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The Energy Twin – A Solution for Techno-Economic Business Case Analysis of Microgrids & Distributed Energy Systems (DES)

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Introduction

We are in the midst of an energy transition. A transition that is driven by the need to de-carbonize and increase sustainability, improve efficiency and enhance reliability and resilience. The maturity of distributed energy resources (DERs) and digitalization via automation and smart grid technology is at an intersecting point on their growth curve to trigger this transition.
Disruptive technologies such as low cost renewable, energy storage system, artificial intelligence (AI), controller technology and smart device connectivity (IoT) set the stage for the paradigm shift from the traditional centralized generation driven by utilities to one that is more distributed and pointed to address specific use cases and problems being faced at the prescribed install point. Key segment areas for such installs include commercial, industrial, grid edge customers as well as critical infrastructure solutions.
Like any other solution being envisioned or proposed to solve a particular set of use cases, the go/no-go decision to proceed hinges on the strength of the business case over the lifetime of the project as well as the requirement for the technical solution to fully address the problem at hand. Inorder to identify the potential solution, the key is well defined comprehensive optimal Microgrid (MG) & Distributed Energy System (DES) planning and optimzation.

Motivation

The predominant use case for microgrid (MG) and distributed energy system (DES) installs from inception of the technology has been resilience; simply because the price points for renewables (such as wind and solar photovoltaic (PV)) and other DERs were not at competing levels with conventional solutions in order to justify the business case.
Today, wind and solar PV are considered as mature technologies positioned in some cases to outcompete existing alternate solutions. Battery Energy Storage Systems (BESS) with their capability to address multiple use cases in an optimum fashion has also become the asset of choice. Actual price points of the above-mentioned assets have surpassed forecasted price expectations year on year and technological advances contribute to the prioritization of selection as well.
Distributed generation is going to be the way of the future and the requirement to have robust tools that address both financial and technical requirements of these complex solutions will be an immediate requirement for stakeholders to use to justify their business cases.
Various tools exist on the market that either address only specific assets, select use cases or are missing an in depth financial or technical focus of the overall solution [1], some of these tools are briefly reviewed here. SOAPP-CT2.5 has been developed by Electric Power Research Institute (EPRI) to obtain optimal sizing of the distributed generators (i.e., combustion turbines) with financial variables such as Net Present Cost (NPC), Internal Rate of Return (IRR), and payback period, considering various techno-economic parameters [2]. DER-CAM has been developed by Berkeley Lab since 2000, used to determine optimal DER portfolio and sizing taking into account various dispatch strategies and wide range of DERs and their characteristics [3]. Other such tool is RETScreen International which has been developed by Natural Resources Canada to identify the feasibility of potential DER solution via considering various techno-economic parameters [4]. However, it is important to note that these tools solve mixed integer linear programming problem for predefined time

period, without considering daily/hourly operating Unit Commitment and dispatch operation. HOMER has been developed by National Research Energy Laboratory to obtain the optimal DER solution for microgrid or larger grid, accounting for various dispatch strategies, DERs, and their characteristics [5]. Note that by considering different DERs and their size, it can lead to lots of cases/scenarios, thus, the pre-screening of the DERs needs to be done to identify the potential DERs and range of their size appropriate for respesctive microgrid. Thus, inorder to obtain a comprehensive MG DES Planning & Optimization Approach, it is important to investigate key components including the requirements, techno-economic parameters - variables, DER availability and characteristics, pre-screening of the DERs and identification of their potential, filtering out range of size for DERs, and energy management system for daily/hourly operation.
This paper examines key requirements of a simulation tool that will build the case both from a technical perspective - ensuring optimized asset (DER) selection and sizing – as well as from an economical perspective – with identifiable fiscal parameters that will drive new types of Investors / stakeholders to proceed and take on the projects being explored.

Keywords
Energy Twin, Microgrid (MG), Distributed Energy Resources (DER), Distributed Energy Systems (DES), DERs Planning and Optimization, Renewables.

1.0. Microgrid / Distribution Energy System Planning & Optimization

This section focuses on the base requirements that need to be addressed and accounted for when carrying out an initial study.

1.1. Background Information

Below is a tabular listing of general information that needs to be collected in order to build out the solution:

Base Information	
Location (GPS)	Location with GPS Coordinates - to check high level Wind / Solar PV Asset Requirement
Geography	
Plot Size	Dimensions, Area, Topography - to identify Solar PV footprint / Wind variability / Turbulence
Soil	Soil Study - Resistivity and Civil Work Requirements
Climate	
Details	Temperature, Precipitation, Rainfall, Snowfall - impact on DERs
Economy	
	Fishing, Aquaculture, Tourism etc. to identify process variability
Demographics	
Details	#Persons, #Households, #Families, Population Density & Growth, Age Profile, Avg. Family Size, Income
Accessibility & Logistics	
Details	Road Access, Bridges obstructions, Sea, Frequency of Access
Other Information	
Details	Flight Path (specific for wind), Peak impact, Business Processes, Thermal Load Considerations,
	Regulation Requirements - Permits, Noise, Emissions
	Other DER Usage - Run of the river - flow requirements (small hydro), storage requirements (Hydrogen)
	Green filed / Brown field requirements; Utility Requirements & Constraints

Figure 1.0 – Background Information

Collection of the above information will assist in high level qualification of asset usage and project viability. In addition to the above, stakeholder analysis will need to be carried out to identify asset ownership and resultant impact of this. For example – if the project involves building of smart homes and the home owners would be responsible for owning roof top solar PV and small BESS, then the appetite for them to buy into the solution would be governed by utility bill savings model adapted, the irradiation levels for the area to define PV output, their age demographic would point to high technological adaption rates, Income will form boundary conditions for price points, and O&M structure would all guide decision making criteria.

1.2. Capabilities & Tools

In order to carry out a bankable in-depth study that will account for DES integration possibilities and changes to status quo throughout the life cycle of the assets being deployed, the capabilities of the Energy Twin tool will have to account for all variabilities that will impact the business case.

Inputs:

Inputs to be taken into consideration will be:
Asset Price curve – decisions could be taken to install particular assets when their forecasted price points are lower along the lifetime of the project (e.g. 20 year time frame)
Load Growth curve – with increased electrification or higher population growth over the years will require assets to be modular and expandable for increased load demand over time
Grid Price Curve – depending on the regulations within the location where the project is being deployed, capability to handle Time-of-Use (TOU) pricing or Time-Varying-Pricing (TVR), or real time price monitoring should be possible within the tool.
Fuel / Commodity Price Impact Curve – assets such as turbines, gensets and reciprocating engines (CHPs) whose operation will impact the business case by this commodity pricing will need to be assessed technically for optimal utilization over the lifetime of the project.
Impact on GHG and Emissions – the impact of utilization of assets that are GHG emitting will need to be considered together with carbon footprint calculation and cost savings models.
Irradiation, Temparature, Wind Speed – Automatic import of this data via web server link or external individual asset tools should be possbile. With the GPS coordinates, localized data can be used to predict generation forecast of the renewables.

Assets:

From an asset perspective, the ability for the tool to run a simulation for a minimum duration of 1 year with 15min input data extrapolated over a 20/25year time frame becomes critical to identify correct technical behaviour of the MG / DES.
A complete digital twin of all assets in the virtual simulation mode will need to be realized in order to achieve 'like' behaviour to the real install. A library of various DERs selectable by individual models of vendors used will allow for complete mimicry of the real-world solution.
Below is a listing of individual virtual model asset requirements that need to be satisfied:
CAPEX, OPEX, Replacement Cost with annual escalation factors – Capital cost for DERs is expected to decrease over time as the technology matures; Operational costs will increase over time as utilization takes place; modular replacement will need to be considered at asset end of life. In addition to this, forecasted asset capital cost over the life time of the project will dictate optimal instal time for each asset and will need to be accounted for as well.
Hydrogen Energy Storage System (HESS)- characteristics of all equipments applicable to this technology such as – Electrolyzer, Fuel Cells, Hydrogen Storage Tanks etc will need to be modelled.
Battery Energy Storage System (BESS) – influencing attributes such as temperature, battery chemistry, operating reserves, inverter losses and operational behaviour as well the individual components – Batteries, Chargers, Distribution Transformers, Containers, racks will need to be included.
Wind Power – Wind speed curves, hub height, rotor diameter, civil install costs, curtailment capability, operating reserve, related civil works all need to be included within the characteristics of the asset.
Solar PV – Footprint for install, type of install – ground mounted, 3D sun tracking etc., curtailment capability, degradation factor, inverter loss, orientation matrix - %, direction, tilt, shading loss etc. are key characteristics that will influence generation output of the PV.

Diesel Gensets / CHPs / Turbines – Critical factors that need to be considered are power to fuel output curves, emission rates based on output, load step requirements, operating reserves etc.

Microgrid Controller

The microgrid controller's role within the solution is to optimize DER control and utilization in order to satisfy specific use cases and achive the overall key performance indicators from a financial perspective over the lifetime of the project.

Controller behaviour and decision-making modelling will need to be replicated by the simulation tool. Either a rule-based microgrid controller (where real time metered and measured data is used together with thresholds to achieve optimal DER utilization and behaviour) or a more sophisticated model predictive control tied with optimization (day ahead energy management algorithm obtains dispatch of DERs considering forecasted renewable generation and load profiles as inputs, repeat the process at defined recalculation) is used.

Other Requirements

Additional requirements that need to be included are:

Stakeholder Analysis – Considering the fact that microgrids are complex and include various stakeholders supplying different assets to realize the final solution, individual stakeholder criteria for taking on the project in terms of technical, operational and financial KPIs will differ from one another. The ability to extract individual stakeholder applicable criteria becomes important to put together the overall solution.

Thermal Modelling Capability – In cases where thermal demand load is satisfied via heat emitting assets (and not electrically) such as CHP, Heat Pumpts etc. the requirement to model these assets become essential.

Multiple Scenario Simulation Runs – Varying asset mixes with differing sizes from a power output perspective need to be analysed in parallel in order to find the optimal asset type and size that best fits the most positive business case. This feature will allow for comparative analysis across the board – both technically and financially.

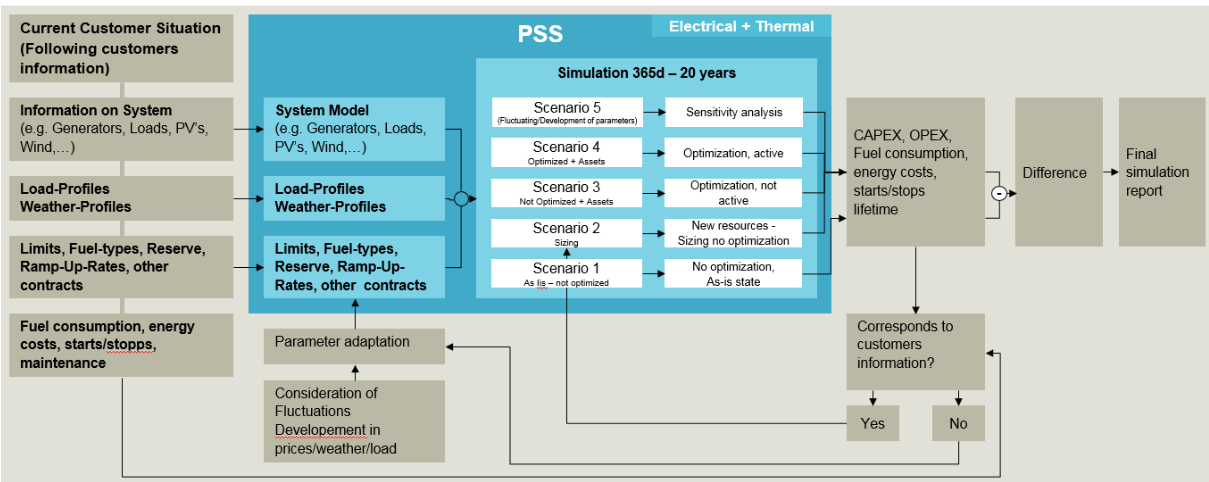

Figure 2.0 – Energy Twin Requirements Flow Chart

The above figure summarizes the inputs, assets, controller and other requirements discussed above.

NOTE: Financial Requirements will be discussed in a subsequent chapter of this document.

1.3. Load Profile Analysis

The load profile is the fundamental starting point for analysis of microgrid solution development. In addition to the load growth curve details in Section 1.2, assessment needs to be made on specific load types and their associated flexibility: sheddable loads (with priority sequence for shedding), shiftable load (that can be time shifted to achieve cost reduction), fixed loads (non shiftable), critical loads (non sheddable).

Together with load classification discussed, microgrid transition from grid-tied mode to an islanding situation that needs to be seamless will have additional technical considerations of the utilized assets to be grid-forming at high speed to fulfil load demand on grid failure. (BESS would be a strong candidate for this use case)

Below are sample load profiles that would be imported into the simulation tool for assessment:

- 2 peak daily load profile – with a peak in the morning and evening (smart home example)
- 1 peak daily load profile – a possible industrial customer running a process
- Flat peak daily load profile – critical load customer with fixed load requirement
- Seasonal variations (Summer & Winter) for heating and cooling are shown

The load profile is typically obtained from utility measured and metered data using smart meters. In order to achieve strong output assessment of the simulation, granularity of 1 minute is best followed by 15min granularity and lastly 1-hour granularity of sampled data over a yearly period. Interpolation to achieve high quality output should be possible together with extrapolation over the 20/25-year lifetime of this yearly input data plus growth factor / curve will help build the business case.

Load demand fulfilment will need to be split into base load (realized with spinning reserve assets (Diesel Gensets / CHP) or HSS or Small Hydro – considering flow) that can operate continually to satisfy base load and renewables (intermittent in nature) being utilized to satisfy peak loads above the base.

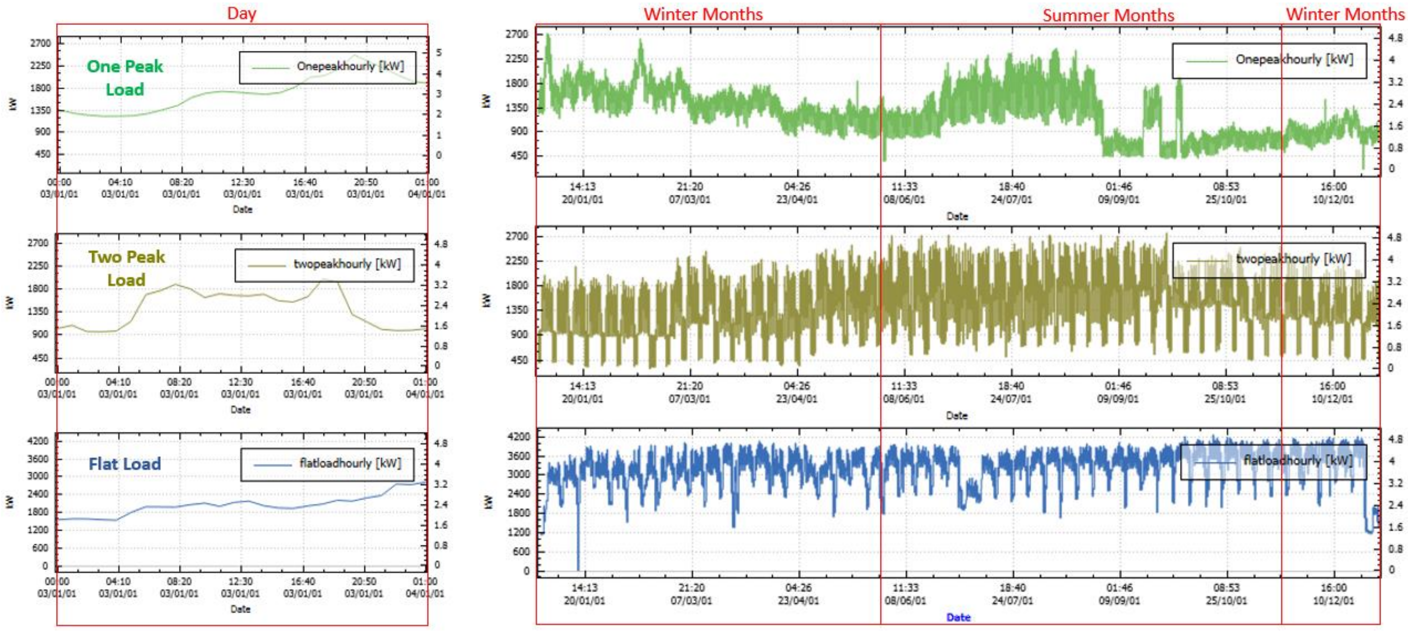

Figure 3.0 – Load Profile Samples

1.4. Qualifying Assets & Sizing

Background Information discussed in Section 1.1 together with analysis of inputs in Section 1.2 will form the basis of a high-level qualification of assets to be used in the MG / DES.

Deep diving into the specific requirements of the assets will be governed by the use cases of the project. (Use cases will be analysed in Section 2.0 of the document)

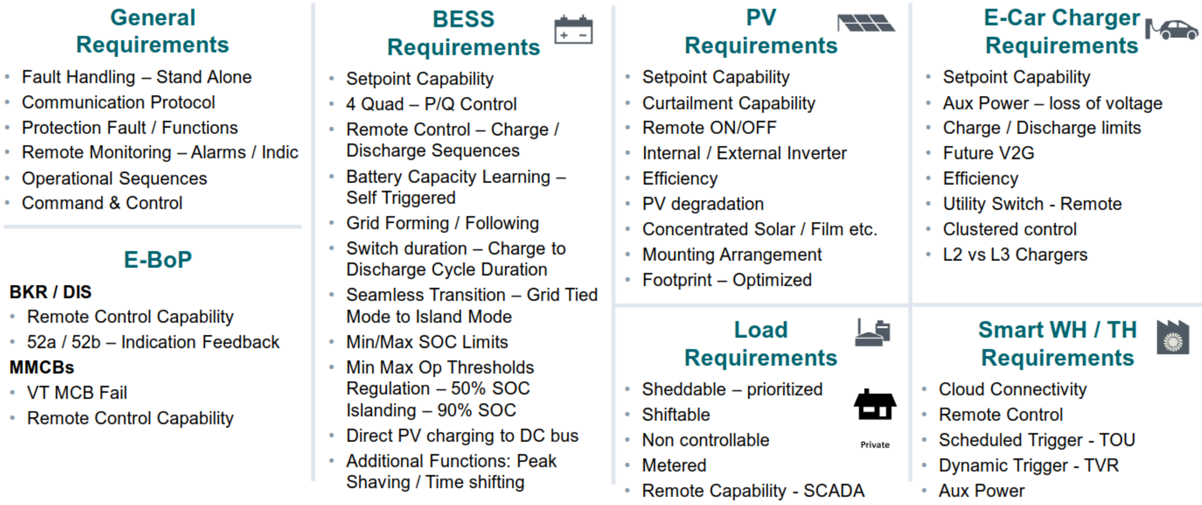

Figure 4.0 – Asset Selection Requirements

The above tabulation details general requirements as well as individual specific asset requirements in order to achieve the use case goals.

Highlighting a few of the critical requirements:

General:

User interface with autonomous modular logic within the controller will have to be utilized. Controller capability from a communication protocol perspective with SCADA functionality. Command and control functionality with setpoint issuance on the controller side and receipt on the asset size in order to allow for generation output rates. Electrical Balance of Plant (E-BoP) switching devices (breakers and disconnects) with remote controllability.

Asset Specific:

- BESS – 4 quadrant inverter for Volt/VAR optimization; Grid Forming / Following capability for seamless islanding and generation support.
- Solar PV – Curtailment capability for excess generation / low load situations
- Load Requirements – Sheddable, shiftable, non controllable
- E-Car Charger – Vehicle to Grid Capability if E-Car battery to be considered as a generation source.
- Smart Water Heater and Thermostat – Remote control capability

1.5. Financial Requirements

Individual stakeholders will utilize different financial parameters to make their assessment on their business case. For example – a Utility that can recover its original capital investment over its rate base will focus on the Net Present Value (NPV) parameter. Independent Power Producer (IPP) that potentially took a loan will be more interested in the IRR, Payback Period, Break Even Point, Interest Rate parameters.
LCoE – Levelized Cost of Energy will serve as a benchmark fiscal parameter to for asset size and selection criteria for any stakeholder.

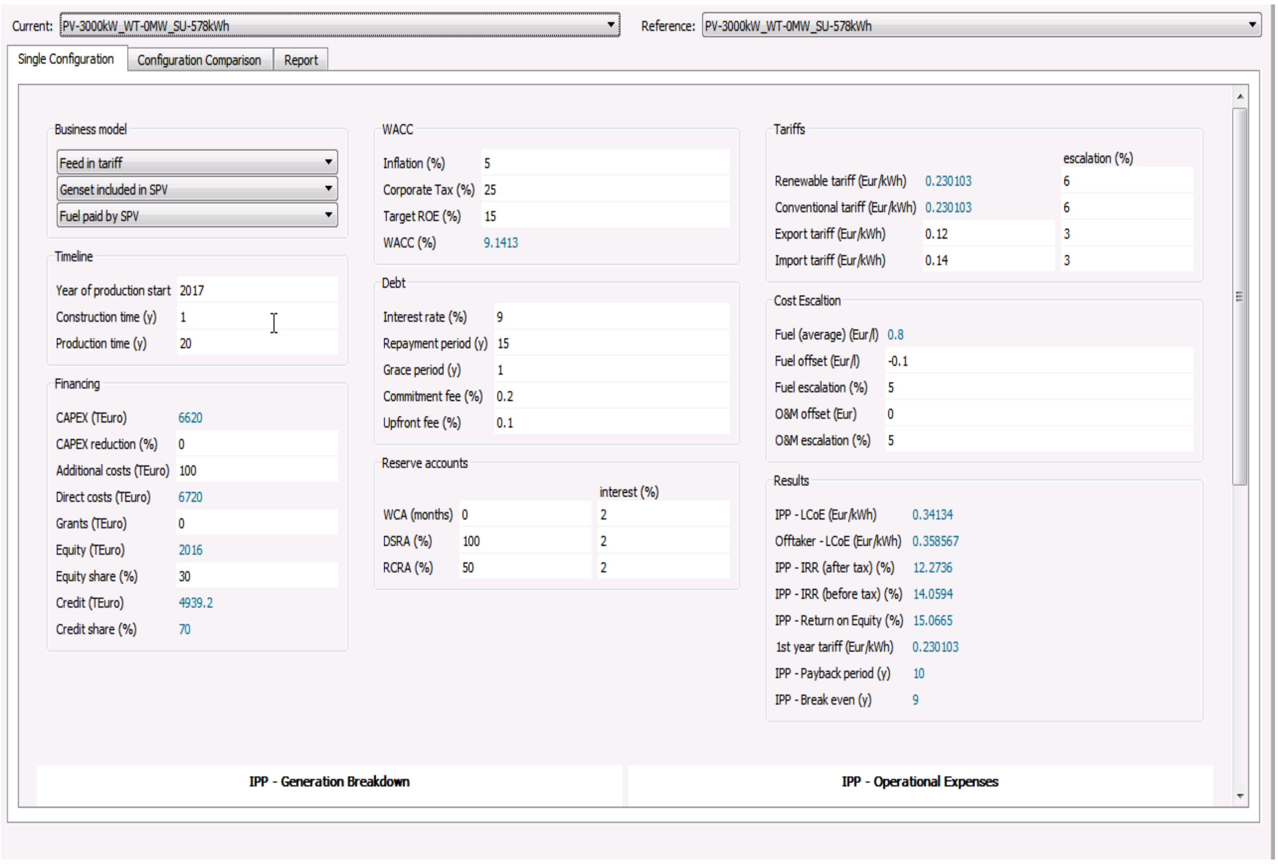

Figure 5.0 – Financial Cockpit – Detailing all fiscal parameters by stakeholder

2.0. Microgrid Use Case Scenarios

The following graph details various use cases that will form the basis of asset selection and solution realization:

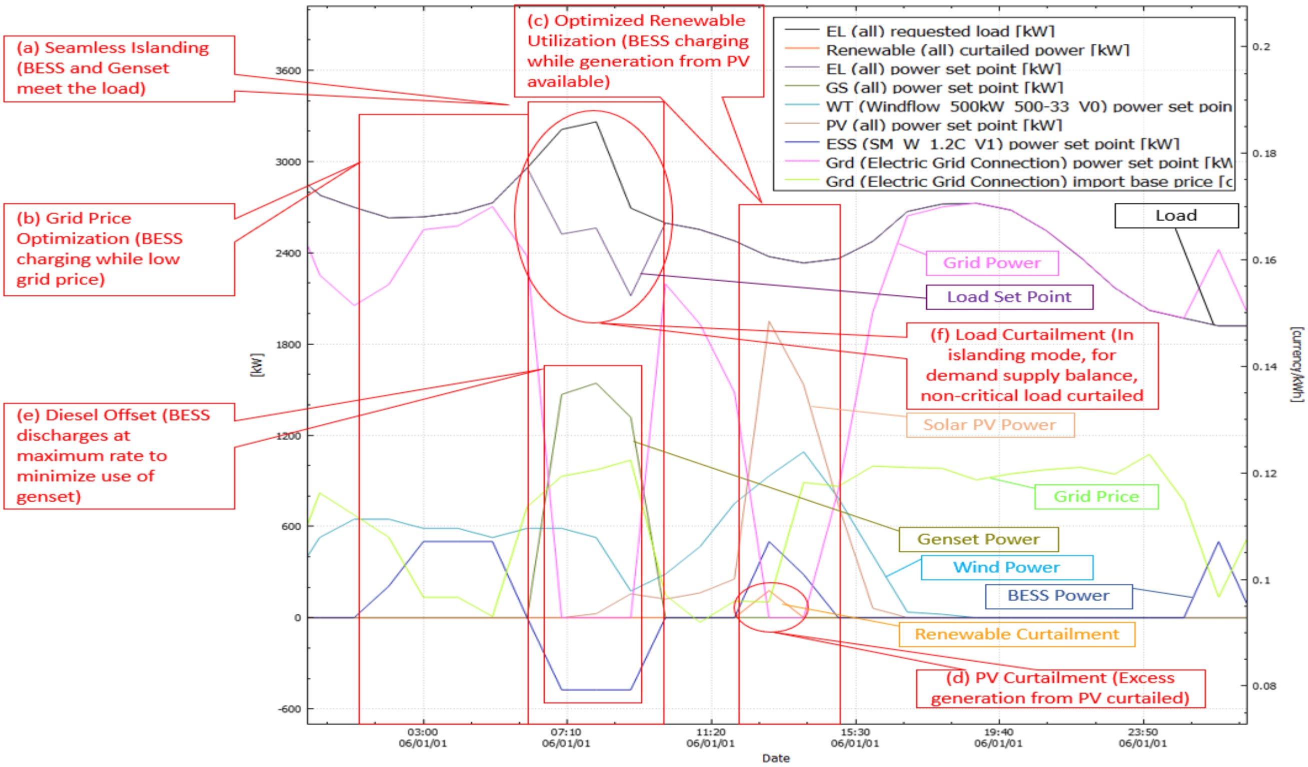

Figure 6.0 – Technical Asset Behaviour Assessment and Use Cases

(a) Seamless Islanding Scenario
From the graph we can see that the Grid Outage triggers the BESS to start on island detection.

(b) Grid Price Optimization Scenario
When Grid Price is cheaper, the BESS is allowed to charge. When expensive, BESS discharges.

(c) Optimized Renewable Utilization Scenario
Using generation from Solar PV to charge the BESS – Cheapest source

(d) PV Curtailment Scenario
In situations of excess PV generation / low load situations, PV curtailment occurs

(e) Diesel Offset Scenario
When there is sufficient state of charge (SOC) in the BESS, Diesel fuel consumption minimized

(f) Load Curtailment Scenario
Generation capacity drop – in this case the grid outage – load shedding of low priority loads

3.0. Conclusion

The increasing number of distributed generation installations clearly point to the requirement to conduct in depth analysis both technically and financially with equal importance to fully assess viability of projects. Key considerations and requirements detailed within this paper will strengthen assessments and positively contribute to a successful and profitable solution.

4.0. Bibliography

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