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Performance Analysis of Analytical Tools in the Techno-Economic Assessment of Electrical Energy Storage and Grid Balancing

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Abstract *— Energy Storage has a crucial role in 'Grid Balancing' with the integration of grid-connected Variable Energy Resources like Wind and Solar Photovoltaic. The selection of appropriate Energy Storage Technology depends on the grid location and the type of grid applications. So a comprehensive study for 'Screening of Energy Storage Technology' is needed. Further, only screening of technology without cost-benefit analysis will not serve the purpose. So it is necessary to select appropriate tools capable of 'Screening of Technology' and carrying economic analysis. Hence ES-Select™ has been used for Screening Storage Technology, and Energy Storage Computational Tool (ESCT) has been used to assess economic and other benefits. The efficacy and limitations of these tools have been shown using a test case. The test case shows that appropriate storage technology can be identified using the ES-Select tool. ESCT tool identifies and quantifies the benefit of relevant grid applications for identified storage technology. Quantified monetary benefits comprise economic and environmental benefits. As per computational results, chosen storage technology has no payback under 15 years. A responsive Regulatory Framework and accommodative energy market that provides a level playing field can ensure economic viability for storage technology.*

Keywords — *Energy Storage, Battery Storage, Grid Balancing, Smart Grid, ES-Select™, ESCT*

I. INTRODUCTION

The substantial percentage of Renewable Energy Resources in the energy mix of a country is the expression of that country's long-term commitment to the environment. This changed energy mix of the world is the result of that resolution and determination. Further, commitment for climate change mitigation under COP 21, as reflected in Nationally Determined Contribution (NDC) of countries, reflects the increased use of Renewable Energy Sources, which is crucial for climate change mitigation. But there are associated challenges as far as grid integrated Renewable Energy Sources are concerned. Variable Renewable Energy Sources (VRES) like wind energy and solar PV are time, weather and season dependent.

With the addition of VRES in the energy mix of a country, associated problems in the form of 'Power Fluctuation' and 'Unreliability' are inevitable as these sources are intermittent in nature. Energy Storage (ES) can help in integrating grid-connected solar PV and wind energy. Further, the 'Unreliability' of wind and solar PV can be solved using ES. Energy Storage can be used for storing the generated power when demand is less and using it at peak hours [1]. ES will have a key task in 'Grid Balancing' with the integration of grid-connected VRES like wind energy.

Broadly, there are four strategies for grid balancing. These are Flexible Generation, T & D Network Enforcements, Demand Side Management (DSM), and Energy Storage Deployment [2].

Presently, 'Flexible Generation' is playing a prominent role in grid balancing strategy for countries with lesser penetration of VRES (5-10%) like wind energy and solar PV. Hydropower and natural gas power stations are two popular options under 'Flexible Generation'. But many countries follow other alternatives too. Germany employs coal power stations and nuclear power stations as 'Flexible Generation' [3]. 'Transmission Enhancement Strategy' is the widening of the area through the interconnection of neighbouring countries' grid, and in turn, smoothening the influence of VRES. Industrial plants such as cement and aluminium plants and Appliances like agriculture pumps taking part in grid balancing strategy are examples of DSM. Under 'Energy Storage deployment', pumped hydro storage (PHS) is the main participant in grid balancing, though it has topographical limitations.

Currently, 'Flexible Generation' is the main strategy adopted by most countries. But with a significant increase of VRES like wind and solar PV in a country's energy mix, grid balancing will be a major challenge. The solution to this problem lies in seeing beyond the existing solution of limited 'Flexible Generation'. Other Advanced Energy Storage Systems like Lithium-Ion (Li-ion) and Sodium-Sulfur (Na-S) Batteries will have a significant contribution in the strategy to balance the grid as their response time, and other key characteristics are capable of various satisfactory grid applications [4].

applications. So it is necessary to go for 'Screening of Energy Storage Technology. Further, only evaluating Technology without cost-benefit analysis will not reflect a broader picture. So it is important to select appropriate analytical tools capable of 'Screening of Technology' and carrying economic and other associated benefits.

The location of Grid-connected Energy Storage and desired grid applications need to be fairly and adequately mapped for the Screening of Energy Storage Technology. This paper's main objective and focus are to screen suitable ES Technology for desired grid applications at specific locations. Further, Technical Analysis must be matched with Economic Analysis for the sake of the holistic picture. The Analytical tools used for this purpose should assess Energy Storage by Techno-Economic Analysis. Taking this need into consideration, the ES-Select has been used for the Screening of Energy Storage Technology, and Energy Storage Computational Tool (ESCT) has been used for the assessment of economic and other benefits. The efficacy and limitations of these tools have been shown using a test case and a real case. The test case shows that appropriate storage technology can be identified using the ES-Select tool. ESCT tool quantifies the benefits of relevant grid applications for identified storage technology. Quantified monetary benefits comprise economic as well as environmental benefits. To ensure the economic viability of storage technology, a responsive Regulatory Framework and an accommodative energy market that may provide a level playing field for storage technology are required. Innovative energy market products, based upon strengths and key characteristics of energy storage such as quick response time in emerging economies like India, will help ensure the economic feasibility of ES Technology.

II. LITERATURE REVIEW

A. Conventional Pumped Hydro vs. Advanced Energy Storage

Based on key storage characteristics [7], PHS is the best for bulk storage. As of 2017, globally, the share of PHS was 153 GW, whereas the share of battery storage was 4 GW [5]. But PHS has geographical location limitations. Advanced Energy Storage Systems like battery storage is independent of geographical location limitation. Further, Battery storage can serve across the whole spectrum of the power system. Battery storage is capable of participating in

The selection of appropriate Energy Storage Technology (ES Technology) depends on the location of grid-connected Energy Storage and the type of grid diverse grid applications, viz. Frequency Regulation, Time Energy Shift or Arbitrage, and Renewable Grid Firming.

Electrical Energy Storage (EES) is classified into Mechanical, Electrochemical, and Electromagnetic according to energy form. PHS, Compressed Air Energy Storage (CAES), and Flywheel fall under the Mechanical category. Batteries such as Li-Ion, Na-S, Flow Battery like Vanadium, and Hydrogen in Electrolyser and Fuel cell come under the electrochemical category. Supercapacitor falls under the electrical category [1].

B. Location for Grid-Connected Energy Storage and their Applications

ES Technology can be deployed ubiquitously in Power System at different locations. These locations may be Generation, Transmission, Distribution, or End User. Further, it is capable of carrying out grid applications with ease, and performance is better with regard to speed and accuracy as compared to conventional sources of grid balancing (Table 1 [6] and Table 2 [8]).

Electrical Energy Storage's utility in various locations like Generation (including Renewable Generation), Transmission, Distribution, and End User makes it versatile (Figure 1). Thus EES is capable of competing in more than one application simultaneously. Therefore, it is imperative for Energy Market and Regulators to provide level playing fields, based upon capabilities and performances, between conventional generating systems and Electrical Energy Storage [9]. Reference [10] uses ES-Select to find the advantages of ES Technologies for the State of Kuwait, and the location of the power system chosen is at the substation level. Reference [11] uses the ES-Select tool to address energy storage system issues for application within the power system of Montenegro. Reference [12] uses the ES-Select tool for the perusal of various ES technologies.

Renewable Capacity Firming (or Renewable Grid Firming) and Renewable Energy Time Shift (Renewable ETS) are a few Grid Applications for EES integrated with Renewable Generation. In Transmission Network, EES can provide Grid applications for EES integrated with Renewable Generation. In Transmission Network, EES can provide Grid applications like Voltage Support, Power Quality, and Reliability. EES at different grid locations and their applications have been tabulated in Table 1 [6].

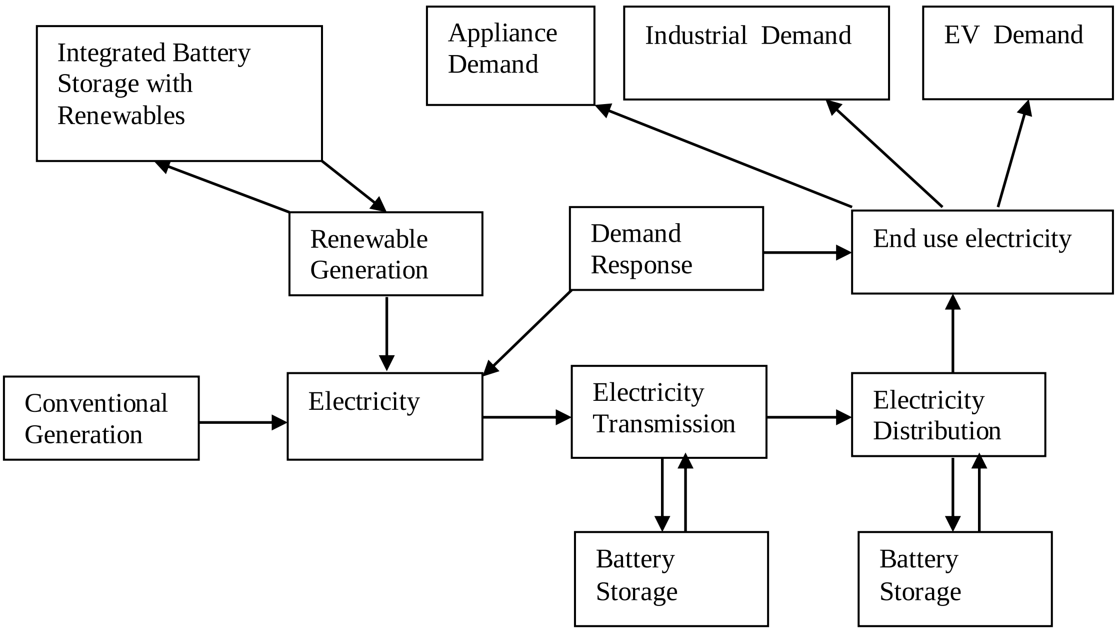

Fig 1: Location for Grid-Connected Energy Storage

Table 1 Grid Location and Probable Application of EES [6]

Grid Location	Grid Application of EES
Renewable Generation	• Capacity Firming • Renewable Energy Time Shift
Conventional Generation	• Arbitrage • Load Following • Frequency Regulation
Transmission	• Voltage Support • Power Quality • Power reliability
Large Industrial Customers	• Spinning reserve

C. Characteristics of Electrical Energy Storage

The International Energy Agency (IEA) characterizes Electrical Energy Storage based on size, discharge duration, cycle life, and response time [7]. Dodds et al. at [2] have compared important characteristics for Electrical Energy Storage based upon studies carried out by IEA, Barton and Infield, and Luo. Barton and Infield take into account characteristics like charge duration, discharge duration, roundtrip efficiency, and energy and power capital cost. Characteristics spelt by Luo et al. [8] are more comprehensive, and these also include O&M cost, technology maturity, energy, and power density. The key characteristics of a few EES technologies are being displayed in Table 2 [8].

Table 2 ES Technology and their Key Characteristics [8]

Technology	Power rating (MW)	Cycles	Response time	Discharge time
PHS	100-5000	10000-30000	min	1-24 hr
Li-ion	1-100	1000-10000	ms	Min-hr
NaS	<8	2500-4500	ms	min-hr
Super-capacitor	0.3	100,000	ms	ms-hr

D. Energy Market

Energy Market may be regulated or deregulated or in between these two. When there is a monopoly and no competition, it is a regulated market. Utilities control every aspect of generation, transmission, and distribution. In the deregulated energy market, there is competition, and utilities are prevented from owning the generation and transmission to deliver customers [13].

Grid services like Frequency control, voltage control, and emergency services are categorized under Ancillary services. Frequency regulation, load following, and reserves fall under frequency control. The grid service that helps to counter fluctuation in short-term demand and supply is known as regulation-up service if accomplished by an increase in the generation or regulation-down service if accomplished by a decrease in the generation. Regulation service has been historically provided by generation facilities with Automatic Voltage Regulation. In 2012, Independent Electricity System Operator (IESO) introduced a Regulation service for battery storage [14].

Operating reserves are spinning reserves and non-spinning reserves. The operating reserve market provides

10-minute spinning, 10-minute non-spinning, and 30-minute reserves in Ontario [14].

Primary Frequency Response signifies local automatic control available in all conventional generators. Such immediate automatic control is executed through turbine speed governors where the generating units respond quickly to the frequency deviation. Historically, Primary Frequency Regulation (PFR) was a granted service available in conventional generating technologies. Significant penetrations of renewable sources such as wind and solar PV may further lessen interconnection frequency response if the installation goes on without PFR capabilities. The introduction of emerging technologies like EES and market demand may need new market designs to adequately compensate EES for this important service [15].

In the USA and India, Primary Frequency Control is a mandatory provision, and hence no compensation.

III. RESOURCES AND METHODS

A. Selection of Analytical Tools

The main focus of the paper is to evaluate suitable grid-connected ES Technology for desired grid applications. So the selected tool should have the capability to combine promising technology and intended grid applications. Tools capable of performing these tasks are ES-Select and ESCT. The ES-Select was developed by KEMA in collaboration with Sandia National Laboratories. Based upon grid applications and the location of grid-connected Energy Storage, the ES-Select tool is capable of evaluating grid-connected ES Technology. The ES-Select tool assigns feasibility scores for various ES technologies based on the maturity of technology, location on the grid, grid applications, and cost. This way, it generates various scenarios for comparative analysis through charts.

Energy Storage Computational Tool (ESCT) has been developed by Navigant Consulting. ESCT is capable of identifying, quantifying, and monetizing the benefits of selected Energy Storage projects. ESCT is also for public use.

ES-Select tool has been chosen for Electricity Storage Technology screening for two reasons. First, it gives a reasonably accurate picture of feasible technology for grid applications. Charts and graphs generated for selected applications are very comprehensive. Further, this tool is amenable and accommodative to change in data of prices and costs of Electrical Storage Technologies. In addition to editing data, new grid applications and new technologies may be included in this tool, making it more flexible and user-friendly.

ESCT tool is capable of quantifying the Revenues, Costs, and Benefits of chosen Grid Applications. ESCT tool monetizes economic as well as environmental benefits. This tool has three modules: Asset Characterization Module, Data Input Module, and Computational Module. Input to Asset Characterization Module and Data Input Module can be made by selecting either default value or can be provided customized value by the user.

B. Characteristics of Selected Tools

The core strengths, focus, and goals of these Analytical Tools have been summarized in Table 3 [16].

Table 3 Analytical Tools for EES Screening and Cost Effectiveness

Category	**Electrical Energy Storage Screening**	**Electrical Energy Storage Cost-Effectiveness**
Analytical Tools	ES-Select	ESCT (Navigant)
Goals	Identifying promising technology	Maximizing expected NPV
Focus	Screening of Storage Technology and service	Evaluating the project cost-effectiveness
Core Strengths	Scoping analysis of a wide range of technologies and services	Financial and cost-benefit analysis

C. Screening of Energy Storage Technologies: ES-Select Tool

ES-Select tool applies a Monte Carlo analysis. This tool may be used for educational, consulting, and screening purposes [17]. First of all location of Electrical Energy Storage on the grid is selected. After that, intended grid applications from the filtered grid applications (filtered on the basis of grid location) are chosen. Once these two inputs are fed, the ES-Select tool will provide a feasible storage solution arranged as per the Feasibility Score. This feasibility score uses Maturity, Location, Application, and Cost into consideration.

D. Monetization of Benefits Associated with Grid Applications of Chosen Storage Option: ESCT Tool

ESCT tool identifies and quantifies the monetary benefits of assessed Electrical Energy Storage. ESCT tool uses information on the location of Electrical Energy Storage, Market, Ownership model and Storage option to suggest various Grid Applications. After that, this tool populates various benefits like economic, reliability, and environmental. Finally, it monetizes all these benefits.

IV. ILLUSTRATIVE EXAMPLES: CASE STUDIES

A. A Case Study and Technical Analysis of 34 MW/245 MWh Energy Storage Integrated with 51 MW wind farms

*1) **Screening of Technology Using ES-Select Tool:*** Location on Grid: Generation (Bulk Storage)

Storage Application:

- Renewable Capacity Firming
- Electric Supply Reserve Capacity – Spinning Reserve
- Renewable Energy Time Shift

Feasible Energy Storage Option: To find (i.e., Screening of Technology to be done)

Broadly Electrical Energy Storage has two applications. One is Power Application, and the other is Energy Application. Generally, the Power Application requires high output power for relatively short periods spanning between a few seconds and a few minutes. The supercapacitor, Superconducting Magnetic Energy Storage (SMES), and Flywheels are appropriate for Power applications. The Energy Applications require a relatively large amount of energy for discharge duration between several minutes and hours. Electrical Energy Storage like PHS, CAES, Batteries fall under this category. Here 34 MW/245 MWh Electrical Energy Storage is an Energy Application as it can provide 34 MW power for nearly 7 hours.

VRES like wind and solar PV are intermittent in nature. This intermittence and variation in output need to be offset. With no ES, this task is done by 'dispatchable' generation, mainly conventional ones. Combining Renewable Generation and ES, the constant output can be fed to the grid. This combination of Renewable Generation and ES is 'Renewable Capacity Firming'.

When demand is low, and Renewables like wind and solar PV are generating in excess, EES captures excess energy and dispatches it during high demand time. This application is 'Renewable Energy Time-Shift'.

Operating Reserves are classified into 'Spinning reserve' and 'Non-spinning reserve'. The word 'spinning' signifies that generation capacity (generator) is online. This generator is alive but unloaded/partially loaded and can come into action within 10 minutes to compensate for outages.

These three applications – Renewable Grid Firming, Renewable ETS, and Spinning Reserve – are energy applications and can be used with a 34 MW/245 MWh Storage system. This 34 MW/245 MWh storage system is integrated into wind farms. So the location of Electrical Energy Storage on the grid is Bulk Storage. Three Grid applications, i.e., Renewable Grid Firming, Wind ETS, and Spinning Reserve, have been chosen for identified location (Bulk Storage). This information of location and grid application will serve the purpose of the Input to ES-Select tool. Based upon these Inputs, this tool generates Feasible Storage options.

Figure 2 below shows various Storage Options based on Feasibility Score. This Feasibility Score is based upon Feasibility Criteria and the Weight of those criteria. Feasibility Criteria takes into account Maturity of the technology, suitability of selected grid location, fulfillment of application requirements, and installed cost. Each criterion has attached some weight to it, and this weight can be varied by the user on a five-level weighting scale (0, 0.5, 1.0, 1.5, and 2.0), the default being 1.0.

As per the Feasibility Score, CAES and PHS occupy the first two slots. As PHS has topographical limitations, the next best available choice is the Na-S battery.

*2) **Comparison of Different Storage Technology:***

The Radar chart shown in Figure 3 compares the feasibility score on all four categories, i.e., Maturity, Location, Application, and Cost. On criteria of Application, Location, and Maturity, Na-S battery is as good as PHS and CAES. It is the cost criterion where the Sodium Sulfur battery is behind the other two options. As far as other storage options like Li-ion battery is concerned, Na-S battery is far ahead on all four categories.

Based on the Application category, the Na-S battery option is the best (Figure 4). Figure 5 shows Discharge duration in hours. As this is an energy application, and the selected technology has to meet 7 hours on rated output (34 MW/245 MWh), the storage option should reflect Discharge Duration in this range. Again Na-S battery is the best among

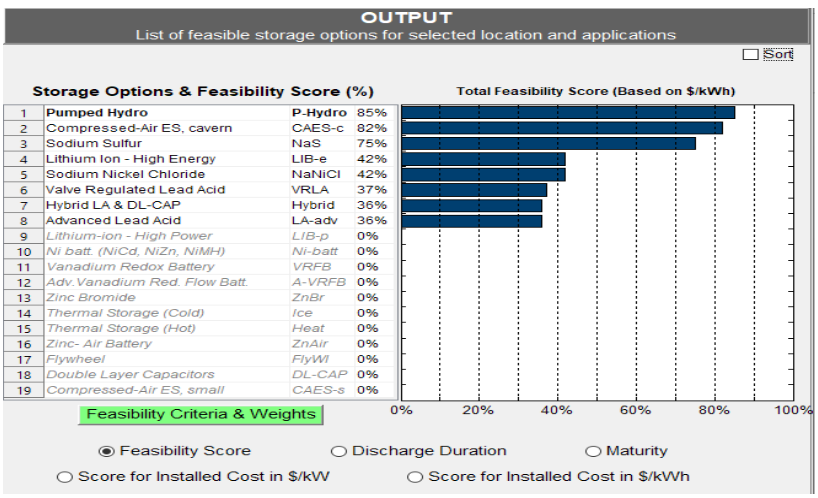

Fig 2: Location for Grid-Connected Energy Storage

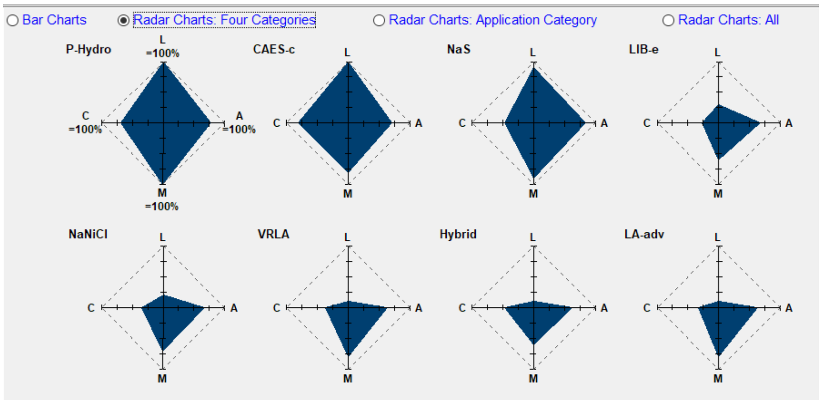

Fig 3: Scores Meeting Application (A), Location (L), Cost (C), and Maturity (M) Criteria

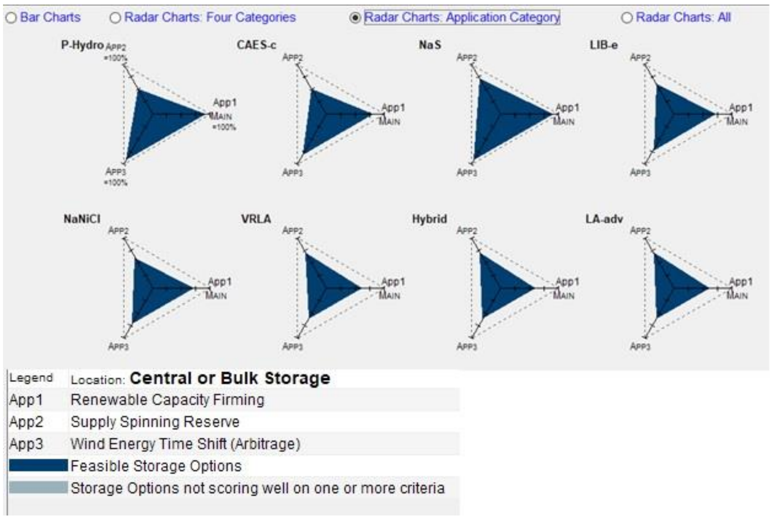

Fig 4: Feasibility Criteria as per Applications

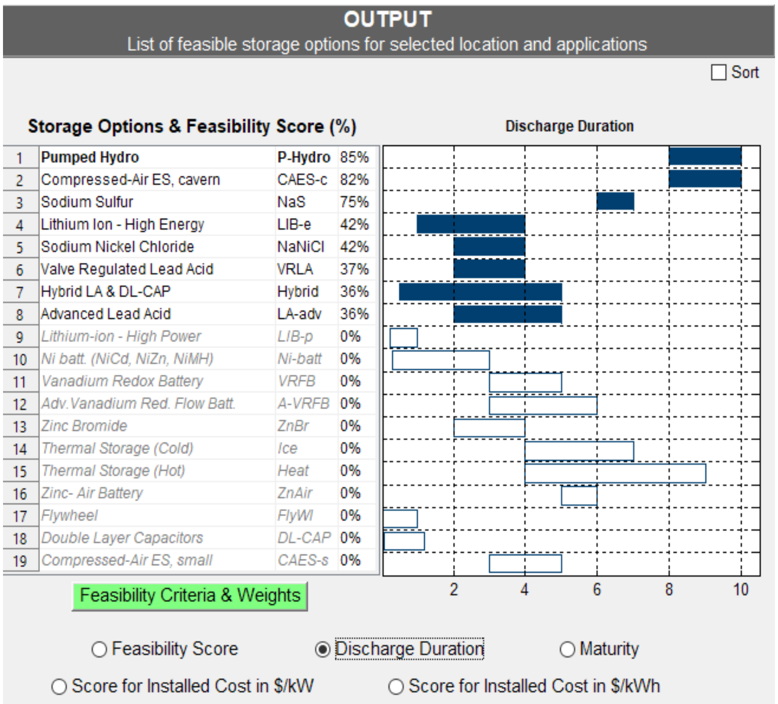

Fig 5: Discharge Duration in Hours for Storage Options

Advanced Energy Storage Systems. Only PHS and CAES are better than Sodium Sulfur battery.

Under Discharge duration of more than 6 hours, Na-S has efficiency in the range of 75%. Other Advanced Storage Systems like Li-ion battery is more efficient, but Discharge Duration is comparatively less. Further, as per the Cycle life and Discharge duration graph, the Na-S is better-placed vis-à-vis Li-ion battery.

B. Economic Analysis Using Energy Storage Computational Tool (ESCT)

***a) Introduction*:** Now, Screening of Energy Storage Technology has been done. It is time to go for the monetization of benefits. Energy Storage Computational Tool (ESCT) will help in performing this task. For the sake of completeness, it is better to go ahead with the previous example of a 34 MW/245 MWh Na-S Energy battery integrated with 51 MW wind farms.

Like ES-Select, ESCT needs the physical location of ES Technology to be one of the inputs. Unlike ES-Select, ESCT gives an option for Grid Applications. It suggests a Primary Application as well as two Secondary Applications.

Unlike ES-Select, ESCT requires data pertaining to system parameters (size, discharge duration, efficiency, cycle life) and cost parameters (Installed cost, maintenance cost, life of deployed storage technology). These data can be taken from ES-Select User Manual or any other authentic source [18-19]. In a way, ES-Select and ESCT complement each other.

Once all necessary fields are inputted, ESCT spells out benefits for required Applications. These benefits can be monetized by providing data related to emission factors, the energy market, and other costs.

b) Selecting Location, Market, owner, and Technology: ESCT requires selection of Location in Power System (Generation and Transmission, Distribution and End User), Market Structure (Regulated/Deregulated), Ownership Model (Utility, Independent Power Producer, End-user), and ES Technology to be deployed at the very onset [15-20]. Generation and Transmission as a Location, Deregulated Market, Independent Power Producer, and Na-S battery have been selected here.

c) The input of System Parameters: Key characteristics of Electrical Energy Storage like size, response time, Efficiency, Cycle Life need to be provided. Accordingly, the value of these characteristics has been fed, as shown in Table 4.

Table 4 System Parameters for Energy Storage Deployment [18]

System Parameter of Storage Battery	Value
Power Output (kW)	34,000 kW
Energy Storage Capacity (kWh)	245,000 kWh
Response time	0.001 seconds
Roundtrip efficiency	75%
Cycle life	4,500

d) The input of Cost Parameters: The cost parameter for the Na-S battery has been shown in Table 5. Life of deployed Na-S battery is 15 years, Installed cost ($ /kW) lies in the range of 2,394-5,170 and Operation and Maintenance cost is 10 ($/year/kW) [18].

Table 5 Cost Parameters for the Energy Storage Deployment

Cost Parameter	Value
The expected lifetime of the deployment	15 years
Average inflation rate	2%
Discount rate	5%
Total installed cost ($ 3600/kW)	$ 122,400,000
O&M cost ($ 10/kW-year)	$ 340,000

e) Primary Application and Secondary Applications: After providing the information as discussed in IV.B.2-IV.B.4, ESCT suggests a set of Primary Applications. These include Bulk Energy Services (Electrical Energy Time Shift, Electric Supply Capacity), Ancillary services (Regulation Services and Operating Reserves), and Renewable specific applications. Here, the Primary Application selected is Renewable Capacity Firming.

Two secondary Applications chosen are Electric Supply Reserve Capacity (this includes spinning and non-spinning reserve) and Renewable Time Shift.

f) Summing up of Benefits: After selection of Primary and Secondary applications, ESCT enumerates benefits. Benefits have been shown for this example in Figure 6. These benefits are categorized as Market Revenue, Improved Asset Utilization, and Air Emission. Arbitrage Revenue, Capacity Market Revenue, and Ancillary Services Revenue fall under Market Revenue, Optimized Generation Operation comes under Improved Asset Utilization, and Reduced Emission is bracketed in Air Emission.

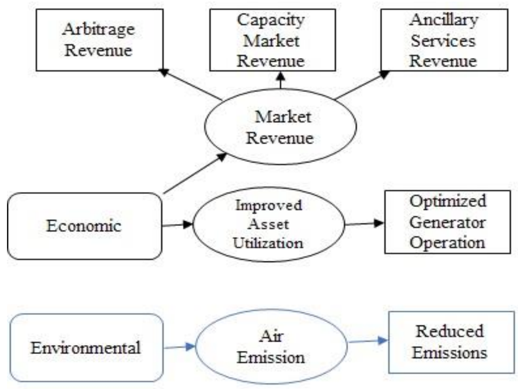

Fig. 6 Benefits

g) Monetization of Benefits: Quantified Economic and Environmental benefits have been summarized in Table 6.

Table 6 Cumulative Gross Benefits over Deployment Period (Present Value)

Benefit	**The monetized value of Benefit**	**% share in total Benefit**
Arbitrage Revenue	$ 10,105,600	19%
Capacity Market Revenue	$ 18,236,400	34%
Ancillary Services Revenue	$ 4,368,100	8%
Optimized Generation Operation	$ 377,400	1%
Reduced Emission	$ 20,032,900	38%
Total Gross value	**$ 53,120,400**	**100%**

V. RESULTS AND DISCUSSION

A. Screening of Energy Storage Technology

Section 4.1 investigates a case of 34 MW/245 MWh Electrical Energy Storage integrated with wind farms. The objective was to Screen Energy Storage Technology for given grid applications and location. Feasibility Scores on all four categories (Maturity, Location, Application, and Cost) find Na-S battery the best option (Note: PHS as Energy Option has not been considered here as it has geographical location limitation). On the Applications front also, the Na-S battery is found to be the best choice. Based on Discharge Duration and Cycle Life also, the Na-S battery is placed well. So Na-S battery Storage Option is suitable for this project.

The above case study is not hypothetical, and rather a 34 MW/245 MWh Energy Storage integrated with 51 MW wind farms was commissioned in Japan in 2008 [21]. The Storage Technology chosen was the Na-S battery. The Example test case and the Real case have been tabulated below for comparison in Table 7 and Table 8.

Table 7 Example Test Case for Testing and Screening of Electrical Storage Technology Using ES-Select Tool

Example Test case	**Result of ES-Select Tool**
Case: 34 MW/245 MWh Energy Storage integrated with 51 MW Windfarms	Analytical Tool ES-Select suggests Na-S Battery

Table 8. Real Case of Japan that Uses Na-S Battery as EES

Real case	**ES Technology used**
34 MW/245 MWh, Na-S Battery Integrated with Windfarms of 51 MW Na-S battery – Rokkasho Futamata Project (Japan)	Na-S Battery

It is evident that Electrical Storage Technology selected on the basis of Feasibility score using ES-Select tool is in consonance with the Real case being used in the Rokkasho Futumata Project (Japan). This project is operational since 2008, and the Ownership Model is the third party.

B. Economic Analysis of Selected Energy Storage Technology

As per the ES-Select tool, there is no payback up to 15 years (Figure 7). Cumulative Gross Benefits, Costs incurred in deployment of Storage Battery and Net Benefits obtained by ESCT tool are shown in Figure 8. As can be observed, the Cumulative Net benefit of the deployed Storage Battery always remains negative. It implies that the deployed Storage Battery has a negative Present Value and is incapable of paying for the investment made.

VI. CONCLUSIONS

Techno-economic assessment of EES for various Grid applications was carried on using Analytical Tools like ES-Select and ESCT. Electrical Energy Storage chosen for assessment was Sodium Sulfur battery, and the Grid applications covered were Renewable Capacity Firming, Electric Supply Reserve Capacity, and Renewable Energy Time Shift. ES-Select tool screened Na-S battery for identified Grid applications. This screening was evident in the test case of 34 MW/245 MWh Electrical Energy Storage and a real case of 34 MW/245 MWh Na-S battery used in the Rokkasho Futamata Project (Japan). Further ESCT tool quantified the economic and environmental benefits of 34 MW/245 MWh Na-S battery. Cumulative Present Value of Net Benefits was negative, implying the non-feasibility of the project. Here comes the role of Regulators and policymakers to decide modalities for the economic viability of Electrical Energy Storage. Innovative energy market products tailor-made for battery storage based on its key characteristics (merits and capabilities) like response time, may be introduced for the economic viability of battery storage.

Here a Techno-economic assessment of Na-S battery for Bulk Storage location has been made for three applications viz. Renewable Capacity Firming, Electric Supply Reserve Capacity and Renewable Energy Time Shift. A similar exercise may be carried out for other locations with a different set of applications for checking the economic feasibility of the project.

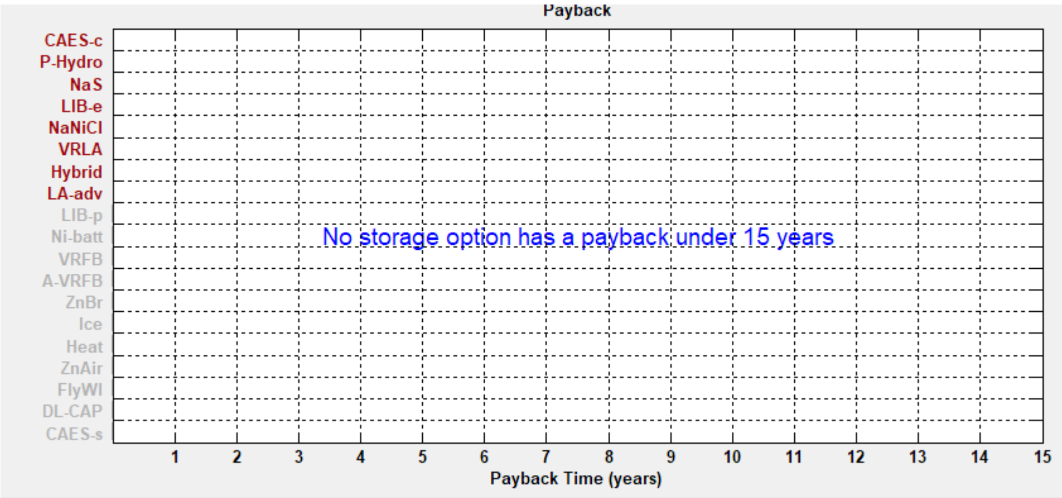

Fig 7. Payback Period as per ES-Select Tool

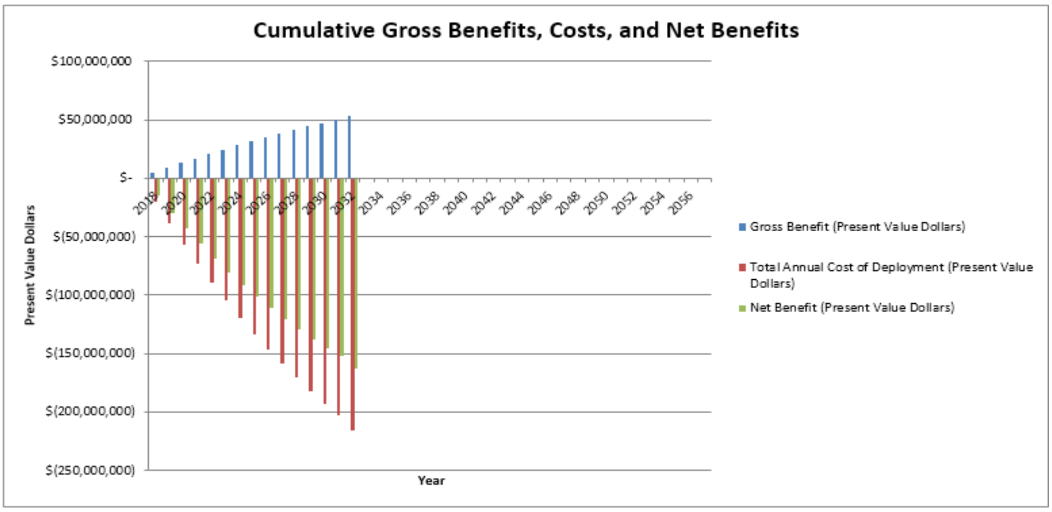

Fig 8: Cumulative Gross Benefits, Costs, and Net Benefits

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