# FEASIBILITY STUDY AND TECHNO-ECONOMIC OPTIMIZATION MODEL FOR BATTERY THERMAL MANAGEMENT SYSTEM

**Mohammad Rezwan Khan[1], Mads Pagh Nielsen and Søren Knudsen Kær**
**Aalborg University**
**Department of Energy Technology**
**Denmark**

## ABSTRACT

The paper investigates the feasibility of employing a battery thermal management system (BTMS) in different applications based on a techno economic analysis considering the battery lifetime and application profile, i.e. current requirement. The preliminary objective is to set the decision criteria of employing a BTMS and if the outcome of the decision is positive, to determine the type of the employed BTMS. However, employing a BTMS needs to meet a number of application requirements and different BTMS associates a different amount of capital cost to ensure the battery performance over its lifetime. Hence, the objective of this paper is to develop and detail the method of the feasibility for commissioning BTMS called "The decision tool framework" (DTF) and to investigate its sensitivity to major factors (e.g. lifetime and application requirement) which are well-known to influence the battery pack thermal performance, battery pack performance and ultimately the performance as well as utility of the desired application. This DTF is designed to provide a common framework of a BTMS manufacturer and designer to evaluate the options of different BTMS applicable for different applications and operating conditions. The results provide insight into the feasibility and the required specification and configuration of a BTMS.

***Keywords**:* Batteries, Economical Analysis, Cash Flow, Batteries; Battery Storage; Techno Economic Model and Analysis; Battery Thermal Management; Lifetime; Feasibility Procurement.

## 1 INTRODUCTION

Temperature excursions and non-uniformity of the temperature inside the battery systems are the main concern and drawback for any attempt to scale-up battery cells to the larger sizes as required for high power applications. The capacity of the battery pack increases as the operating temperature is raised for a battery pack. However, this is associated with a very high expense of accelerated capacity fade. Subsequently the lifetime of the battery system is reduced. Moreover poor performance (limited capacity availability) is observed at low operating temperature [1, 2]. In addition, excessive or uneven temperature rise in a system or pack reduces its cycle life significantly [3].

In general, temperature affects several aspects of a battery including operation of the electrochemical system such as round trip charge/discharge energy efficiency, charge acceptance, power and energy capability, reliability, lifetime, life cycle cost and so on [4].Thereof, temperature uniformity, within a cell and from cell to cell inside a pack (a collection of cells) and/or system (a collection of packs), is essential to achieve the maximum cycle life of battery system [5]. The battery thermal management system (BTMS) is an integral part of a battery management system (BMS) for this particular purpose. Basically, battery system design requires a trade-off between the risk of overheating individual cells of relatively large sizes and the cost of insulating or cooling a complex array of small cells. Usually, the BTMS is a combination of both hardware and software to preserve the temperature difference of battery cells in a pack in an optimal range to enhance the lifetime while ensuring safe and secure operation. Simulation results showed that thermal management systems might improve battery performance by 30–40% [6].

[1] Corresponding author, E-mail:rezwankhn@gmail.com; mrk@et.aau.dk

The BTMS designed on the basis of the given application requirements can be described in terms of its main characteristics. These form obviously the BTMS design specifications, which list the requirements rooted from the application and also the outputs from the design process that characterize the functions of the BTMS to have the long lasting life within restricted constraints.

The feasibility study of a BTMS means the appraisal of possibility and justification of employment of BTMS among possible alternative solutions. The economic feasibility of BTMS depends on several parameters: Thermal accessories' prices, battery prices, the corresponding lifetime, economic parameters e.g. real interest rate, inflation, financial stimulation structure etc. The preliminary target is to provide management with enough information to recommend BTMS is needed to be employed, if it is indeed needed to be employed what type is better among the alternatives so that a selection can be made in subsequent phases and the determination of a preferred alternative. A "go/no-go" decision is the consequence of the feasibility study by the management. Also the management needs to examine the problem in the context of broader business strategy [7]. However the design process of BTMS for the particular application design process is typically is complicated by the large number of variables involved for instance battery pack configuration, battery materials, mechanism of coolant flow etc. that require countless amount of demonstrations to find variability of parameters on different type of design. As a result of the various simplifications and approximations, the BTMS design problem is brought to a stage where it may be solved analytically or numerically. The next step in the BTMS design process is the evaluation of the various designs obtained for determining feasibility. This BTMS design effort would generally direct to a domain of acceptable or workable designs. From this domain, the best BTMS design is chosen based on different given criteria such as maximisation of return of investment (ROI).

Evaluating the feasibility of the design in terms of the results from the simulation and the given design problem statement is an important step in the design process because it involves the decision to continue or stop the procurement of the BTMS for desired application. Optimization is of particular importance in choosing BTMS because of the strong dependence of cost and application profile on system design. Usually, the optimal design is not easily determined from either available simulation or acceptable design results. The optimization process is obviously applied to acceptable designs so that the given requirements and constraints are satisfied. Then the design finally obtained is an optimal one, not just an acceptable one. Optimization of a thermal system can be carried out in terms of the design hardware or the operating conditions. In these circumstances, modelling helps in obtaining and comparing alternative BTMS designs by predicting the performance of each feasible design ultimately leading to an optimal design. With optimization indicates the values at which the performance is optimal with respect to optimization criteria of the ROI.

In different literature battery systems are found to be in diverse applications. The applications may include electric power generating stations, substations, vehicles, telecommunications installations, large industrial and commercial installations, large uninterruptible power supply (UPS) installations and renewable energy plant installations etc. [8, 9]. Typically, the storage for PV panels is used in stand-alone applications [10, 11]. The potential profits of grid-connected storage are studied with help of a control mechanism but without dimensioning the storage size [12]. In Ref. [13] an empirical method is presented to determine the optimal battery size to cover most of the electricity needs using PV in a home. The financial aspects like battery costs were not taken into account while a similar analysis in a commercial building [14]. Ref. [15] presented an idea to use battery storage for district level autonomy for multifunctional application on transmission congestion and arbitrage application he profit potential without dimensioning the storage size based on a future peak pricing of electricity [16]. Ref. [17] performs an internal rate of return calculation over a range of battery sizes and prices of Real PV and consumption data and an economical evaluation for domestic batteries with a cost range per kWh is explained [18]. Additionally, most assumptions did not account explicitly for the battery cost and life time. An economic analysis based on the feed-in tariffs and an inflation of 1.6%/annum is assumed [19]. Ref. [20] contains a multi-objective optimisation technique to determine the trade-off between the quality of ancillary services and its economic cost for a household with a PV installation.

The paper introduces with the proposed methodology on section 2, The decision framework on section 3, the application load profiles, and the design problem is formulated depicting requirements and specification (section 3.1), given quantities of technical and financial input (section 3.2), design variables (section 3.3), constraints (section 3.4) and relevant assumption (section 3.5). Within this a model (section 3.6) is built on governing equations (section 3.7). The results and discussions are elaborated on section 4. Unless stated specifically the methodology are valid for all battery chemistries.

## 2 METHODOLOGY

**Fig. 1** illustrates the method used in the paper for the proposed feasibility study. A number of real life profiles originated from electric vehicle (EV) and photovoltaic (PV) application (specimen of the profile **Fig. 2**) have been selected so that they represent the best correspondence for the particular application. For a given battery chemistry with a given configuration, a thermal model is executed to find the temperature increase due to the current profile. However, practical BTMSs are largely very complex and must be simplified through idealizations and approximations to make the problem manageable to a solution with necessary accuracy. A mathematical model is employed. The mathematical modelling of BTMS generally involves modelling of the various components and subsystems that constitute the thermal components including the battery system, followed by a coupling of all these batteries and the relevant accessories' models to obtain the final, combined model for the system. The general procedure outlined in the preceding may be applied to a component and the governing equations derived based on various simplifications, approximations, and idealizations that may be appropriate for the circumstance under particular application. The simplification is carried out largely to reduce the number of independent variables in the problem besides to generalize the results so that they may be used over wide ranges of conditions. The thermal model is executed for a given pack application. Using the result of the prospective increase of temperature range, the best suitable thermal system is chosen according to satisfy the application requirement. In this model, the economy based lifetime model is simulated to find the best optimum configuration that satisfies the maximum return of investment (ROI).

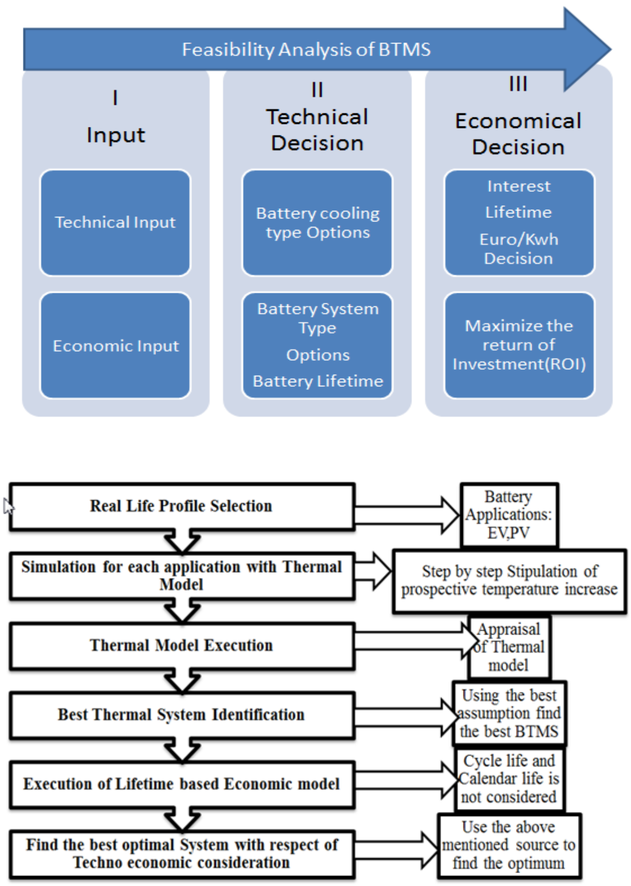


**Fig. 1** Methodology used in feasibility study.

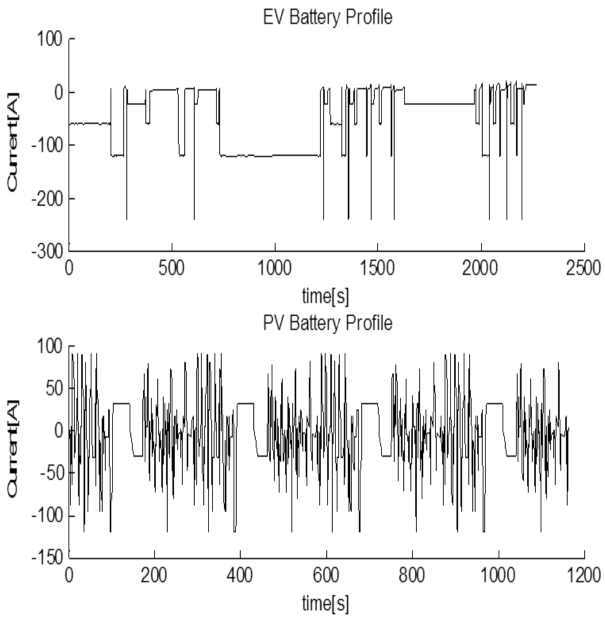


**Fig. 2** Corresponding application profile [Top].Electrical Vehicle (EV) application. [Bottom] Photo Voltaic (PV) battery application load profile.

## 3 DECISION FRAMEWORK TOOL

The final design of the decision framework tool is obtained for the BTMS through the following steps elaborated in the subsequent sections.

### 3.1 Requirements and Specifications

Certainly the most important consideration in BTMS design is the requirements or the functional tasks to be performed by the specified system. A successful, feasible, or acceptable BTMS design must satisfy all the application requirements. The requirements form the basis for the design space of BTMS and for the establishment of evaluation of cost and consequently ROI of the different designs of BTMS.

The final specifications of the system include the performance characteristics; expected life of the system, cost associated, lifetime. An example for requirements for BTMS is shown in **Table 1**.

**Table 1** A typical specification of BTMS [21, 22]
Characteristic For EV application

| Characteristic | For EV application |
|---|---|
| **Cooling capability** | 800 W |
| **Refrigerant type** | R134a |
| **Operation Temp of cells** | < 35-45°C |
| **Temperature difference from cell bottom to the top of the cell** | < 10°C |
| **Temperature difference from cell to cell** | < 5°C |
| **Max. pressure drop in the evaporator (stationary)** | 300 mbar |
| **Additionals** | No overheating at the outlet of the evaporator.<br>Constant temperature in the evaporator.<br>Heating for power and energy availability at low temperatures . |

### 3.2 Given financial and technical input

The next step in the formulation of the BTMS design problem is to identify, determine and quantify of the entities that are given and are thus assumed to be fixed. In this paper, materials, dimensions, geometry, and the basic concept or method, particularly the type of energy source are given in the design of a thermal system considered as a lumped system. These include the components of the BTMS such as accessories, dimensions, materials, geometrical configuration, and other quantities that constitute the hardware of the system. In the paper, li-ion/ lead acid (PbAc) battery system and the corresponding cooling scheme air/liquid/refrigerant cooled BTMS are assumed to be fixed lumped parameter. In case of varying these parameters individually in general has several unwanted implications. For example physical size change of the battery that entails changes in the fabrication and assembly of the BTMS except the situations when these parameters are indeed available to change due to presence of the control over design. Furthermore, changes in the hardware are not easy to implement if existing systems are to be modified for a new design, for a new product even for optimization.

To complete the analysis the following battery and financial data are necessary as fixed parameters costs and lifetime of the battery systems and required thermal accessories, their investment cost and operating cost, the discount rate (nominal interest rate) and the inflation as provided on Table 2.

**Table 2** Different given model parameters used in the simulation.

| Technology / Attribute | Lithium ion | Lead Acid |
|---|---|---|
| **Price/KWhr(€)** | 1000 | 400 |
| **Efficiency(Full Cycle)** | 92-96% | 80-82% |
| **Calender Lifetime yrs** | 20 | 10 |
| **Cycle Lifetime** | 5000 @60% DOD<br>5000@90% DOD | 2500 @50% DOD<br>2500@60% DOD |
| **Self-Discharge** | 3%/Month | 5%/Month |
| **Operating cost** | 1.5% | 1% |

| **Economic** | |
|---|---|
| **Project Period** | 1,3,5,10,15 year |
| **Interest** | 4.8% |
| **Inflation** | 2% |

| | **Air BTMS(€)** | **Refrigerant** | **Liquid** |
|---|---|---|---|
| **Lithium ion** | 50 | 90 | 150 |
| **Lead Acid** | 30 | 70 | 120 |

Finally, the discount rate and inflation have to be considered. A discount rate of 4.5% is based on the yield of Danish loans on the secondary market. This was taken from 15 year maturity bond market between 4.2%-4.7 % [23]. The inflation is considered to be 2%, in line with the objective of the Central European Bank [24].

### 3.3 Design Variables

The design variables are the quantities that may be varied in a BTMS in order to satisfy the specified application requirements. In this paper for instance, the varying parameters are the choice of the battery system, $i$ and associated accessories, j options of cooling systems (details in section 3.7) for thermal management. Therefore, during the BTMS design process attention is primarily focused on these varying parameters that determine the behaviour of the BTMS and are then chosen so that the system meets the given constraints of lifetime and financial aspects.

Three schemes are taken as the main factor to investigate in this study. Those are the air-cooling scheme; refrigerant cooling scheme and a liquid-cooling scheme. **Fig. 3** illustrates the basic schematics of the cooling options of the thermal management system while **Table 3** corresponds a comparison of the three schemes.

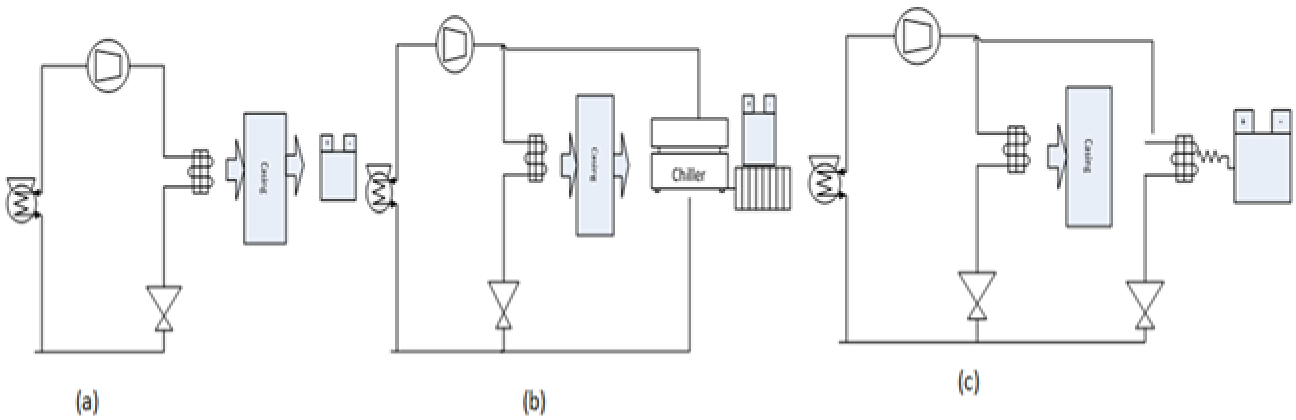


**Fig. 3** Cooling options of a battery thermal management system generic diagram. (a)Air cooling, (b) liquid cooling, (c) Refrigerant cooling.

**Table 3** Comparison between different cooling schemes in traditional BTMS.

| Scheme | Description | Application | Temperature differntial allowed between the cells |
|---|---|---|---|
| **Air cooling** | -Both cooling and heating is feasible.<br>-Good performance<br>-Normally large space needed<br>-Cheapest<br>-Lower development effort is needed | -Application is limited but in most cases sufficient for HEV/48V/12V applications. | Temperature difference between air and cells can be > than 15°C limitation. |
| **Liquid cooling** | -Sufficient cooling capability.<br>-Lowest temperature gradients.<br>-Cooling and heating is feasible.<br>-Best performance<br>-Liquid cooling circuit is needed so moderate space is required.<br>-Most expensive.<br>-Most development effort is required | Liquid cooling can be found in EV, PHEV, HEV, 48V batteries. | Cooling plate 1-3°C |
| **Refrigerant cooling** | -"Aggressive" cooling due to very low cooler temperatures. Intelligent thermal management and specific pack design needed to avoid a too aggressive cooling and condensation of humidity<br>-Heating can only be realized with extra devices.<br>-Better performance<br>-Low space requirement<br>-Moderate expense<br>-Moderate development effort is required | HEV,48V batteries | Cooling plate 3-8°C; |

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### 3.4 Constraints or Limitations

The BTMS design must also satisfy various constraints or limitations in order to be acceptable. These constraints generally arise due to the BTMS's material, weight, cost, availability, and space limitations. The maximum pressure and temperature to which a given BTMS's component may be subjected are limited by the properties of its material. The choice of the material itself may be limited by cost, availability, and environmental impact even if a particular material has the best characteristics for a given problem. Volume and weight restrictions also frequently limit the domain of acceptable design. In this paper, the constraints are project lifetime ($L_{i,j}$), expenditure caps ($\mathrm{AC}_{\max}$)—more on section 3.7.

### 3.5 Assumptions and rational behind the assumptions

Knowledge of existing systems, characteristics of similar systems, governing mechanisms, and commonly made approximations and idealizations provides substantial help in BTMS techno economic model development. Material property data and empirical results, available on the characteristics of devices and components that comprise the system, are also incorporated into the working model through lumped approximation of the battery system ($i$) and cooling system type ($j$)--more elaboration on section 3.7. In this paper, a predictive mathematical model for BTMS is of particular interest to the current problem and is employed because this can be used to predict the techno-economic performance of a given BTMS. However, thermal systems are often governed by sets of time-dependent, multidimensional, nonlinear partial differential equations with complicated domains and boundary conditions. Finding a solution to the full three-dimensional, time-dependent problem is usually an extremely time and cost consuming process that may not be existent while finding and choosing the feasibility for a BTMS over other alternatives and options. In addition, the interpretation of the feasibility results obtained and the particular application to the BTMS design process are typically complicated by the large number of variables involved for instance battery pack configuration, battery materials, mechanism of coolant flow etc. that require countless amount of experiments to find variability of parameters corresponding to different type of design. Even if the experiments are carried out to obtain the relevant input data for feasibility study and design, the expense incurred in these experiments makes it pragmatic to develop a model applicable for BTMS and the battery system to emphasis on the dominant parameters e.g. lifetime, costs on different choices. Therefore, it is necessary to neglect relatively unimportant aspects, combine the effects of different variables in the problem, employ idealizations to simplify the BTMS design for the feasibility analysis, and consequently reducing the number of design parameters that govern the system for the specified application but emphasising more on the economic effect of the system for instance ROI and costs, since those may be the most important decision parameter to build and procure a battery system for desired application. Consequently, the first step is to consider the simulation results in terms of the physical nature of the system and to ascertain that the observed trends somewhat agree with the expected behaviour of the real BTMS in terms of the respective application load profile and corresponding lifetime. But the precaution is to be taken that all these measures are relatively approximate indicators, which generally suffice for the purpose of the feasibility study and evaluation of the different designs obtained. Since the design strategy, evaluation of the BTMS designs developed, and final design are all dependent on the problem statement, it is important to ensure that all of these aspects are considered in adequate detail and quantitative expressions are obtained to characterize those as explained in section 3.7.

Estimates of the relevant quantities are used to eliminate considerations that are of minor consequence. In this paper, negligible effects are heat removal rate, time to reach the required temperature and so on. Practical BTMS and associated processes are certainly not ideal. There are non-exhausting list for instance undesirable energy losses, friction forces, fluid leakages, operating conditions and so forth, that affects the system behaviour. However, in this paper a number of idealizations are usually made to simplify the problem and to obtain a solution that represents the best performance for proposed feasibility analysis. Actual systems may then be considered in terms of the ideal behaviour originating from this and the resulting performance given in terms of efficiency, coefficient of performance (COP), or effectiveness of this ideal system. The paper can be used to estimate how the specific BTMS perform against the representative ideal system functioning on the given application. Scaling laws are employed because they allow the modelling of complicated systems in terms of simpler, scaled-down versions. Using these laws, the results from the models can be scaled up to larger systems. All the results are shown in the paper consider the utilization of battery of 200 cycles per year is assumed as used in [1].

However in reality these refer to quantities of BTMS that can often be varied relatively easily over specified ranges with the holding the current structure of the hardware of the given BTMS, such as the operating settings for temperature, flow rate, pressure, speed, power input, etc. Therefore, several of these are generally kept fixed as stated section 3.2 in this paper and the ranges over which the others can be varied are determined from physical constraints, availability of parts, and information available from similar systems.

Even using the above mentioned simplifications and idealizations the techno economic model is said to have some level of precision due to inclusion of degrees of freedom than can be found in the literature [13, 15, 20, 25].

### 3.6 Modelling

The modelling of BTMS is an extremely important step in the feasibility study based on the design and optimization of the system. Modelling is generally first applied to the obvious components, parts, or subsystems related to its functionalities that make up the BTMS for current consideration of commissioning in battery system for the particular function. These models comprised of different type of battery systems in this article lead acid and lithium ion battery systems respectively as well as the corresponding accessories counterpart are assembled with necessary cost information in order to take into account the utility and interaction between the integrated battery systems cost and lifetime those are worthwhile for the desired application. By executing these individual models, the actual utility of a battery system in term of costs with necessary adjustment inflation and real interest rate is calculated with each other for finding the overall model that satisfies the maximum ROI for the thermal system is obtained. The model is subjected to a range of project lifetime conditions due to various cost and performance options to choose the best of the system within the required constraints. A mathematical model that represents the performance and characteristics of BTMS in terms of mathematical equations is employed. The dominant considerations in the particular BTMS are to determine the important variables such as costs, lifetime costs etc. and the governing parameters (the battery system choice and the corresponding thermal system choice) because of their considerable versatility in obtaining quantitative results that are needed as inputs for the design. The price of different BTMS depends on the scale, volume of cost, quality and the lifetime as well as the financial aspects such as year of the investment, interest rate, inflation etc. Therefore it is imperative to take a financial cash flow with adjusted interest rate that ensures common ground base for the calculation that includes discount rate and inflation. Return on investment (ROI) measures the gain or loss generated on an investment relative to the amount of money invested. ROI is usually expressed as a percentage and is typically used for internal financial decisions, to compare an enterprise's profitability or to compare the efficiency of different investments.

In order to calculate the real present values of the battery systems with BTMS nominal interest rate is converted to real interest rate to accommodate inflation. The nominal interest rate (sometimes simply called the nominal rate) is the interest rate that is quoted by central banks. It is the rate that is used to discount actual, inflated future values. The real interest is the rate earned on a capital investment after accounting for inflation. The real interest rate should be used to discount future values that are expressed in current monetary values. In this article the real interest rates are considered than the nominal interest rate.
Let:

$i$ = the nominal interest rate,
$r$ = the real interest rate, and
$k$ = the inflation rate.

Now, the formula for combining the real interest rate and the inflation rate to get the nominal interest rate is:

$$r = \frac{(1+i)}{(1+k)} - 1\ldots\ldots(1)$$

Discount real future values with a real interest rate, and discount nominal future values with a nominal interest rate. Real future values are uninflated; nominal future values are inflated.

To discount real future values, a real interest rate is used. To discount nominal future values, a nominal interest rate is used. Compounding a present value with a nominal interest rate results in a nominal future value. Converting a real future value $\overset{*}{C_n}$ to a nominal future values $C_n$ is an example of inflating. In order to schematically represent the present values and future values with interest rate inflation and real interest rate with different cost of capital present capital apparent capital future value of present capital is described in the following **Fig. 4**.

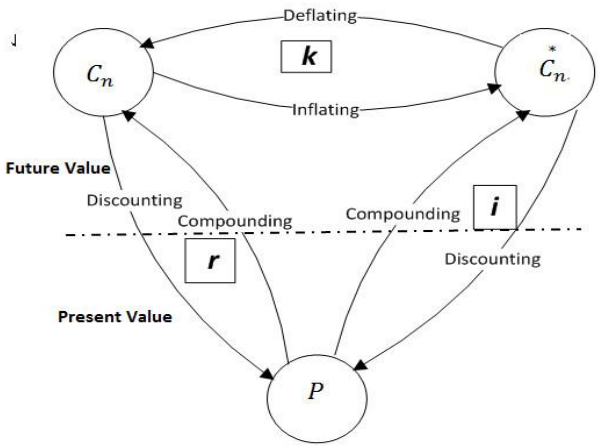


**Fig. 4** Financial model schematics present and future values of capital using real and nominal interest rate.

All these considerations secure a permissible level of accuracy and credibility. A standard investment calculation is used. This calculates the net present value of cash flows under influence of inflation, discount rate (the given rate of return) and return of investment. This means that the real discount rate is taken as reference instead of the nominal discount rate (i.e. without inflation) [24]. The investment in a combination of thermal accessories and battery system that leads to the highest ROI is the most attractive option, since it is the highest profit in absolute terms. In formula form this is expressed as:

$$\mathrm{ROI} = \frac{\text{Lifetime Benefit} - \textit{Life time}\ \text{Cost}}{\text{Cost}} \ldots \ldots (2)$$

Besides the net present value, also the internal rate of return (IRR) and the payback period (PB) are important financial indicators that can be incorporated into the calculation.

The payback period represents the operational year that the sum of the cash flows starting from the initiation of BTMS acquisition period is higher than the investment without taking the discount rate (or real interest) into account. It is also sometimes indicated as simple payback period to emphasise that no discounting is used. In the paper, the payback period is not shown. In this paper, the base cost for ROI calculation has been chosen as the choice when there is no BTMS for the two battery systems. So in calculation of ROI of these systems, this is worked like the lifetime cost. Since there is a lifetime increase in case of BTMS usage, the benefit is calculated. In all cases cost and benefits are calculated per annum basis to have a common scale for further comparison.

### 3.7 Governing equations

This section deals with mathematical modelling based on physical insight recourse and on a consideration of the governing principles that determine the behaviour of a given thermal system.

The governing equations are first written. After the governing equations are assembled, along with the various approximations and idealizations outlined here, further simplification can sometimes be obtained by a consideration of the various terms in the equations to determine if any of them are negligible. Table 4 provides the options for BTMS choices that are used in the simulation.

**Table 4** Battery thermal management choice in the simulation.

| **Battery System** | $\boldsymbol{i}$ |
|---|---|
| Lithium ion | 1 |
| Lead Acid | 2 |

| **Thermal System** | $\boldsymbol{j}$ |
|---|---|
| **No BTMS** | 0 |
| **Air Cooled** | 1 |
| **Refrigerant** | 2 |
| **Liquid** | 3 |

Total battery system cost

$$\mathrm{TC}_{i,j} = \sum_{i,j=1} \mathrm{KC}_i + \mathrm{KC}_j + K_{i,\mathrm{j\_op}} \ldots \ldots (3)$$

$\mathrm{KC}_i, \mathrm{KC}_j, K_{i,\mathrm{j\_op}}$ annotates battery system price, the cooling options and operation cost respectively.

Per Annum Cost $C_{i,j} = \frac{\mathrm{TC}_{i,j} * \mathrm{CRF}}{L_{i,j}} \ldots \ldots (4)$

Subject to

$$\mathrm{TC}_{i,j} < \text{Maximum allotted cost}, \mathrm{AC}_{\max}$$

$$CRF = \left(\frac{1 - 1/(1+r)^{\mathrm{yr}}}{r}\right)^{-1} \ldots \ldots (5)$$

ROI is calculated using Eqn.(2)

So the target is to determine the maximum ROI. Find best $i, j$ for the best ROI.

$$\max_{i,j}(\mathrm{ROI})$$

## 4 RESULTS AND DISCUSSION

Ultimately, a satisfactory mathematical model of the feasibility analysis of BTMS is obtained and this can be used for design, optimization, and feasibility study of the battery system in the particular application, as well as for developing models for other similar systems in the future.

The following temperatures and temperature differences are ensured:

- ✓ Max. Temp. in the pack <40°C
- ✓ Max temperature difference between cells < 2°C

- ✓ Max temperature difference cell bottom – cell tap< 6°C

Two battery pack applications with cooling plates (**Fig. 3** ) on the bottom of the cells but different cooling media have been introduced and validated on the test stand. Air cooling can be critical in matter of terms of cooling capability and temperature gradient within the battery pack. Besides that safety and comfort aspects have to be considered in real systems.

A sensitivity analysis is undertaken to determine how the choice of BTMS varies with the design variables and the operating conditions in order to choose the most appropriate, convenient, and cost-effective values at or near the extremum that would optimize the system or its operation.

In this paper the project horizons of 3 and 5 year (short term), 10 and 15 year (long term) are chosen. Also to show the results with a base project spanning 1 year is used. The system is simulated on same interest rate with inflation to compare each other's feasibility. Using the modelling methods and governing equations the model is simulated to find the maximum ROI. The short term result implicated that PbAc battery systems are more feasible and yield more ROI than its lithium ion counterpart. But if the project tenure is bigger than 5 years, Li-ion becomes the preferred technology. The reason is that Li ion has higher longevity and need to be replaced less times than PbAc counterpart.One of the further comment can be that the price of batteries are going down sharply for lithium ion batteries and in coming years the trend is going to persist. In that case again Li -ion batteries offer more prospects to change their PbAc counterpart.

The two applications EV and PV impose different type of thermal system requirement. The thermal system must adhere to the ever changing profile of the EV application cycle. Due to the restrictions that are needed to comply for EV application, the system is best suited to go with liquid and refrigerant type cooling mechanism as illustrated on **Fig. 5** So a cooling system is recommended to be employed while using the battery systems for EV systems. However, the choice among the liquid, refrigerant or air cooled may also be dictated by space constrains. Additionally, selected cooling layout can make use of battery's thermal capacity also participate on cost reduction of the whole vehicle.

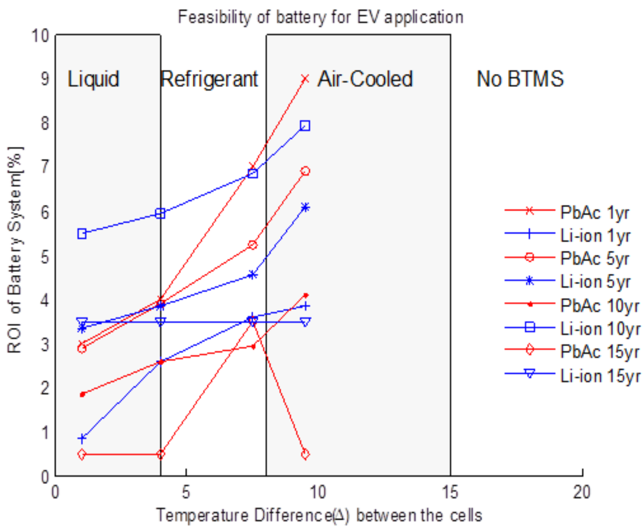


**Fig. 5** Feasibility result for Electrical Vehicle application commissioned with different cooling BTMS with different PbAc and Li-on Battery system.

The result is congruent with real life project results. Especially for large size battery systems liquid cooling is the best compromise. Choice of cooling concept depends on battery pack requirements as well as on vehicle requirements and architecture.

But in case of PV application, the air and refrigerant type provide the optimized ROI criteria shown on **Fig. 6** . It is observed that PV profiles are not as much as varying as EV power requirement that results less temperature increase and consequently the stationary battery becomes more profitable by avoiding extra expenditures of the expensive BTMSs.

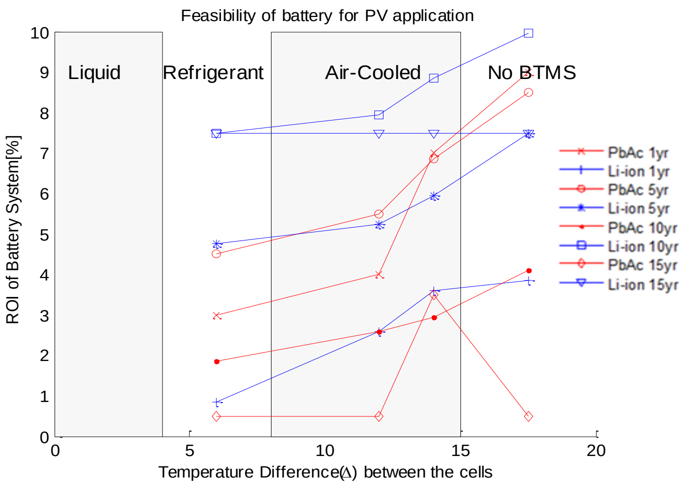


**Fig. 6** Feasibility result for Photovoltaic application commissioned with different cooling BTMS with different PbAc and Li-ion Battery system.

This techno economic effort also generalizes the problem so that in future the results obtained from the analytical result originate from the techno-economic model can be compared to the experimental study that can be used without major modifications to other similar systems and circumstances covering all the scopes as detailed by this paper. Alternatively, if experimental data from a prototype are available, a comparison between these and the results from the simulation could be used to determine the validity and accuracy of the latter.

Since the basic concept introduced in the paper is not fixed, different concepts may be considered irrespective of battery chemistries resulting in considerable flexibility in the design. However, in many cases, different considerations may lead to different scaling parameters and the appropriate model may not be uniquely defined at least on the feasibility stage.

## 5 CONCLUSIONS

This paper provides a complete feasibility analysis of battery systems with necessary thermal management accessories functional in transport and photovoltaic applications based on a statistical significant amount of data, based on real system prices and technical lifetime expectations. The method takes into account technical parameters as battery lifetime and application requirement. Future work will be oriented towards applying the analysis to different types of profiles using taking more degrees of freedom into account for example impact of heating rate and method of cooling e.g. convection or forced based cooling and design of hybrid optimal system. Furthermore the method can be applied to determine the feasibility of the inclusion of any accessories that may be introduced over time corresponding to increased lifetime for different application criteria than PV-battery and EV-battery systems. The present paper aims to serve as decision-making support for researchers, practitioners and policy makers by reviewing costs and performance of battery before purchasing or acquiring a required BTMS. For most battery storage applications, the methodology can be used without major modifications.

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