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Distributed Storage Applications for Public Facility

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Abstract

Time-of-use energy cost management involves the use of storage by customers to reduce their electricity bills. This can be accomplished by charging the storage during off-peak time periods, when electricity energy prices are low, and discharging it during times when on-peak energy prices are applied. This article addresses the question whether it is economically viable to install medium-scale distributed storage devices in the power system designed to lower the electricity cost for a customer-side application, assuming flexible electricity tariffs. The technical/economical evaluation is carried out referring to Lithium ion (Li-ion), Sodium Sulphur (NaS) and Vanadium Redox Battery (VRB) technologies, performing a parametric analysis by changing the capital cost of the batteries and the difference between the maximum and minimum electricity price. A case study is performed to show the advantages/disadvantages of the proposed approach.

1 Introduction

Decentralized production and the introduction of variable, fluctuating sources (such as solar or wind energy) pose severe disadvantages for the competitiveness of these Renewable Energy Sources (RESs) in the electricity market and could ultimately limit their expansion. The variability and non-dispatchable nature of these sources has led to concerns regarding the reliability and stability of associated electric systems [1]. Energy Storage Systems (ESSs) represent the most significant solution to these problems and are poised to become a fundamental element of the electricity infrastructure of the future [2].

A primary characteristic of the electrical system is that generation and demand need to be in balance for each time interval. In order to assure this condition, the Transmission System Operator (TSO) is obliged to keep additional capacity available in order to meet deviations from the forecast demands and compensate for losses on transmission lines and in traditional power plants, and other contingencies [3].

At present, only energy producers and large industrial facilities are able to adjust their production and demand in order to stabilize the grid, while public institutions and commercial and residential customers have not yet been involved in balancing the electric system. In Italy, this situation has changed in recent years, as load-dependent tariffs have been introduced.

This work presents an estimate of the economic benefit from using an ESS for Time-Of-Use (TOU) energy cost management at a consumer level, assuming flexible electricity tariffs. A TOU energy cost application is used by customers to reduce their electricity bills, charging the storage during off-peak time periods, when electricity energy prices are low, and discharging it during times when on-peak energy prices are applied [4]-[9]. This application could yield major benefits, including a reduced need for peak generation (particularly from expensive peaking plants) and reduced charge on Transmission and Distribution (T&D) systems [10].

The facility considered for the analysis is a public institution, the DEIM, Department of Energy, Information Engineering and Mathematical Models of the University of Palermo.

The economic benefit is estimated performing a parametric analysis, by varying the capital cost of the batteries and the difference between the maximum and minimum electricity prices.

The total investment and replacement costs are estimated in order to calculate the cumulated cash flow, the Net Present Value (NPV) and the Pay-Back Period (PBP) for the installed Battery Energy Storage Systems (BESSs).

2 Electrical Energy Storage Applications

In addition to the capability of enabling the integration of more RESs into the network, ESSs can provide many other benefits that can be summarized as follows [11]-[15]:

- benefits related to load/generation shifting;
- benefits related to ancillary services;
- benefits related to grid system applications.

Benefits related to load/generation shifting may include: TOU energy cost management, electric energy time shift, demand charge management, renewable energy time shift, renewable capacity firming.

Benefits related to ancillary services may include: load following, frequency regulation, contingency reserve, voltage support. Benefits related to grid system applications may include: ability to reduce transmission congestions, deferral of investment in T&D network upgrades, ability to improve reliability and power quality of the electrical system, black start. If the storage system is properly sized, it can be used for more than one application at the same time [16]. In the following, only the benefits related to load/generation shifting are described, since they are those of interest in this context.

2.1 Benefits related to load/generation shifting

Load/generation shifting can be used by customers, utilities, or renewable power producers to take advantage of the different electricity rates at various times of the day. Load shifting can be used by customers to reduce the overall costs for the absorbed energy. If the beneficiary is a regulated utility or a non-utility merchant, the application is named "electric energy time shift". Thus, the two applications are similar, but the electricity prices are based on the customer's retail tariff when TOU energy cost management is used, whereas, at any given time, the prices for electric energytime-shift are the prevailing wholesale prices.

Demand charge management involves an overall cost reduction for electricity services by reducing demand charges, i.e., reducing the power draw during a specified period, normally coincident with the utility's peak demand period. This application enables end-users to cut peak demand charges by providing insight into power absorption and giving customers the ability to shift demand from periods of peak usage to less expensive off-peak hours.

Peak demand charges are one of the two major components of a customer's power bill and they are accounted based on short, infrequent periods of maximum consumption. To account for peak demand, utility companies are compelled to purchase reserves that remain untapped most of the time, only to be used for brief periods of high demand or during failure of other reserves.

In a similar manner, two different production shifting applications are available for a renewable power producer: renewable energy time shift and renewable capacity firming. In effect, most RESs generate a significant part of the produced energy when the electricity value is low, e.g., during the night, holidays, etc. In this case, renewable energy time shift can be used to shift the RES energy from off-peak to on-peak hours by using the renewable energy to charge the storage when the electricity value is low, spilling it to the grid during high-value periods. Thus, the use of storage in conjunction with RESs helps to increase the value of the RES energy.

Renewable energy time shift is particularly valuable for intermittent sources, specifically wind generation. In effect, unlike photovoltaic (PV) generation, where most energy is produced during the day, a lot of wind energy is generated at night and can be shifted for a more valuable use.

Renewable capacity firming involves only intermittent energy sources, whose output is variable, for the purpose of "filling in" the RES power diagram in order to obtain a more levelled power curve. Therefore, renewable capacity firming allows the use of a variable source as a nearly constant power source in order to reduce the power-related charges. This strategy is particularly valuable during peak demand periods, often eliminating the need for T&D upgrade.

3. Economic Analysis

The economic benefits related to load/generation shifting are evaluated by calculating the cash flow, the PBP and the NPV of the investment for the BESS installations [17]-[19].

The cash flow depends on several factors such as the gain for the avoided bill cost, the total investment cost, the storage replacement cost, and the Operation and Management (O&M) cost. All these factors can be translated into cash flow, C_t^*, by means of the following equation, obtained by adding algebraically all the costs, $C_{i,t}$, and the profit, P_t, related to the generic t^{th} year:

$$C_t^* = P_t - \sum_i C_{i,t} \tag{1}$$

The BESS cost includes the total investment cost, the storage replacement cost, and the O&M cost.

The savings depend on the battery operation mode and on the gap between high and low electricity prices. Let us to consider the electricity bill relative to the day d (without storage):

$$C_{E,d} = \sum_{h=1}^{24} (c_h . E_{h,d}) \tag{2}$$

where c_h is the electricity cost in the h^{th} hour and $E_{h,d}$ is the corresponding purchased energy. In the present analysis, the component proportional to the power draw has been neglected as it is a constant that does not influence the results of the calculations. The modification of the daily user's power diagram after the installation of the storage system causes a change in the user's daily consumption. The daily saving from installing the battery can be expressed as follows:

$$P_d = C'_{E,d} - C_{E,d} = \sum_{h=1}^{24} c_h .(E'_{h,d} - E_{h,d}) \tag{3}$$

where $C'_{E,d}$ and $E'_{h,d}$ are the daily electricity bill and the user's consumption in the generic h^{th} hour, respectively, when storage is added.

Ultimately, the profit, P_t, related to the generic year t can be expressed as:

$$P_t = \sum_{d=1}^{365} P_d \tag{4}$$

The total BESS cost can be obtained by decomposing the battery into three different components: storage, Power Conversion System (PCS) and Balance Of Plant (BOP). BOP cost includes the auxiliary components outside of the storage

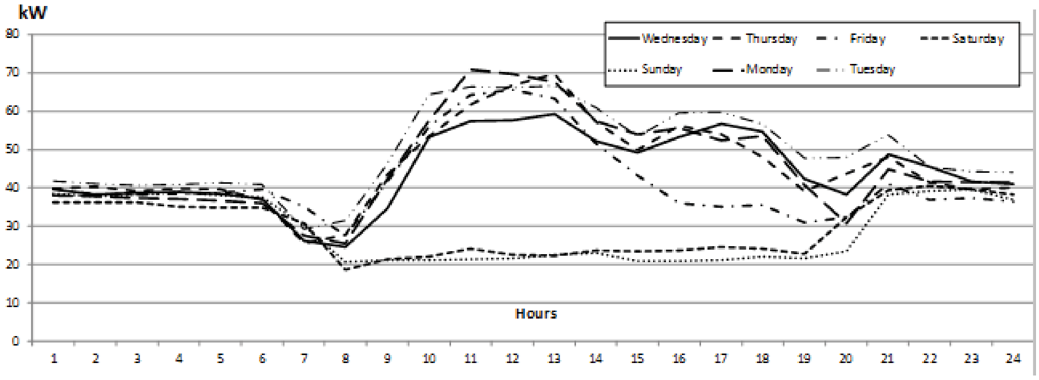

Fig. 2. Weekly power diagram for the considered public institution

The BESS is assumed connected to the LV bus-bars of the transformer, inside the C9.1 substation.

The benefit of using BESSs for TOU applications was assessed considering two different scenarios:

- SCENARIO 1: the electricity purchase prices are assumed to be equal to the real electricity tariffs of DEIM in each reference period, reported in Table 1^1, while the installation cost of the BESS is variable;
- SCENARIO 2: the components of the installation cost of the BESS are assumed equal to those in Table 2, estimated by averaging the costs of the three considered storage technologies, including installation, interconnection, and grid integration costs [20]-[22]. The minimum electricity price is assumed equal to the F3 price in Table 1, while the difference between maximum and minimum electricity price is assumed variable.

Time slot	**F1**	**F2**	**F3**
Energy price (€/kWh)	0.1334	0.09390	0.06450

Table 1: Energy price tariffs applied to the DEIM

C^u_{STOR} (€/kWh)	280
C^u_{PCS} (€/kW)	190
C^u_{BOP} (€/kW)	76

Table 2: Per unit BESS costs

The BESS is sized in order to maximize the TOU energy cost benefit for the customer, fully offsetting the power diagram when the electricity prices are the highest (through battery discharge) while increasing it in the off-peak periods (through charging the battery).

Table 3 shows the BESS parameters, assumed equal for the three different storage technologies [22].

Discharge duration [hours]	4
Capacity [kWh]	350
Rating power [kW]	70
Estimated life [years]	15
Round-trip ac-to-ac efficiency	80%

Table 3: Average BESS parameters

The battery capacity was calculated referring to the maximum energy absorbed from the DEIM during off-peak hours, under the assumption that the battery fully offsets the power diagram when the electricity prices are the highest. The rated power was selected with reference to the maximum hourly power value in the reference period.

Simulation Results (SCENARIO 1)

In the first scenario the cash flows, the NPV and the PBP were calculated by varying the installation cost as a percentage of the average BESS cost derived using the data in Tables 2 and 3. In particular, the estimated BESS average cost is equal to:

$$C_{TOT} = C^u_{PCS} \cdot P_{BESS} + C^u_{BOP} \cdot P_{BESS} + C^u_{STOR} \cdot C_{BESS=}$$

$$= 190 \cdot 70 + 76 \cdot 70 + 280 \cdot 350$$
$$= 111620 <$$

The economic analysis was performed considering the following percentage of the average cost: 25%, 50%, 75%, 100%, 125%, 150%. Table 4 reports the NPV and the PBP values for the different cases.

C_{TOT} [%]	NPV [k€]	PBP [years]
25%	67.6	4
50%	38.5	8
75%	9.3	14
100%	-19.8	20
125%	-49.0	>>15
150%	-78.1	>>15

Table 4: NPV and PBP values (Scenario 1).

In Fig.5 are reported the cumulated cash flows for the six cases.

Simulation Results (SCENARIO 2)

In the second scenario the cash flows, the NPV and the PBP were calculated by varying the difference between the maximum and the minimum electricity prices. In the economic analysis, the BESS installation cost is assumed equal to that derived from the data in Tables 2 and 3, the minimum electricity price was considered equal to the F3 price (Table 1), and the maximum price was assumed variable according to the following percentages of the F1 price: 25%, 50%, 125%, 150%, 200%, 300%.

Table 5 reports the NPV and the PBP values for the different cases.

C_{MIN} [%]	NPV [k€]	PBP [years]
25%	-93.9	>>15
50%	-71.3	>>15
125%	-3.4	16
150%	19.3	13
200%	64.6	9
300%	155.2	5

Table 5: NPV and PBP values (Scenario 2).

In Fig. 6 are reported the cumulated cash flows for the six cases.

Discussion

As specified in Section 4.1, the BESS installation cost was estimated by averaging the costs of the three considered storage technologies. Specifically, according to [20]-[22], VRB have costs in the range of (50%-60%) C_{TOT}. Li-ion batteries have higher cost, in the range of (200%-280%) C_{TOT}. Otherwise, using NaS batteries (composed of liquid sulphur and sodium, separated by an electrolyte in the form of solid ceramic), makes it possible to contain the installation cost in the range of (65%-75%) C_{TOT}, maintaining, at the same time, a medium-high efficiency value (75%-90%).

Therefore, among the various technologies taken into account, the NaS battery appears to have the greatest potential for TOU applications, essentially due to its lower cost. Conversely, Li-ion technology is not still recommended for load/generation shifting applications, mainly due to the higher installation costs (higher storage cost compared with the BOP and PCS costs), and to the shorter life (11 years against 15 years of the other battery technologies). The situation could obviously change if the same battery is used for more than one application.

Li-ion batteries are currently widely used in the consumer electronics sector and automotive sector (hybrid and electric vehicles), but they have recently faced challenges in relation to grid applications because of the differences in performance and cost requirements for stationary applications [23]-[24].

The main advantages of Li-ion technology are the high power and energy density and the very high efficiency (90%–95%).

With regards to the variation of the gap between the maximum and the minimum electricity prices, the simulation results of scenario 2 indicate that the use of BESSs for TOU applications allows to obtain significant benefit for the customer only when the maximum electricity price is higher than 150% of the minimum price. This condition, however, rarely occurs, especially in those countries where there is a large share of energy produced from renewables.

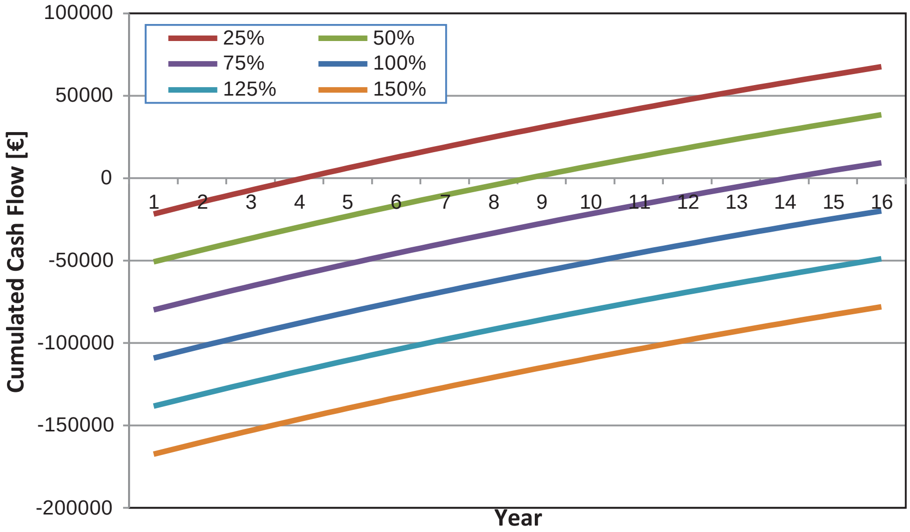

Fig.5. Cumulated Cash Flows (SCENARIO 1).

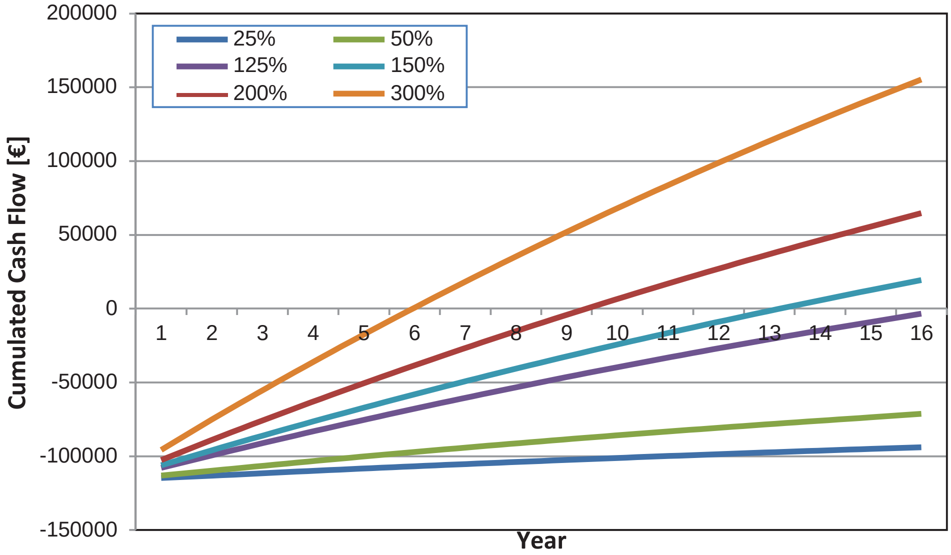

Fig.6. Cumulated Cash Flows (SCENARIO 2).

Conclusions

The aim of the present study was to evaluate the economic viability of using BESSs for TOU energy cost applications at a consumer level, when flexible electricity tariffs are applied.

The economic evaluation was carried out taking into account average values for the BESS cost and for the round-trip ac-to-ac efficiency and considering two different scenarios in order to perform a parametric analysis of the possible economic benefits for the end-user.

The analysis reveals that, at the current cost of VRB and NaS storage technologies, the use of BESSs for TOU applications can be economically advantageous for a medium-scale public institution facility only when there is a significant difference between the maximum and the minimum electricity price. Conversely, the use of Li-ion technologies, despite its performance advantages, it is still not economically attractive for the end-user.

Anyway, the rapid decrease in the cost of storage technologies [22], the aggregation of different benefits, and the introduction of more flexible tariffs in the electricity market should make storage technologies more competitive for load shifting applications, independently on the adopted storage technology.

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