance to the Variable Renewable Energy (VRE) developers to construct and operate renewable energy generation projects, primarily variable renewable energy generation projects. The Program supports the preparation of the application for interconnection to the country's grid. For these reasons, USAID Energy Program prepared recommendations for the Marneuli Solar Power Project (SPP) on the connection of solar power to the Georgian Transmission System.

Marneuli Solar Power Project approached USAID Energy Program with the request to provide recommendations on the connection of Marneuli SPP to the Georgian Transmission System. VRE generation will play a vital role in the electric energy sector in Georgia in the coming years. The connection of solar generation to electrical power systems influences the system operation point, the load flow of real and reactive power, nodal voltages and power losses. The rising impact of solar power generation in power systems forces system operators to extend grid connection requirements to ensure its accurate operation.

2. EXECUTIVE SUMMARY

PREPARATORY PART

The objective of this report is to ensure an improved understanding among developers of factors and estimation procedures that may be considered and undertaken at the initial pre-feasibility development stage of Solar Power projects. Particularly, this is relevant in terms of estimating the feasibility of the project and ensuring the successful connections to the transmission grid.

The report focuses on the importance of ensuring the compliance of the proposed equipment with the requirement of Network Rules as a key input for the successful accomplishment of connection procedures. It also highlights the significance of considering the required equipment prices in the initial estimate of project Capital Expenditure (CAPEX) - capital cost.

The Report provides a reference to available online tool – JSC Georgian State Electrosystem (GSE) Connection Cost Estimator for cost estimation of the transmission network connection cost. This section is supplemented with the cost estimation of the proposed connection.

The Document also incorporates the examples of variability for SPP power output and solar irradiation based on 5 and I0 minutes timestamp data. The last section includes assumptions and raw cost estimation for setting up the Battery Energy Storage System which may require compliance with the requirements of SPP, set by GSE through the letter provided as feedback on the connection point and free capacity availability submitted by Marneuli Solar.

SUMMARY

SPP design is developed initially as a part of a pre-feasibility study which is based on preliminary energy resource and yield estimates, as well as other site-specific requirements and constraints[1]. The preliminary design is initially developed (prefeasibility study) along with a high-level assessment of the regulatory environment and price of power, to determine if a project meets investor's requirements. A similar analysis is repeated in the feasibility study at a more granular level, ultimately leading to another "go/no-go" decision.

The existing network rules prescribe specific requirements which are mandatory for the new generators with regard to voltage, frequency, and other parameters of grid operation. Recently, the European Network of Transmission System Operators for Electricity (ENTSO-E) Requirements have been transposed to the existing Network Rules and in 2021 those requirements will become mandatory. An applicant, willing to connect to the transmission grid, shall take all necessary measures in advance, with the consideration of the Network Rules requirements. Otherwise, there is a risk to fail the Testing stage that is the final step in the process of grid connection. Early consideration implies the proper design of the wind farm and the selection of equipment in line with the Network Rules requirements.

The important parts of the pre-feasibility study are CAPEX and Operation and Maintenance (O&M) cost components. Project financial feasibility heavily depends on a CAPEX+O&M cost and Annual Power Yield Assessment. Power equipment (substation equipment, inverters, controllers. communications equipment etc) with different parameters and specifications may have a different cost. Respectively, identification and consideration of power equipment cost at a pre-feasibility stage would be beneficial for developer and may reduce uncertainties during the estimation of plant component costs. Thus, in the case of Marneuli SPP, there is a rationale for the identification of power equipment at the initial stage of development, then check the compliance of the proposed SPP and constituent power equipment's specifications and its parameters with the existing Network Rules requirements.

Another important cost component to be considered in a CAPEX of a prefeasibility study is a connection cost. For the estimation of Marneuli SPP 50 MW connection cost, the application of GSE online Connection Cost Calculator may be recommended at pre-feasibility stage.

If proper inputs are available, such as the type of connections (cell arrangement or line), technology (underground cable or overhead line with single circuit or double circuit), the length of connection, the capacity and voltage, needed to evacuate power, then GSE Connection Cost Calculator provides the estimation of connection cost which may be used in a pre-feasibility study.

[1] IFC Utility-Scale Solar Photovoltaic Power Plants In partnership with A Project Developer's Guide

For Marneuli SPP, in the absence of expansion plan and a need to evacuate only 50 MW power, 110 kV single circuit line may serve as a cost-effective alternative. In the case of future expansion plans, the more cost-effective option relative to the doble circuited 110 kV transmission line may be a single circuit 220 kV transmission line.

Nevertheless, according to the existing Network Rules, the identification of connection point, acceptance on connection design details and testing before the connection - is GSE's authority. Respectively, Marneuli Solar shall consider that a more accurate cost of connection will become available after starting connection application, completing design work and performing respective cost estimation.

According to Marneuli SPP documentation, shared with the USAID Energy Program, the 50 MW SPP may be connected to the Transmission Network if potential SPP ensures, that the variability in generation capacity 10 MW per second and 20 MW per minute never happens during the operation of a station.

The Pre-feasibility study of the Marneuli SPP is based on 15-30 min irradiation data (at list 4 sources) and it seems that one-second solar irradiation and PV output data are not available. Thus, the Marneuli SPP detailed ramp characteristics can't be captured. Setting up proper ground-based remote measurement campaign, to some extent, may handle the identification of probable rumps and drops at planned 50 MW SPP output.

Supposedly, to make 50 MW SPP compliant with the mentioned change in generation capacity under the respective paragraph of this report, it is assumed that the deployment of 10 MW Battery Energy Storage System (BESS), during the lifetime period, may handle variability in generated power of 50 MW Marneuli SPP.

Marneuli Solar should consider that the need in BESS and required capacity shall be determined during the detailed design phase of the project. Also, the exact cost of BESS will become available after surveying BESS producers and starting procurement procedures.

3. DETAILED ANALYSIS

PROCEDURES FOR CONNECTION

According to the existing Network Rules the connection to the Transmission Grid shall be carried out in two phases:

a) During phase I, an applicant willing to connect to the transmission grid *(applicant for grid connection)* shall submit the application and documents requested under the Network Code to transmission licensee.

b) During phase II, the transmission licensee, the dispatch licensee, and the applicant shall sign a Grid Connection Agreement; engaged parties shall perform work in line with the technical requirements of grid connection.

The last stage of grid connection envisages an equipment testing. Only after the successful testing, a Solar Farm will be allowed to be connected to a transmission grid.

An applicant, willing to connect to the transmission grid, must take all necessary measures in advance with the consideration of the Network Rules requirements – Otherwise, there is a risk to fail the Testing. Consideration in advance implies the proper design of the wind farm and the selection of equipment in line with the Network Rules requirements.

FACTORS TO BE CONSIDERED FOR THE CONNECTION COST ESTIMATION

Connections Cost Calculator from GSE web page may be applied to estimate the cost of connections. However, the use of a calculator requires the considerations of several factors such as the type of connection, length, and the voltage of connection.

Type of Connections – Construction of Overhead Line and Cell arrangement in Substation.

Based on the information provided by Marneuli SPP, the connection specification of potential SPP are as follow:

Connection length - 6 km.

*The Voltage of Connection*s - 110 kV.

Cost for 6km Transmission 110 kV line and cell arrangement in substation - $414000.

CONNECTION COST ESTIMATION OF 50 MW MARNEULI SOLAR POWER PLANT

Hypothetically 110 kV one circuit transmission line can withstand 50 MW load. However, if the development plan of Marneuli SPP envisages the station expansion to 50 MW Solar PV Peak Capacity, this might trigger the need for considering 110 kV double circuit transmission line.

Through the application of the GSE Connection Fee Cost calculator, below is provided cost estimation for 110 kV single and double circuit and 220 kV single circuit transmission lines. 220 kV single circuit transmission line may withstand at list 130 MW capacity and therefore might be considered herein as a cost-effective alternative for double circuit 110 kV transmission line.

ASSUMPTIONS FOR CONNECTION COST ESTIMATION

Table 1: Connection Specifications

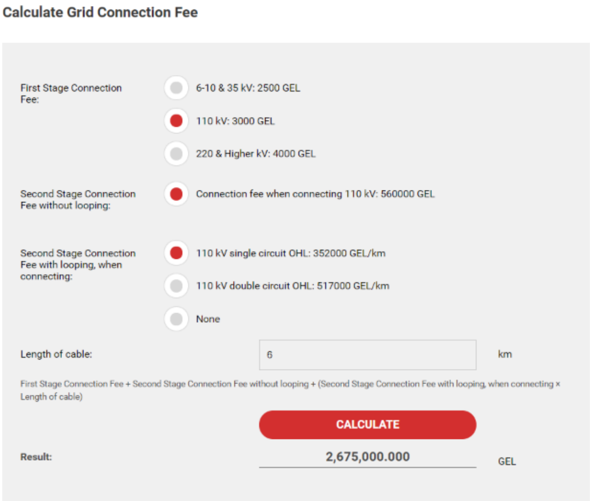
Distance to Substation	Voltage	Number of Circuits	Cell arrangement in Substation	
6km	110 kV	Single	Yes	110 kV
6Km	110 kV	Double	Yes	110 kV
6Km	220 kV	Single	Yes	220 kV

Table 2: Cost Estimation from GSE Connection Cost Calculator

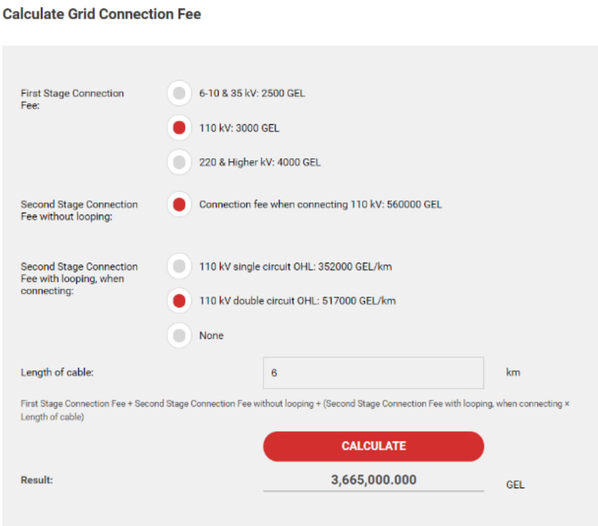
#	Connection	Estimated Cost
1	First Stage Connection Fee	GEL 2,675,000 USD 877,049
	110 kV single circuit line 6 km	
	Cell Arrangement in Substation	
2	First Stage Connection Fee	

#	Connection	Estimated Cost
	110 kV double circuit line 6 km Cell Arrangement in Substation	GEL 3,665,000 USD 1,201,640
3	First Stage Connection Fee 110 kV double circuit line 6 km Cell Arrangement in Substation	Gel 3,391,000 USD1,111,803

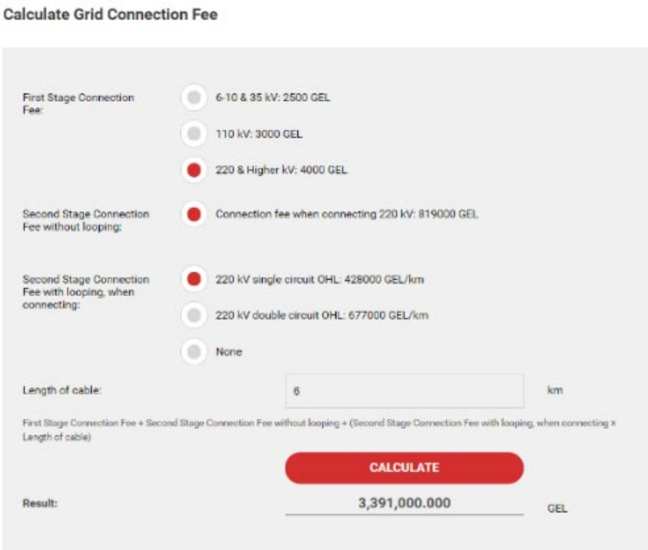
110 kV 6 km Single Circuit



110 kV 6 km Double Circuit



220 kV 6 km Single Circuit



To check the rationale of the connection cost at the pre-feasibility stage of the potential 50 MW SPP, connection cost for Alternative 1 – 110 kV Single Circuit Transmission line can be considered as a tentative budget. If a developer has a capacity expansion plan for the nearest future, a 220 kV single circuit transmission line seems more feasible.

A developer shall consider that the accurate cost of connection will become available after starting connection application, completing design work and respective cost estimation.

LIMITING THE VARIABILITY OF GENERATION CAPACITY FOR GRID CONNECTION

LIMITING VARIABILITY OF POWER PRODUCTION CAPACITY FOR CONNECTION TO THE GRID

According to Marneuli SPP documentation shared with the USAID Energy Program, the 50 MW SPP may be connected to the Transmission Network if potential SPP ensures that the variability in generation capacity 10 MW per second and 20 MW per minute never happens during the operation of a station.

According to delivered documentation, both irradiation and power generation data are represented on a monthly scale. This, in turn, challenges the identification of plant performance in terms of capacity change during the day on a second and minute scale. Moreover, the database indicated as a source for estimation are in a 15-minute or 30-minute granularity (at list 4 of them).

VARIABILITY OF SOLAR PLANT OUTPUT

Below are several examples, demonstrating the drop and increase in power and irradiation. It shows how the generation capacity may be changed in 5 minutes and on a minute scale.

Figure 1: Greece hh-iliaktida-trina Solar PV / Installed Capacity 85 kW 23/07/2020

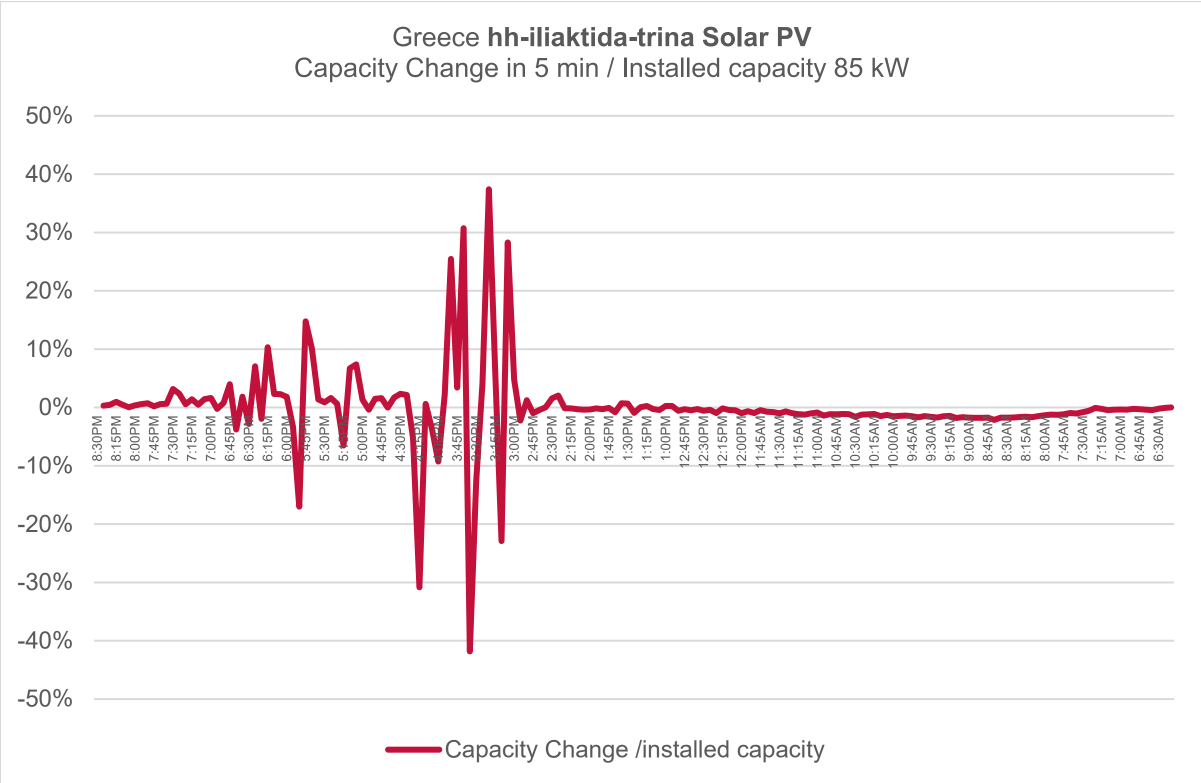


Figure 2: Greece hh-iliaktida-trina Solar PV / Installed Capacity 85 kW 23/07/2020

Axis 3% *Axis 45%*

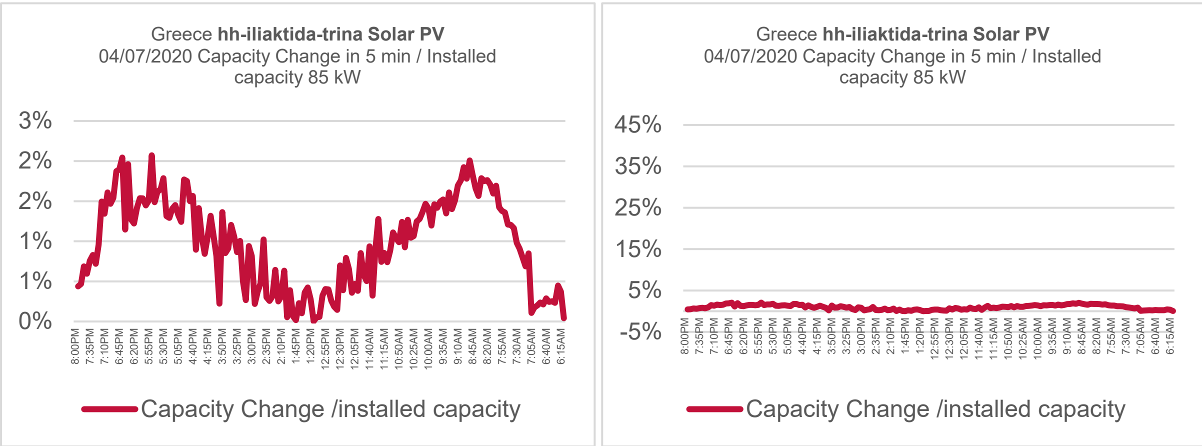
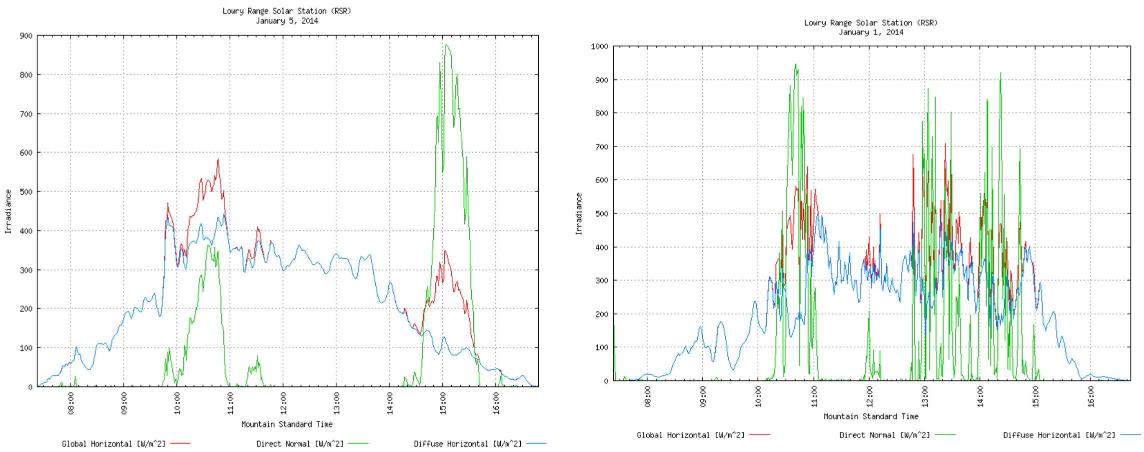


Figure. 1 and Figure 2 demonstrate a fall and growth in generation capacity in Solar Plant. Changes might be substantial one day and insignificant on the other day. The most likely reason for such a change might be clouds, shades etc.

However, for a very large array of solar panels, there may be a smoothing of the fluctuation, compared to the sharp spikes and plunges that can happen when a cloud passes by a single panel or rooftop array. If an engineer has good statistical information on cloud patterns, a system may be designed along certain orientations to minimize the impact of cloud passage and dampen those fluctuations[2].

Figure 3: Lowry Range Solar Station (RSR) January 2014 Solar Calendar



The U.S. Department of Energy's (DOE) National Renewable Energy Laboratory (NREL) produced and made available a rich data set showing what happens, second-by-second when clouds pass over a solar power installation. Figure 3 depicts a change in solar irradiation components measured in the Lowry Range Solar Station (RSR).

Figure 3 demonstrates an example of changes in solar irradiation components that impact the Solar plant Output. The solar resource of a location and SPP output is usually defined by the direct normal irradiation, the diffuse horizontal irradiation and the global horizontal irradiation.[3]

A Pyranometer is a device that measures solar irradiance. It measures the global horizontal solar irradiance (GHI) which is composed of defuse horizontal solar irradiance (DHI) from the sky and direct normal solar irradiance (DNI) from the sun. If shaded from the direct sun a pyranometer measures DHI. DNI is measured by a pyrheliometer continuously pointed at the centre of the sun by an automatic sun tracker.[4]

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[2] https://phys.org/news/2011-09-clouds-effects-solar-power.html
[3] https://www.ifc.org/wps/wcm/connect/a1b3dbd3-983e-4ee3-a67b-cdc29ef900cb/IFC+Solar+Report_Web+_08+05.pdf?MOD=AJPERES&CVID=kZePDPG
[4] KIPP & ZONEN Pyranometers for Accurate measurement of Solar Irradiance.

ASSUMPTIONS FOR SETTING UP BATTERY ENERGY STORAGE SYSTEM FOR 50 MW SOLAR POWER PLANT

To meet the requirements of variations in a SPP generation capacity, solar irradiation data must be collected every second, as PV systems respond to shadows very quickly. Setting up proper ground-based remote measurement campaign, to some extent, may handle the identification of probable rumps and drops in at planned 50 MW SPP output.

However, according to the pre-feasibility study of the Marneuli SPP, one-second solar irradiation and PV output data can't capture the detailed ramp characteristics. Supposedly, to make 50MW SPP compliant to the generation capacity requirement change, the BESS may be deployed.

A developer must consider that the need in BESS and required capacity shall be determined during the design phase of the project. Also, the exact cost of BESS will become available after surveying BESS producers and starting procurement procedures.

ASSUMPTIONS FOR COST ESTIMATION

- 50 MW Marneuli SPP arrays of solar panels are large enough in dimension for smoothing the fluctuation down to 10%-20%, compared to the sharp spikes and plunges that can happen when a cloud passes by a single panel or small rooftop array.
- 10 MW BESS capacity may be suitable to avoid Solar PV output ramped and dropped 10 MW per second.
- 10 MW BESS capacity may be suitable to avoid Solar PV output ramped and dropped 20 MW per minute.
- Type of BESS technology selected based on cost criteria.
- Cost is determined based on capacity kW and projections for 2025.

Information on BESS Cost

In July 2019 U.S Department of Energy published BESS cost for 2018 and projections for 2025. The summary table provided below.

Table 3: A summary of compiled 2018 findings and 2025 predictions for cost and parameter ranges by technology type – BESS.

Parameter	Sodium-Sulfur Battery		Li-Ion Battery		Lead Acid		Sodium Metal Halide		Zinc-Hybrid Cathode		Redox Flow Battery	
	2018	2025	2018	2025	2018	2025	2018	2025	2018	2025	2018	2025
Capital Cost – Energy Capacity ($/kWh)	400-1,000 **661**	(300-675) **(465)**	223-323 **271**	(156-203) **(189)**	120-291 **260**	(102-247) **(220)**	520-1,000 **700**	(364-630) **(482)**	265-265 **265**	(179-199) **(192)**	435-952 **555**	(326-643) **(393)**
Power Conversion System (PCS) ($/kW)	230-470 **350**	(184-329) **(211)**	230-470 **288**	(184-329) **(211)**	230-470 **350**	(184-329) **(211)**	230-470 **350**	(184-329) **(211)**	230-470 **350**	(184-329) **(211)**	230-470 **350**	(184-329) **(211)**
Balance of Plant (BOP) ($/kW)	80-120 **100**	(75-115) **(95)**	80-120 **100**	(75-115) **(95)**	80-120 **100**	(75-115) **(95)**	80-120 **100**	(75-115) **(95)**	80-120 **100**	(75-115) **(95)**	80-120 **100**	(75-115) **(95)**
Construction and Commissioning ($/kWh)	121-145 **133**	(115-138) **(127)**	92-110 **101**	(87-105) **(96)**	160-192 **176**	(152-182) **(167)**	105-126 **115**	(100-119) **(110)**	157-188 **173**	(149-179) **(164)**	173-207 **190**	(164-197) **(180)**
Total Project Cost ($/kW)	2,394-5,170 **3,626**	(1,919-3,696) **(2,674)**	1,570-2,322 **1,876**	(1,231-1,676) **(1,446)**	1,430-2,522 **2,194**	(1,275-2,160) **(1,854)**	2,810-5,094 **3,710**	(2,115-3,440) **(2,674)**	1,998-2,402 **2,202**	(1,571-1,956) **(1,730)**	2,742-5,226 **3,430**	(2,219-3,804) **(2,598)**
Total Project Cost ($/kWh)	599-1,293 **907**	(480-924) **(669)**	393-581 **469**	(308-419) **(362)**	358-631 **549**	(319-540) **(464)**	703-1,274 **928**	(529-860) **(669)**	500-601 **551**	(393-489) **(433)**	686-1,307 **858**	(555-951) **(650)**
O&M Fixed ($/kW-yr)	10	(8)	10	(8)	10	(8)	10	(8)	10	(8)	10	(8)
O&M Variable (cents/kWh)	0.03		0.03		0.03		0.03		0.03		0.03	

BESS COST ESTIMATION

As shown on Table 3, Lithium-Ion Battery Energy Storage is a cost-effective solution based on Total Project cost $1446/kW projection for 2025.

10 MW=10000kW;

10000 kW*$1446=$14 460 000 is a tentative cost of BESS that may be considered in a 50 MW SPP pre-feasibility tudy.

BESS O&M COST

As given in Table 3, to operate and maintain BESS, a developer has to incur both Fixed and Variable Costs.

When estimating the O&M cost of 50 MW Solar PV, the respective cost of BESS O&M has to be added to the project O&M cost.

For 10 MW BESS, it may be as follow:

Fixed Cost 10000 kW$8=$80 000*

*Variable Cost 10000 kW * $0.03=$3000*

A developer must take into consideration that the Cost of Electricity for Charging and recharging is not included in O&M Cost provided above.

BESS USEFUL LIFE

A Lifetime of BESS is another important aspect to be viewed by a developer. Li-ion systems have a typical useful lifespan of approximately 10 years and require major maintenance of battery system, every 5 to 8 years to remain operational.

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