Optimization Concepts for the Integration of Electric Vehicles in Renewable Energy Grids

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Abstract

This paper presents a discussion of different necessities and reasons for optimization concepts and strategies for an efficient integration of electric vehicles into a complex grid with renewable energy converter. For this purpose, the electrical storages of the vehicles should be used as consumer, as well as distributed energy supply systems in bidirectional modes. In this case, the temporarily grid connected electric vehicles could support stationary electrical energy storage systems especially in renewable energy supply systems. As a consequence, the dimensioning of the energy converter could optimally be based on the time averaged load demand. This would have a very great effect on the overall costs. Special problems, in order to define optimization gaols, are worked out and discussed concerning their pros and cons, especially the problem to find sufficient precise mathematical models for an integration in numerical processes for optimization. The most important problem is to find a good overall objective function. With respect to the manifold different parameters and objectives in detail, this trial leads to the so called multi criteria optimization (MCO) or multi criteria decision making processes (MCDM). With respect to the mathematical description, the necessary constraints have to be worked out.

Renewable Energy Grids

The following figure 1 shows a fundamental scheme of a PV Hybrid System. Many of these local systems could be modular interconnected with the help of an electrical grid structure. This is a possible way to build up a complex renewable energy supply system. This is an alternative kind of view, in contrast to the method of the integration of decentralised renewable energy converter in existing electrical grids, which is the usual way for industrialised countries. One of the most important advantage to use the modular construction with hybrid systems as a model, is the possibility, to search the optimum of the final state of these structures, without historical given constraints of the existing energy supply systems. The key research question is, what is the best final structure regarding real sustainability, and how great would be the contribution of each of the different renewable energy sources. The scheme in figure 1 is especially a valuable description to develop mathematical formulations in order to get dimension criteria as well as objective functions for optimisation strategies. A sufficient dimensioning of the energy storages, especially for electrical energy has a significant influence of the sizing of the converter and therefore on the costs of the whole system. A first step of optimisation may be for this reason the integration of electric vehicles as consumer as well as storage components in a bi-directional manner [1], [5]. Additionally, the equalised power conversion with the combination of wind and solar energy minimises the required capacity of storage batteries.

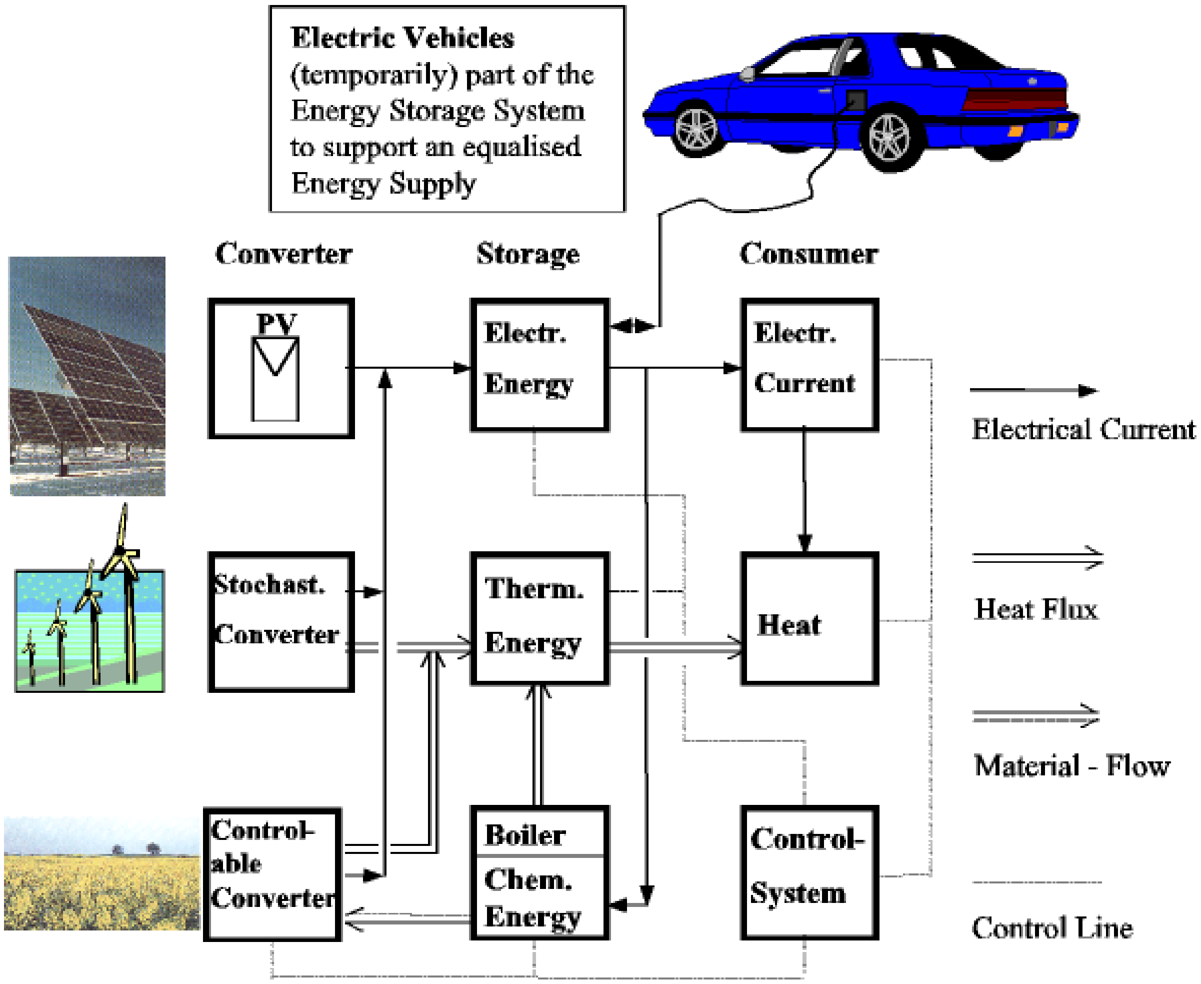

Figure 1: Structure of hybrid systems with electric vehicles [1], [5]

Electric Vehicles

Because of the different stochastically and dynamical behaviour of the renewable energy supplies in comparison to the consumption, it seems to be unavoidable for such supply systems to integrate sufficient energy storage capacities. This circumstance is often used as a critical argument to point out a great disadvantage of renewable energy systems. But a careful dimensioning of hybrid systems and their interconnections can help to reduce these capacities to an absolute minimum only for security. A special capacity would be necessary to cover the peak power short-time demands, in order to avoid an over dimensioning of the hybrid system converter. In this case electric vehicles could serve as (additional) storage capacities, if they are not used for driving. During and after their charging period, the vehicles were able to support the equalisation of the power supply and if necessary to increase the availability. Additionally, it is very important to minimise the energy demand of electric vehicles. For this purpose effective optimisation strategies are necessary, naturally with multi criteria objective functions. There are individual wishes as well as physical properties concerning the representative route classifications, which have to be taken into account. [2], [4], [3].

Individual "Wishes"
• Range [km] • Maximum Speed [km/h] • Average Speed [km/h] • Maximum Amount of Passengers • Maximum Load [kg], ...etc.

Table 1: Technical demands from the consumer

Additionally, there exist typical demands, which follow from the individual daily driving route. If one takes into account only statistically usual routes, it may be possible to classify them roughly in the following categories.

Route Class	
i)	Flat Plane
ii)	Highlands
iii)	Mountains

Table 2: Rough classification of usual driving routes

The following scheme gives a scope of the procedure to get optimised design data:

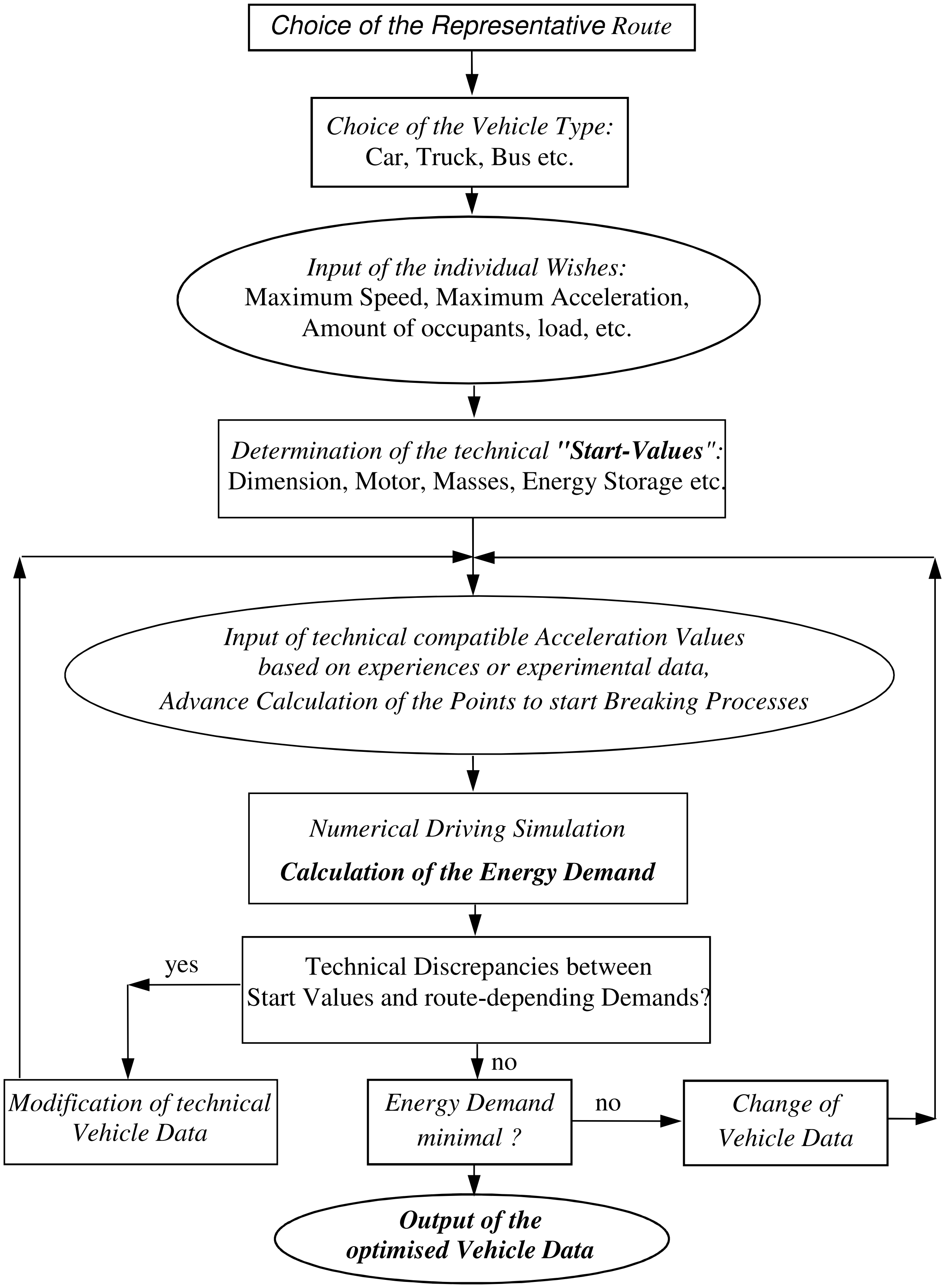

Figure 2: Process Scheme of the Optimisation Procedure [2], [3]

Especially of course of the limited range of electric vehicles, the route classification is an important step to determine for example the necessary battery capacity. Essentially for a successful implementation of this proposed optimisation routine, is the availability of all necessary technical data and characteristic curves of the single components for the vehicle. This means a detailed and differentiated extensive data base to be stored in a computer. As far as possible, proved realistic characteristic curves for example for the driving unit, recuperation, battery charging and recharging etc. should be used. Even constructive experiences concerning the automobile bodies are very important, because they have to be compatible to all the other masses and internal forces. Last but not least, security aspects have naturally to be included. In summary this procedure, fitting one part to another in a compatible way, leads to a set of data which gives a great probability to construct an energy demand optimised vehicle. Further optimisations have to follow on the 'real' vehicle.

Energy Management

Basing on the scheme in figure 1 for PV Hybrid Systems it is possible to develop a principal structure for intelligent EMS [6], [10] including electric vehicles, as demonstrated in figure 3. The basic structure of the presented EMS consists of three important modules, the forecast-module (FM), the optimisation-module (OM) and the demand-side management-module (DSM), which are also classified in detail in [6]. All three modules can be considered and classified in different detailed levels. The forecast-module generates the future schedule of potential energy production of the renewable energy generators (solar and wind energy). The forecast-module can be built on in different ways. Three basic types are differentiated and presented precisely in [6]. The main task of the EMS is to improve the operation of the energy system. The classification of different possible EMS depends substantially on the functionality of the optimisation-module. According to this the objective function and side conditions of the optimisation task (OT), the optimisation process, the length of the optimisation interval and the structure of the optimisation process can be distinguished. In off-grid energy systems with a high portion of renewable energies the task of DSM is an adequate adjustment of the power consumption to the power production. Three different types can be differentiated: directional, automatically bi-directional and interactive bi-directional demand-side management. The forecast-module generates the future schedule of potential energy production of renewable energy generators (solar and wind energy). But these forecasts are afflicted with inaccuracies, which depend on different boundary conditions and can be changed in the course of time (behaviour of solar radiation or wind speed). Controlling the system components of the hybrid system, it is necessary to know these inaccuracies.

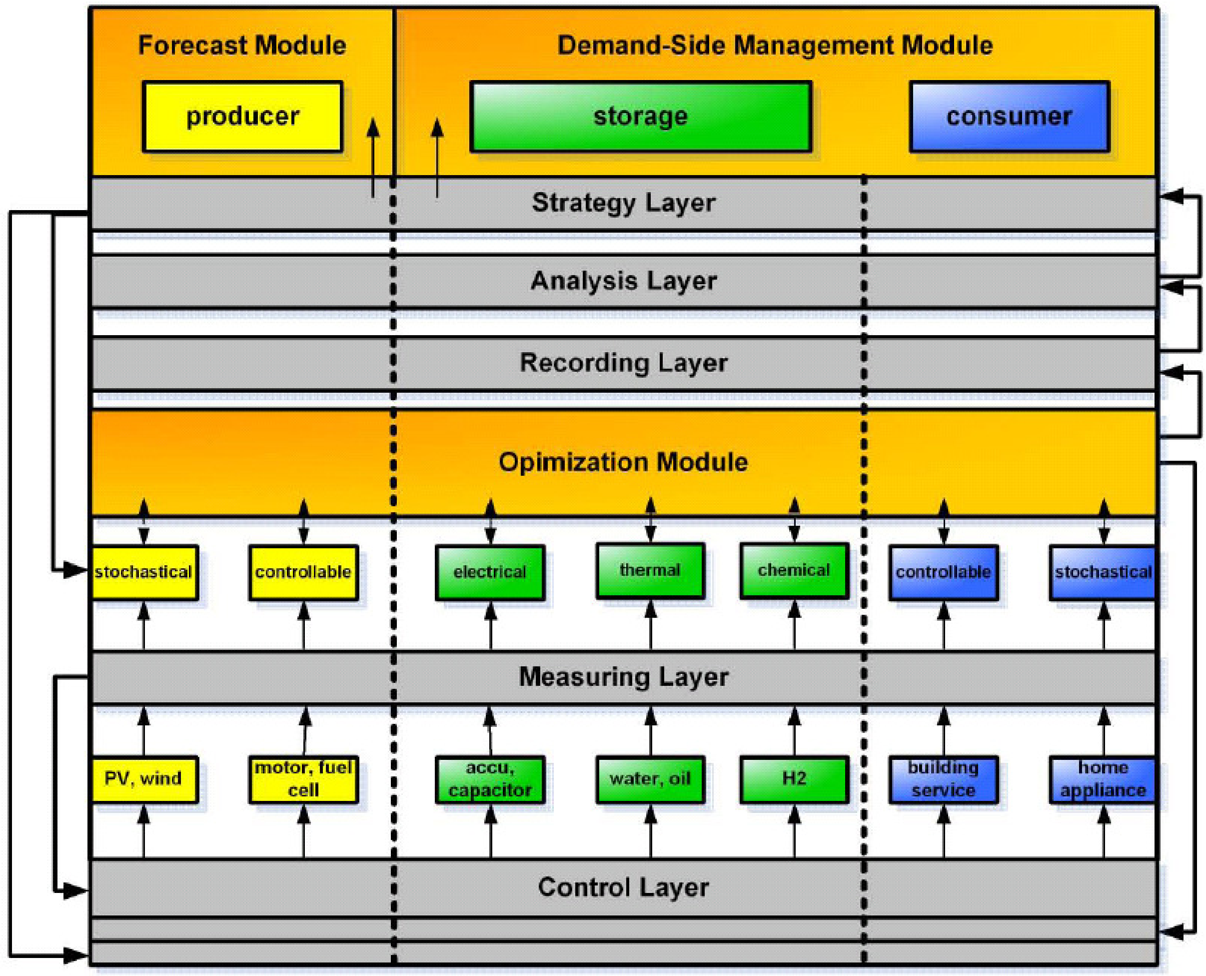

Figure 3: Layout of the EMS-Design [3], [8]

The FM can be built on in different ways. Data origin plays a decisive role for determining the required forecast method, the length of the forecast interval, the achievable forecast horizon, the required hardware, costs and the forecast accuracy. Three basic types can be differentiated according to data origin: the first type is based on measured data of produced power, the second type is based on internal and external weather forecasts and the third type describes a combination of the both mentioned types. A combination of power measurements with internal and external weather forecasts leads to further additional possible functionalities. For the integration of electric vehicles the demand-side management-module (DSM) plays an important rule with respect as well to the storage necessities as to their consumption statistics.

Optimisation

Generally the optimisation task can be defined with the help of different objective functions and side conditions for the energy supply system as well as for the electric vehicles and their integration as storages an consumer. As objective functions can be seen for example the security of supply, the total costs, the total efficiency or the emissions etc. Side conditions can be avoidance of unnecessary operation hours, nominal system operation, minimization of battery load, operating the system with maximal efficiency, maximal use of renewable energies, and minimal use of controllable power generators and avoidance of losses through unnecessary energy flow through the battery or minimization of output surpluses etc.
Unfortunately, the above mentioned optimisation criteria are often of contrary nature. For example, the minimisation of the CO_2-Emissions is not necessarily compatible to a minimisation of the operation costs. For this reason, the best choice would be a multiple-criteria optimisation (MCDM: Multiple Criteria Decision Making). The MCDM-Modelling [9] is characterised by the assumption that many decisions have to be done with respect to many different criteria, which may in some cases represent contrarily targets.
One of the most important development tasks for the design of the optimisation module is therefore the search for a useful and effective objective function vector, followed by the next research problem to find a mathematical algorithm to find the solutions of such problems. The numerical calculations for the optimisation have also to be done in an acceptable time interval with respect to the different dynamic operation behaviours of the single converter and components as well as the complete energy system as a unit. The optimisation interval complies with the available data from the forecast-module and the demand side management-module. Regarding the time horizon the present optimisation and future-oriented optimisation can be differed. To classify the optimisation process, several layers have been developed, interacting with the three modules and the systems components. Some layers are essential for each kind of EMS like measuring layer and control layer. To enlarge the functionality of EMS and integrating future events of producer and consumer a model layer and a recording layer are added. In case of self-learning and self-diagnostic features, the EMS has to be equipped with an analysis layer and a strategy layer.

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