Application note
CalBatt NomoStor for energy storage systems

1. Overview

Traditional energy storage management strategies are usually aimed at selecting the charging/discharging power of the storage system just as a result of the instantaneous difference between the power available from sources and that required by loads, **making the storage system to operate in “random” working regions**.

This “blind” approach completely neglects the fact that both the efficiency and the life of the storage system are strongly affected by the selected charging/discharging power profile. As a consequence, conventional energy management strategies usually lead to a **real efficiency remarkably less than the peak efficiency** achievable by the storage system when operating optimally.

For example, experimental results have shown that a storage system with a peak efficiency of 85% (equipped with high-quality batteries and a battery inverter with a peak efficiency of more than 95%) can have a real efficiency of about 70% when managed according to traditional energy management strategies (Fig.1).

CalBatt innovative approach is aimed at changing the energy management paradigm, introducing the innovative concept of considering the **battery charging/discharging power as a degree of freedom** in setting the best energy management strategy.

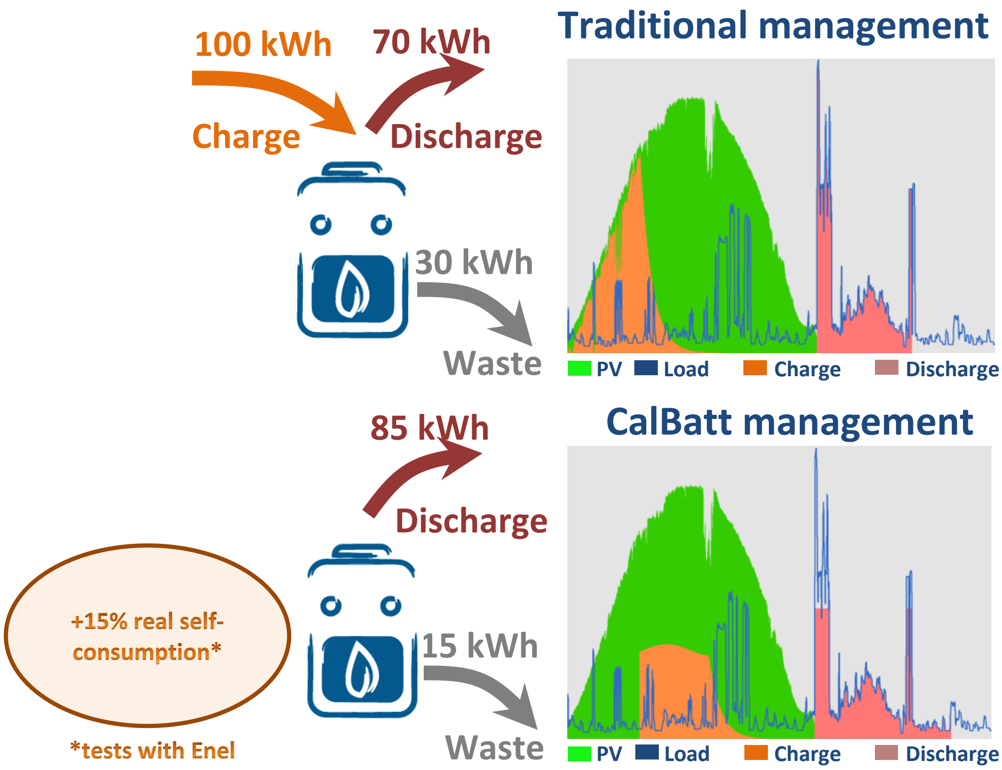

Fig. 1: conceptual example showing the difference between the conventional and the innovative CalBatt approaches to energy storage management

In fact, in several real situations, the **battery charging/discharging power can be perfectly “trimmed”** in order to achieve always the best scheduling for the storage usage during the day to achieve maximum efficiency and life of the storage system.

Also in the case of grid related services where charging/discharging power are fixed by the particular application (frequency and voltage regulation, peak shaving, etc.), it is possible to exploit the typical modular structure of the storage system by managing optimally the power of each module to achieve the targeted charging/discharging power of the overall storage system.

Obviously, when considering the battery charging/discharging power as a degree of freedom, a fundamental question arises: "**which is the best value of the charging/discharging power to be used at each time instant**?" This answer is **practically impossible to be obtained** just from measurements carried out by sensors available into the system (power meters, voltage, current and temperature sensors etc.). Even **common existing battery monitors (both as stand-alone devices or integrated into the Battery Management System (BMS)) are useless to this purpose**, because they are just able to estimate battery state of charge and lifetime.

To solve this problem, we have developed NomoStor, **the innovative storage controller based on CalBatt patented and internationally awarded technology**. It is a **decision support tool**, capable of suggesting the best battery charging/discharging power at each time instant to the Energy Management System (EMS) which supervises the storage operation.

NomoStor is designed to be a very flexible solution, which can be:

- **embedded by the storage system manufacturer** directly into the Power Conversion System (PCS) as an electronic expansion card (**NomoStor Card**) put in communication with the PCS controller (Fig. 2a). This is the most suitable solution when the EMS functionalities are carried out by the PCS controller, which is for example the typical situation in small residential renewable storage systems. In this case, NomoStor Card interacts directly with the PCS, receiving from it the data needed to carry out a dynamical analysis of storage system performance and sending to it the suggested values of charging/discharging power to optimize system performance;

- **used by system integrators** as a stand-alone device (**NomoStor Box**) put in communication with the EMS (Fig. 2b), when it is external to the PCS controller. This is normally the situation occurring in larger storage systems (for renewable integration, industrial and grid-scale applications), in which the EMS manages the energy flows between sources, loads and storage in order to carry out specific functionalities which depend on the particular applications.
  In the case of an array of storage elements (intended both as independent systems or modules of the same storage system which can be managed separately), a NomoStor Box is used for each storage element. Each NomoStor Box interacts with the EMS, receiving from it the data needed to carry out a dynamical analysis of performance of the storage element related to the specific NomoStor device, and sending to it the suggested values of charging/discharging power to optimize the performance of the storage element. This allows the EMS to perform an advanced management strategy capable of optimizing the overall energy efficiency through an appropriate modulation of charging/discharging power signals exchanged with the PCS controller of each storage system (obviously, the essential condition to exploit the functionalities of NomoStor Box is the capability of the EMS of modulating the charging/discharging power of the storage elements through a proper interaction with each PCS).

It is crucial to highlight that **NomoStor is absolutely not intended as substitutive of existing BMS**. In fact, BMS are normally aimed at monitoring voltage, current and temperature of single cells (or small groups of cells) of the battery pack, indicating maximum ratings of the charging/discharging power to be respected by the PCS to guarantee safe operations for the battery, and performing equalization when needed. Instead, NomoStor is aimed at **monitoring and controlling the overall system efficiency** (taking into account the efficiencies of both the PCS and the battery pack), suggesting the best instantaneous values to be used for the charging/discharging power **always fully in compliance with maximum ratings set by the BMS**.

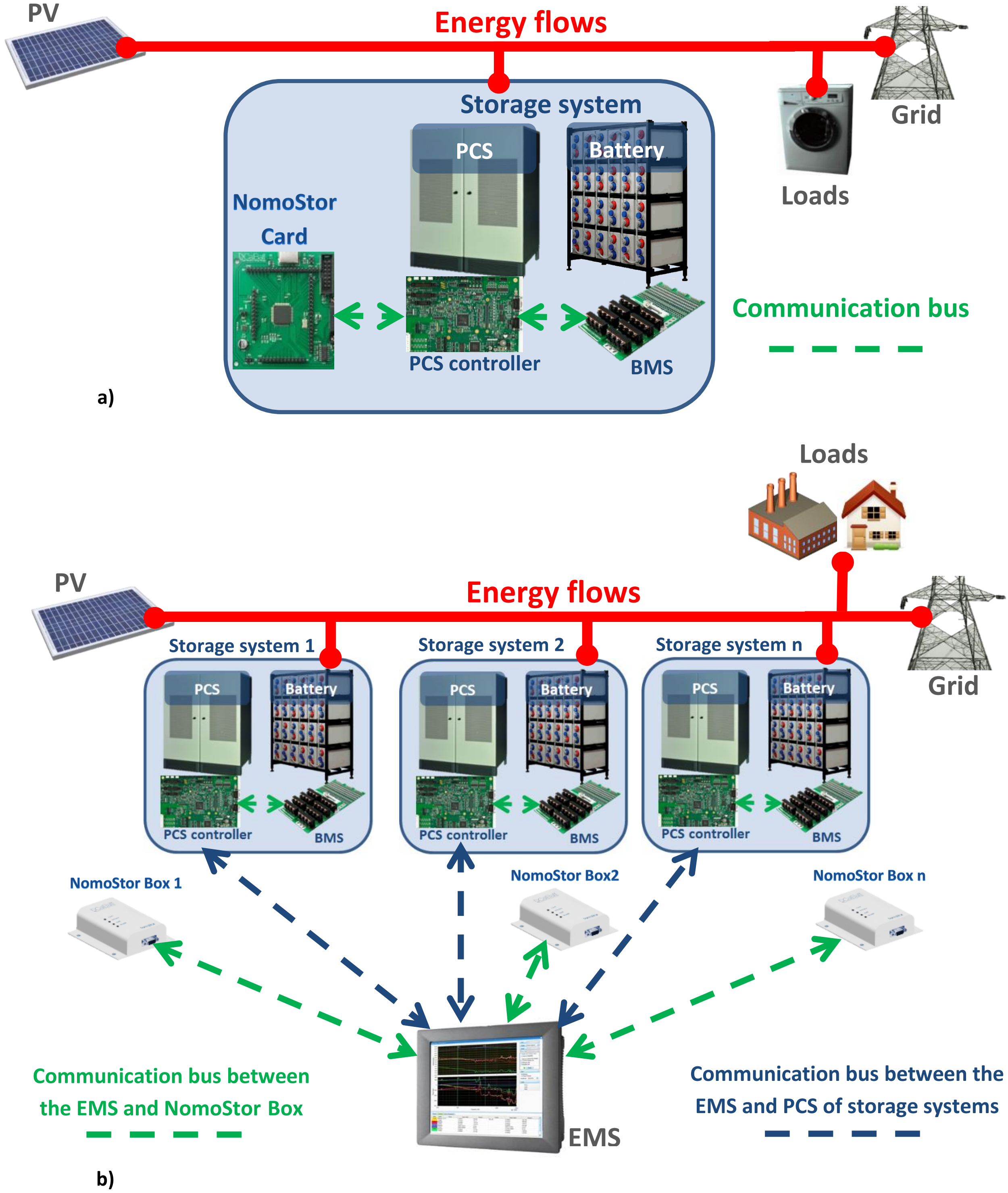

Fig. 2: block diagram showing the connection of CalBatt NomoStor with the devices of the storage system: 2a) NomoStor Card embedded into the storage system and interacting with the PCS controller; 2b) NomoStor Box as a stand-alone device interacting with the EMS external to storage systems.

In other words, using **NomoStor can allow the unique possibility of moving carefully into the admissible charging/discharging power range set by the BMS**, in order to bring always the operating conditions of the system near to those maximizing energy efficiency. As a consequence of the working principle of CalBatt technology, the efficiency increase attainable depends, case by case, not on the absolute value of the peak efficiency of the storage system (determined by the intrinsic qualities of both the battery and the PCS), but on the relative distance between the real efficiency achieved in random operating conditions without using NomoStor, and the peak efficiency achievable really on the field by using NomoStor (in several tests carried out on commercial systems, a 15% relative efficiency increase was measured as a consequence of using CalBatt optimization technology).

2. CalBatt NomoStor operating modes

NomoStor has three operating modes:

- Mode 1: DynAnalysis
- Mode 2: MaxEff
- Mode 3: WhatEff

These three operating modes are based on parameters exchange between NomoStor and the related device (the PCS controller for NomoStor Card and the EMS for NomoStor Box) according to a specific communication protocol. The list of parameters exchanged, as well as details about the communication protocol (standard, baud rate, etc.) are available on request.

2.1. DynAnalysis operating mode

In the DynAnalysis operating mode, NomoStor implements **CalBatt method for the dynamical analysis and characterization** of efficiency performance of the storage system. The implementation of the method requires that NomoStor receives data related to some relevant operating parameters of the storage system (among which, for example, the battery voltage and current and so on) (Fig. 3a).

2.2. MaxEff operating mode

The dynamical analysis carried out in the DynAnalysis operating mode allows NomoStor **to predict the charging/discharging efficiency of the storage system in every possible operating conditions**, taking into account the evolution of the storage system characteristics (especially the battery state of charge) during system operation.
These unique forecast capabilities allow NomoStor to identify the best charging/discharging power to guarantee the efficiency maximization.
When NomoStor works in MaxEff operating mode (Fig. 3b), it communicates **the right charging/discharging power value to be set at each time instant for maximum efficiency** and a forecast about the resulting time required to complete the charge/discharge process (it is worth noting that the best charging/discharging power value is not a fixed number, but it varies instant by instant during the charging/discharging process according to the complex evolution of storage system parameters, such as the battery state of charge).

2.3. WhatEff operating mode

In some cases, **maximizing the storage efficiency may not be the only goal** of the energy management strategy. For example, sometimes it could be suitable to identify sub-optimal charging/discharging profiles in terms of efficiency in order to comply with charging/discharging time or power constraints.

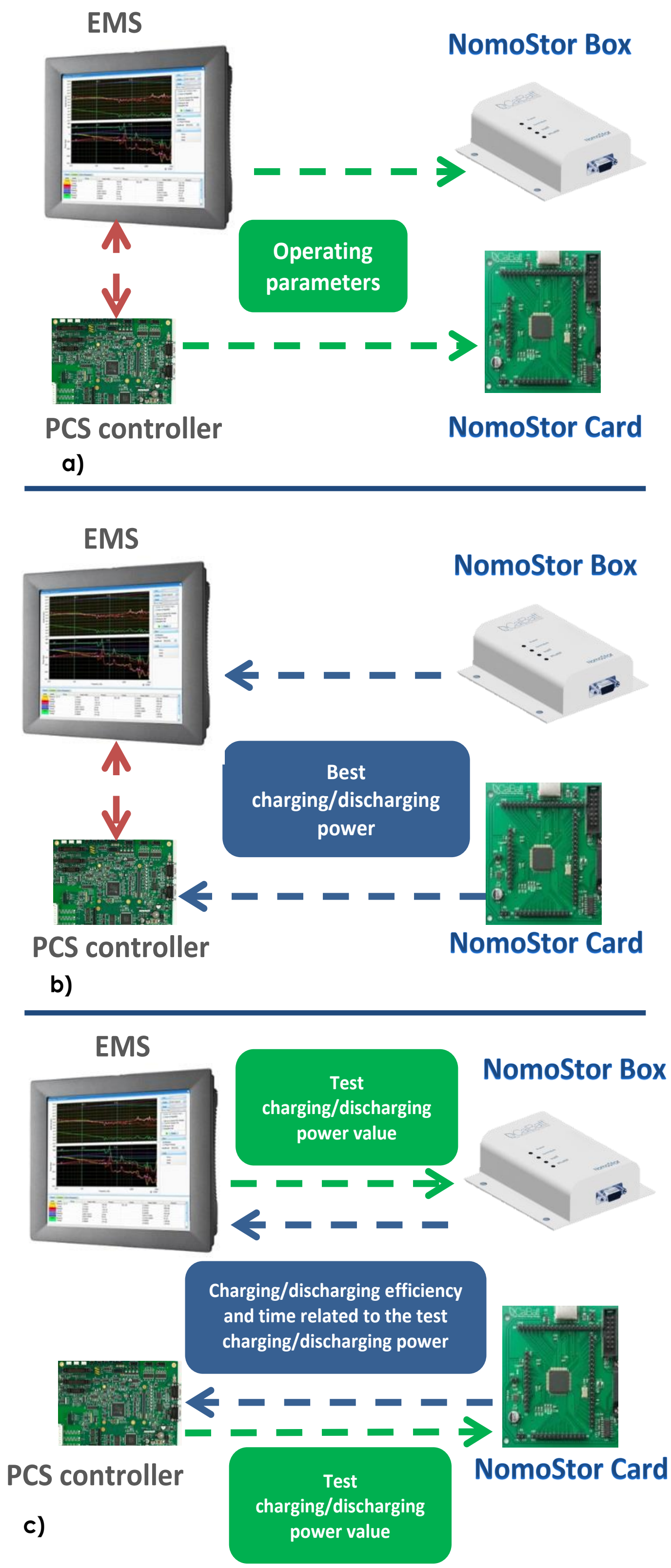

Fig. 3. NomoStor interaction with the other blocks of the storage system in the three different operating modes available: 3a) DynAnalysis mode; 3b) MaxEff mode; 3c) WhatEff mode.

In these cases, the best energy management strategy is obviously that allowing to achieve the maximum efficiency by respecting all the other constraints. This could not be achieved without knowing the impact of charging/discharging power on the system efficiency.

To solve this problem, NomoStor has been designed to implement a very useful functionality by working in the WhatEff operating mode (Fig. 3C), in which:

- the EMS/PCS controller sends to NomoStor a test charging/discharging power value;
- NomoStor calculates and sends to the EMS/PCS controller the forecasted values of both the efficiency and charging/discharging time corresponding to the test charging/discharging power value, in order to allow the EMS/PCS controller to decide the best scheduling of charging/discharging processes according to constraints defined by the application.

Application example

The features allowed by CalBatt NomoStor are highlighted in the following for a typical situation in which a storage system (with a maximum efficiency of 85%) is used in a grid-connected PV plant such as that of Fig. 2a. The two profiles in Fig. 4a are assumed for the power available for charging during PV production hours (green color) and for the load demand to be satisfied by the storage system when production ends (blue color). Fig. 4b reports a conceptual example of a typical conventional energy management strategy, according to which:

- the battery charge is performed as soon as possible by using the entire power available up to the end of the process (occurring when battery is completely charged);
- the battery discharge is performed to satisfy the entire load demand up to the end of the process (normally achieved when the battery state of charge reaches a given minimum level).

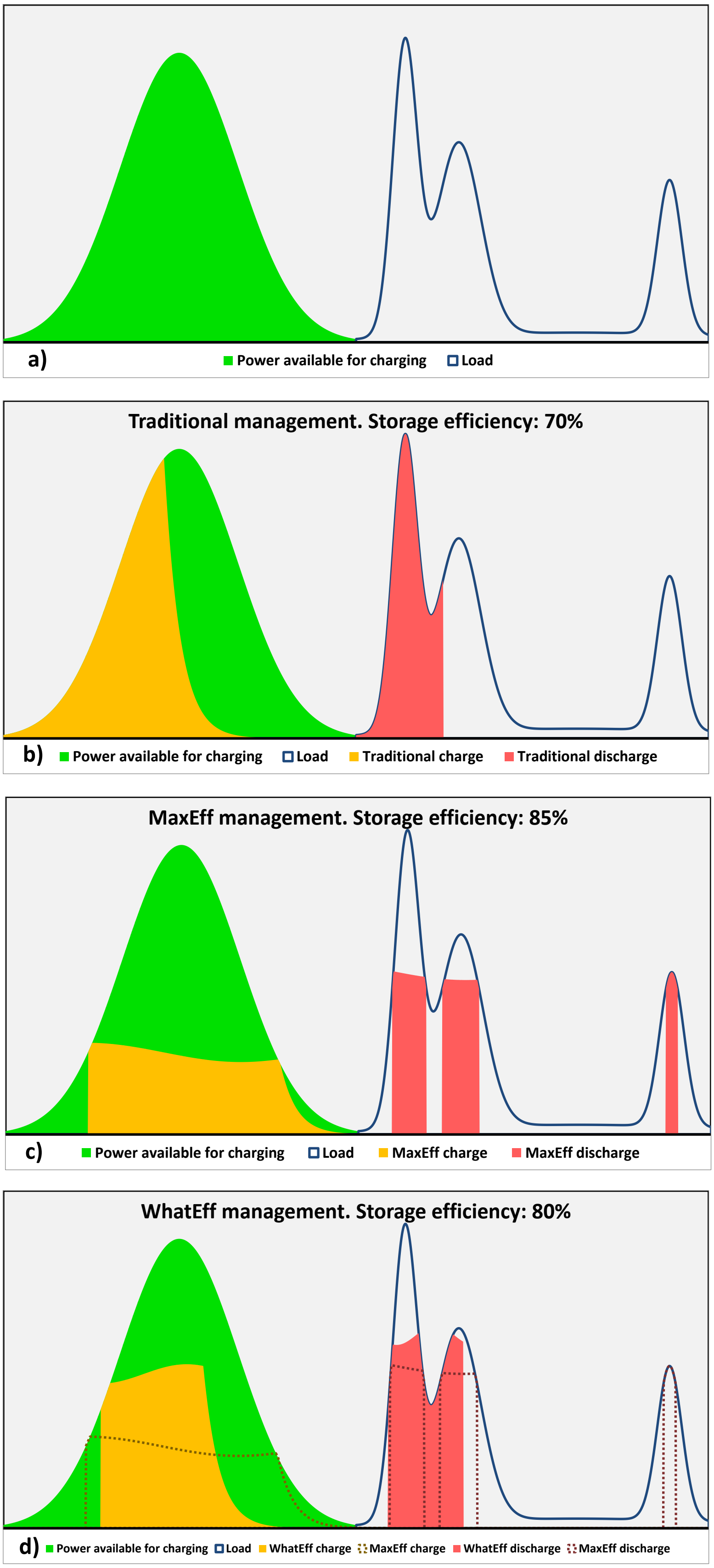

Fig. 4. Example of NomoStor application: 4a) typical profiles of power available for charging and loads; 4b) traditional storage management; 4c) storage management according to NomoStor MaxEff operating mode; 4d) storage management according to NomoStor WhatEff

In this case, the storage efficiency is 70%, i.e. 15% less than the maximum achievable by the system.

Fig. 4c reports instead what happens when the EMS/PCS controller exploits the information provided by NomoStor in MaxEff operating mode, in order to achieve the maximum efficiency (85%) by means of perfectly tailored charging/discharging power profiles. To this aim:

- the battery charge is not performed as soon as possible by using the entire power available, but by fixing the optimal charging power value suggested by NomoStor at each time instant;
- the battery discharge is performed by setting the optimal discharging power suggested by NomoStor, thus satisfying the load demand at each time instant by using a mix of power coming from both the battery and the grid.

Finally, Fig. 4d shows the further opportunity offered by NomoStor in WhatEff operating mode. In this case, the EMS/PCS controller can exploit the useful forecasts provided by NomoStor to fix sub-optimal charging/discharging profiles in order to meet other constraints (for example in terms of charging/discharging times) without sacrificing excessively the system efficiency, which is 80% in this case.

Obviously, the NomoStor features highlighted in the example above can be extended to every other application of stationary storage systems in which there is a degree of freedom in managing the charging/discharging power, as discussed previously.