Regulatory analysis and economic challenges to enable new energy storage systems in power systems

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***Abstract*—This paper presents a methodology for analyzing the feasibility of the insertion of energy storage systems in electric distribution networks due to different regulatory policies. Various topologies are used as input data, and as output, we have the maximum possible cost that the energy storage system may have to be considered viable by the potential investor. With the input data is possible any combination of these 8 regulatory policies, generating 255 scenarios for evaluation. For each scenario, the possible revenue was estimated, with each one scenario generating 441 sub-scenarios resulting from the test of several levels of WACC and taxes. Thus, in all, there are 112,455 possible regulatory configurations for evaluation. Based on the calculation of cash flow in each sub-scenario, the work determined the maximum possible cost in each of these. The proposed method allows the validation of which energy storage technologies are feasible or not, and which technological development they need to achieve considering the regulatory framework in which they are inserted. Through simulations with standard distribution networks using worldwide economical reference values, it is possible to determine which changes regulatory agents must make to enable the rise of storage systems in power distribution networks.**

Keywords—* *Distributed Generation, Economics, Economics In Power Systems, Energy Markets, Energy Storage

I. Introduction

In recent years, there has been an expressive increase of renewable energy sources in electric power systems, where many of these sources are by their nature intermittent, that is, they have a high variability in the short term, which represent a new challenge for the system. As a result, energy storage systems (ESS) have emerged initially to resolve such problems [1]. The challenge for energy system operators in this context would be to limit renewable generation capacity to a maximum value of their total capacity, in order not to expose the system to a risk of collapse due to loading, tension or stability constraints. In this way, this has stimulated the development of regulatory frameworks that encourage the insertion of SAEs that could mitigate such restrictions [2]. For network operators, ESSs can offer benefits to the operation of the electric power system, especially in technical aspects [3].

In addition, the greater benefits that ESSs can be economical, since they are able to improve the rate of use of energy equipment, provide a lower cost of supply and increase the utilization rate of new power plants [4]. In this way, ESS can be a solution to make the energy market more efficient in competitive markets, because it is able to efficiently allocate consumer and generator surpluses. Its operation can lead to significant changes of prices to the consumer and the producer, obtaining the maximum overall benefit to the system [5].

II. Energy Storage Systems

For the expansion of solar and wind energy sources and their intermittent nature, the integration of ESS has been the best solution since it is able to ensure the necessary stability and quality in electric power systems [6]. However, ESSs when evaluated alone are considered expensive and not viable when compared to other solutions and their attractiveness only tends to increase with the increase of these renewable sources [7]. In this scenario, the benefits of ESSs have been studied and measured as a way to leverage their use and in distribution systems ESSs have played a relevant role, as they can generate both economic and technical benefits [8].

The profitability of ESSs can also be ensured in other uses, as they are excellent candidates for large consumers and generators because they can ensure the physical guarantee of generation for intermittent sources [9] or even to support the residential demand can change the dynamics between supply and demand through shared systems of ESSs among several consumer units [10]. However, even when considering only their use for generation, ESSs only tend to become economically viable when they are able to provide ancillary services to the systems making it important to regulate such services [11]. In addition to the technical services, ESSs can be used to regulate energy market prices, by arbitrating these markets and can help to stimulate renewable sources and discourage thermal systems [12]. In markets with merit dispatch, the challenge is to pursue the global economic optimum and in this objective when considering all costs ESSs has been an increasingly viable choice [13].

ESSs in the power system, especially in the distribution sector, have generally been limited due to three major problems being: low energy market liquidity, changing market conditions and lack of standards and procedures to connect, operate and maintain ESSs. To mitigate these constraints, the main recommendations are in the regulatory framework in the sector [14]. Such changes are essential to enhance the benefits of ESSs and thus enable their expansion, which will only occur if their cost is lower than the benefits that the system offers [15].

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However, recent research indicates that revenues from ESSs decreased significantly in the last period, suggesting the need for new regulatory arrangements that would reverse this scenario, with the risk of making new ESS investments unfeasible [16].

Studies indicate the best economic configuration would be the combination of the models, allowing the ESS to provide multi-services and performance in the energy market, enabling them to maximize their revenues and to make new investments easier, but only if such changes are associated with changes in the regulatory framework [17]. It is considered that all the benefits that the ESSs provide to the system could be remunerated, such as: reduction of the peak of load, reduction of the operating cost of the system, reduction of the cost of generation, more efficient use of the generation system, impacts on the prices of energy market, among others [18].

Thus, any change must seek a clear regulatory framework guaranteeing a reasonable rate of return to enable new investments and that these standards be periodically revised in order to create a more competitive and attractive business environment [19]. There are also other aspects that regulators have no direct influence on, but can be treated in some way in their current regulatory standards, such as capital costs, operating and maintenance costs, technology efficiency, financing, government incentives and among others [20]. Finally, in many aspects the technological maturity of ESSs has not yet been reached, whose costs can still be high, creating a difficulty in finding a minimum return for the investor, and it may be necessary to establish some public policy contributions until this technological maturity is reached [21].

Thus, it is expected that there will be an increasing penetration of renewable generation sources and what is observed is that the higher this level of penetration, the less competitive the traditional sources of generation and more attractive become the ESSs, initiating a virtuous cycle where ESS can drive the very establishment of renewable sources and so on.

III. Methodology And Problem Formulation

ESS applications can be evaluated from a variety of perspectives, the challenge is to determine how to conduct this assessment in a comprehensive and through possible regulatory policies. The objective is to carry out an evaluation from a regulatory and financial perspective, in order to determine the appropriate incentives for expansion of new ESSs

A. Restrictions for ESS Operation

In the simulations, the following restrictions were evaluated:

- Voltage: Increase of voltage in the discharge and decrease in the loading of the ESS;
- Load: In the load of the ESS it is analyzed the increase in the loading of the system;

B. Regulatory Policies

The following services were evaluated that ESS can perform when economic regulation allows:

- Loading: Service provided to reduce peak loads in the system;
- Expansion: Service provided to postpone investments;
- Losses: Service provided to reduce losses;
- Reactive: Service provided for absorption or injection of the reactive;
- Penalties: Penalty for non-availability of ESS;
- Support for Generation Unpredictability: Service provided when its expected and negotiated generation in the market is lower than what is actually generated;
- General System Support: Supplying the system;
- Primary Energy Market: Arbitrage of prices in the market;

C. Financial Revenue Model

The financial revenue model should consider all constraints presented and returns on each service provided by the ESS to the system. The total return will be according to (1).

$$F_{(t)} = (\mu_{Load}Ret_{Load}) + (\mu_{Inv}Ret_{Inv}) + (\mu_{Loss}Ret_{Loss}) + (R\mu_{Reat}Ret_{React}) - (\mu_{Pen}Pen) + (\mu_{SGen}Ret_{SGen}) + (\mu_{SSyst}Ret_{SSyst}) + (\mu_{Mark}Ret_{Mark}) \quad (1)$$

Where:

F(t) = total revenue;

Ret_{Load} = Financial return on Service to reduce peak loads;

μ_{Load} = Regulatory standard for service of load reduction;

Ret_{Inv} = Financial return on Service to postpone investments;

μ_{Inv} = Regulatory standard for Service to postpone investments;

Ret_{Loss} = Financial return to reduce losses;

μ_{Loss} = Regulatory standard for reduce losses;

Ret_{React} = Financial return to absorption or injection of the reactive;

μ_{React} = Regulatory standard for absorption or injection of the reactive;

Pen = Penalty for non-availability;

μ_{Pen} = Regulatory standard for Penalty for non-availability;

Ret_{SGen} = Financial return to energy generation;

μ_{SGen} = Regulatory standard for energy generation;

Ret_{SSyst} = Financial return to Supplying the system;

μ_{SSyst} = Regulatory standard for Supplying the system;

Ret_{Mark} = Financial return Arbitrage of prices in the market;

μ_{Mark} = Regulatory standard for Arbitrage of prices in the market.

Defining each μ as 1 when there is this regulation and 0 when there is no.

D. Possible Scenarios

Considering that all regulatory policies will not always be in place, it is important to define different scenarios from one where there is only one policy in place or one in which all possible policies will be in place. Therefore, it will be necessary to evaluate 255 possible regulatory scenarios.

E. Investment Model

The investment model should consider as much as possible of existing variables and that impact the decision to make investments. In this work were considered:

- ESS Costs: Considers values of initial investments and their costs for their operation and maintenance, which depend on the maximum capacity of power and energy;
- Weighted Average Capital Cost (WACC): The cost of capital to make the investment;
- Tax Rate: The tax rate applied on ESS operations (it reduce your possible revenues);

The feasibility analysis of investments can be measured by several methods, one of the most common being through the Internal Rate of Return (IRR) of the project. However for regulated sectors, the minimum profitability can be defined as the regulatory WACC of the sector. But, the purpose of the analysis is not to determine the appropriate IRR considering a pre-defined WACC. The objective is to vary the WACC possible and thus to seek a possible investment considering this WACC and the values of the defined cash flows for each regulatory scenario. Thus, the response for each evaluation will be a maximum investment value according to (2).

$$C_{investiments} = \sum_{t=1}^{N} \frac{R_{Real(t)}}{(1+WACC)^t} \quad (2)$$

Where:

$C_{investiments}$ = Initial Investment Cost;

R_{Real} = adjusted annual Revenue, discounting the tax rate;

t = number of years in operation;

Thus, the objective is to determine a limit value for the investment to be viable, that is, it seeks to define the maximum possible investment value. In this way it is possible to determine in which scenarios the ESS installation will be feasible or not, both for the technical and regulatory aspects, validated through a financial model and considering the typical values of ESSs.

IV. Case Study

The evaluation is carried out based on the proposed methodology and on a standard distribution network denominated IEEE34 with the OpenDSS and Matlab software.

A. Regulatory and Financial References

For this work, international regulatory and financial references were used, with a focus on more mature markets, especially the American market. The references of services price and energy market were obtained from the references presented by DOE (U.S. Department of Energy) and the energy market of California according to [22], [23], [24] and [25].

For the ESSs costs, the values of initial investments a range of values was used for evaluation according to Table I, additionally it is used 2% of the initial capital for use in operation and maintenance per year and a replacement asset value of approximately 30% of the initial capital according to [26], [27], [28], [29] and [30].

B. Assumptions

Assumptions are done based on technical references and market values presented. The technical, regulatory and economic references are presented in Tables I, II and III, respectively.

TABLE I. TECHNICAL ASSUMPTIONS

Item	*Reference*
Efficiency	95% in discharge and 90% in load
Dimension	100 kW (power) and 100 kWh (energy)
Location	In the bus with greater reduction of losses
Time per year	80% days of the year
Time per day	1h in load e 1h in discharge scheduled
Unavailability	4 unscheduled interruptions per year
Generation Support	30 minutes per day in 50% days of the year
System Support	20 minutes per day in 100% days of the year

TABLE II. REGULATORY ASSUMPTIONS

Item	*Reference*
Reduce peak loads	37.00 US$/kW per year
Postpone investments	43.75 US$/kW per year and WACC 4%
Reduce losses	50% mean price of 28,359 US$/MWh
Absorption reactive	2.63 US$/kvar per year
Penalties	1.00 US$/kWh per unavailability
Generation Support	75.79 US$/kW per year
System Support	21.72 US$/kW per year in normal system and 79.92 US$/kW in overload system 70.88 US$/kW per year in long term
Market energy	Load in the minimum price and discharge in the maximum price, for 80% of the days in operation and efficiency of 90%

TABLE III. ECONOMICS ASSUMPTIONS

Item	*Reference*
Life cycle	15 years
Operation Cost	2% of initial investment per year
Replacement Cost	30% of initial investment in all life cycle
Microeconomics	ESSs do not influence the market price
Profit	10% of remuneration per year
WACC	Variations from 0% to 20%
Tax	Variations from 0% to 40%
Load growth	4% per year
Load curve	Based on California market energy

V. Results

A. Simulations

The simulations correspond to the evaluation of each one of all possible combinations of the regulatory policies evaluated and described in Table IV, promoting in all 255 scenarios.

TABLE IV. REGULATORY POLICIES

ID	*Regulatory Policy (Services Provided)*
1	Reduce peak loads
2	Postpone investments
3	Reduce losses
4	Absorption reactive
5	Penalties
6	Generation Support

ID	Regulatory Policy (Services Provided)
7	System Support
8	Market energy Arbitrage

For each of the 255 scenarios, we created other sub scenarios where it was tested the WACC variation and the tax rate, providing for each scenario another 441 sub scenarios for evaluation, in this way, there were 112,455 possible for evaluation. For reference of feasibility of investments two limits were adopted that would allow the installation of ESSs:

- Limit 1: Values that would allow the installation of mature technologies, with a reference value of 900 U $ per 1kW of power and 1kWh of storage;
- Limit 2: Values that could enable non-commercial technologies, with a reference value of US $ 2,000 per 1kW of power and 1kWh of storage;

The result of each scenario is illustrated in Table V.

TABLE V. IDENTIFICATION OF RESULTS

Code	Evaluation
(green)	Value above Limit 1 and Limit 2 Allows installation of non-commercial and mature technologies
(blue)	Value above only limit 1 Allows installation just of commercial technologies
(yellow)	Value at 80% of Limit 1 value New technological advances in cost-effectiveness may allow commercial technologies
(gray)	Values make any technology unfeasible

B. Main results

The following figures present the main results for some combination of possible scenarios as summarized below:

- Only one Policy in Operation: The highlight is the application of policy 8, which, although it did not obtain an adequate response, presented values at 80% of this limit 1, as can be seen in Fig. 1;

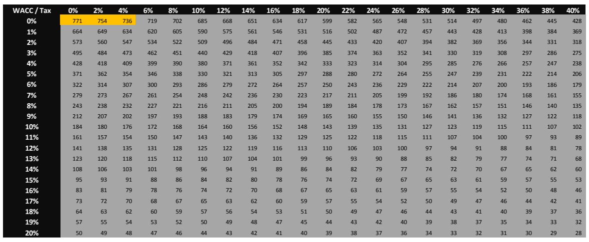

Fig. 1. Application of Regulatory Policy 8

- Two Policies in Operation: There are 28 possible scenarios, being in 8 scenarios with sub-scenario above limit 1 only and 5 scenarios above 80% of this limit 1. The most promising scenario corresponds to the association of policies 6 and 8, according Fig.2;

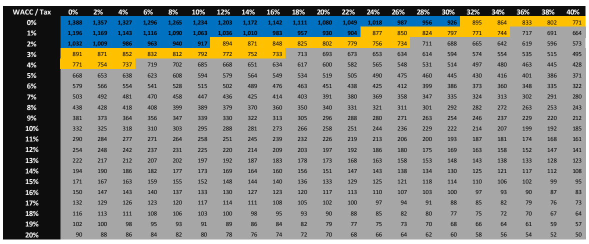

Fig. 2. Application of Regulatory Policy 6 and 8

- Three Policies in Operation: It has a total of 56 possible scenarios, with 32 scenarios make feasible limit 1, but still without any exceeds limit 2. The most promising scenario is the regulatory arrangement that combines policies 6, 7 and 8;
- Four Policies in Operation: With 70 possible scenarios, it is possible to verify 3 scenarios where there is feasibility of investments above limit 2, and in addition there are still 54 scenarios with viability above the limit 1. The scenario more promising, combining policies 2, 6, 7 and 8, according Fig.3;

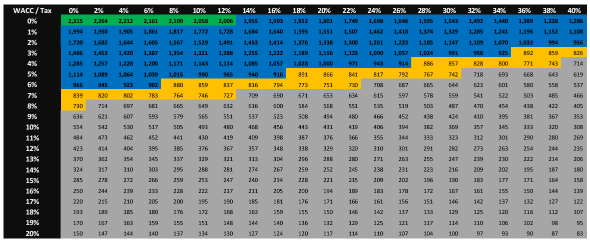

Fig. 3. Application of Regulatory Policy 2, 6, 7 and 8

- Five Policies in Operation: There are 56 possible scenarios, with 11 scenarios make feasible the limit 2 of investments and 43 scenarios with viability above the limit 1. The highlight is in the scenario that combines the policies regulatory bodies 1, 2, 6, 7 and 8;
- Six Policies in Operation: With 28 possible scenarios, there are 13 scenarios enable investment limit 2 and above limit 1 are all scenarios evaluated. The best scenario evaluated is the one combines the regulatory policies 1, 2, 3, 6, 7 and 8;
- Seven Policies in Operation: It has 8 possible scenarios, where there are 7 scenarios that enable investment limit 2 and above limit 1 are all scenarios evaluated. The best scenario is the combination of regulatory policies 1, 2, 3, 4, 6, 7 and 8;
- Eight Policies in Operation: The application of all policies at the same time implies 16 sub possible scenarios above limit 2, according Fig.4.

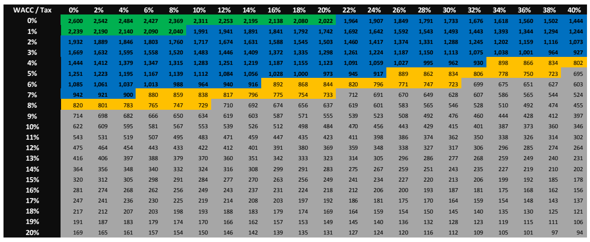

Fig. 4. Application of all Regulatory Policies

VI. CONCLUSION

The evaluations made it possible to verify that there are some regulatory policies most significantly impact the viability of ESSs, since they allow a large increase in the inflow of revenue to provide certain services. In this way, the focus is on interventions in the energy market for price arbitrage and also on services to support the unpredictability of generation and in the support to system.

Finally, it was observed that the greater variability in the feasibility analysis of the ESSs are not always in the scenarios, but rather in the sub scenarios of the same scenario, mainly due to the high sensitivity of the response to the WACC. For any scenario or sub-scenario evaluated, the unfeasibility of any investment for WACC above 9% per year was verified. The taxation influences the final results, but its sensitivity to the final response is less significant in relation to the variation of WACC.

In this way, it is concluded that being of great importance by the regulator not only an evaluation of the technical and economic frameworks that can influence directly the sector, but also aspects whose interference is not direct, but that must appear in the metrics of its modeling as the WACC and tax rate.

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