CLASSIFICATION AND COMPARISON OF MULTI AGENT BASED CONTROL STRATEGIES FOR ELECTRIC VEHICLES IN DISTRIBUTION NETWORKS

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ABSTRACT

As electric mobility and decentralized generation are gaining more interest by industry and end users, future grid operation and augmentation strategies are facing a significant change. It becomes more likely to operate the system at its dynamical limits, which makes the operation more complex, e.g. higher voltage fluctuations.

Hence, new operation, control mechanisms and schemes are to be evaluated with respect to different aims and their impact on different voltage levels. Therefore, the paper depicts the challenges of grid operation with respect to electric mobility and points out possible control strategies enhancing the scheduling of charging and discharging processes of electric vehicles (EV). Within this framework two main management concepts have been evaluated. The first is based on a centralized control and the latter is based on a decentralized approach. It is shown, that a centralized control even poses an additional burden on distribution grids as local technical conditions are hardly capable of being integrated. Therefore, a decentralized scheme based on multi agent systems is proposed and discussed.

INTRODUCTION

Integration of intermittent generation into the electricity system enables a significant contribution towards a sustainable future with reduced local as well as global emissions. However, increasing intermittency of the power generation also increases complexity in system operation.

With this respect electric vehicles seem a promising and therefore often discussed opportunity to compensate inherent variability of intermittent resources which at the same time increases grid stability. In [1] it is shown, that additional storage equipped with the ability to act as virtual synchronous machines might help increasing grid stability during unstable conditions. However, utilization of a significant number of mobile storage systems might also impact the entire electricity system in terms of additional uncontrolled load or generation and even during controlled conditions, if charging or discharging processes are synchronized based on a centrally acting controller. Controlled conditions are expected from the use of variable tariffs initiating charging or discharging processes or from synchronization with intermittent generation to smooth the variability of production and to store excessive generation. As current electric mobility strategies are mainly linked to emission reduction, it is of essence to evaluate these and beyond to analyze further possible strategies with respect to their impact on the electricity system. For this purpose, two main concepts are suggested and assessed based on their impact on distribution grids with the aim to optimize conditions for the introduction of electric vehicles as there is a strong alignment of interests to reduce emissions and to cope with upcoming technical challenges.

CLASSIFICATION OF CONTROL STRATEGIES FOR ELECTRIC VEHICLE CHARGING

Various strategies to control electric vehicle charging have been presented in [2], [3] which mainly assess the impact on generation and transmission system. However, none of these strategies have been classified and compared with respect to complexity and purpose. Besides, grid aspects particular at distribution level have hardly been related to control strategies and their technical impact, respectively.

Therefore, in the following, a classification of different control strategies is presented, describing fields of application as well as requirements for implementation.

Starting with uncontrolled charging of electric vehicles, only controlled by users preferences plugging in a vehicle [4] indicates, that only very few cases do have an impact on German distribution grids. Hence, there is no urgent necessity to augment existing distribution grids. However, a penetration of approx. 22% changes the severity, resulting in thermal stress and voltage instability along lines. Besides, if certain goals are to be met through synchronization of charging and discharging processes such as provision of ancillary services, significant impacts are expected at distribution level in particular. Due to this fact, it is deemed as crucial to characterize controls following a thorough assessment of their impact on distribution grids and possible realization drawbacks. In order to characterize charging strategies, different classification schemes can be applied, which are listed below:

- Classification by purpose of control strategy
- Classification by complexity of communication and processing power
- Classification by location of intelligence

Purpose of control strategy

A number of strategies pursuing different goals are introduced within this chapter while at the same time evaluating benefits and drawbacks of different approaches. However, this does not claim to be complete.

Provision of ancillary services

Due to their ability to store energy and to start and stop charging at very short notice, electric vehicles are technically able to participate in markets for different kinds of reserve energy. While profitability is not within the scope of this paper, technical requirement to offer reserve energy shall be discussed.

As individual vehicles have only limited power ratings and battery capacities, large pools of vehicles are suitable to deliver such services. In Germany provision of secondary reserve power requires a minimum of 10 MW power to be delivered on request within only 5 minutes. According to [5] 61.000 vehicles are required to achieve this goal.

Different kinds of reserve power (except of primary reserve) are activated in Germany by the transmission system operators, who usually do not have any information about the state of the distribution level. Due to the fact that all vehicles within pool have to start or stop charging simultaneously in order to provide the requested amount of reserve power, the coincidence factor of vehicle charging significantly rises. This in turn may cause additional problems at DSO level, where grids are not planned to cope with coincidence factors of close to one.

Integration of Wind:

Similar to strategy of reserve power provision, electric vehicles can be used to integrate more wind energy into the system. This can be done by charging vehicles at times when the wind blows and the energy cannot be used by other consumers. Control signals will be required to initiate or interrupt the charging process.

Integration of photo-voltaic:

While wind turbines are most often connected to MV and HV level, photo-voltaic (PV) systems are usually connected at LV level in residential areas. The close distance between PV systems and EV allows for the use of electric vehicles to store electric energy generated by those systems and therefore reduce voltage problems, overloaded assets, changes of load flow direction etc. While this also requires control signals to start and stop charging, the strategy has to be executed locally without a centralized initiator of these processes.

Optimization of DSO-grids:

Leveling or peak shaving of demand is one of different goals for optimizing the utilization of present grids through scheduling of charging processes in to times with high or low load conditions. Integration of PV also enables a better utilization of existing assets in conjunction with electric mobility. It therefore is concluded, that on optimized utilization of assets needs consideration of local circumstances such as grids conditions, which are also influenced by different technologies installed e.g. PV.

Complexity of control strategy

All control strategies described before require a certain control scheme (central or decentral) for operation. This again requires investments for design, test and implementation – both for hardware and software. A short classification of the level of complexity shall be given at this point, as it highly determines how successful a strategy may be in reality.

Implementation of reserve power can be done in a very simple way by sending out control signals to all contracted vehicles whenever required. On the other hand this neither takes into account the user's needs (one will not want to stop charging when the next trip is shortly ahead) nor the state of the LV grids where the cars are connected. Taking into account any one of these additional information increases the complexity of the overall control algorithm. In addition, every of these requirements can be taken into account in different ways, some of them maybe combined, as the following examples illustrate.

It is assumed that charging is initiated within a region in order to pursue a certain goal, e.g. storing of wind energy. In order to prevent the assets from overloading resulting from charging process commenced on a signal a *simple first come first serve* strategy may be sufficient only requiring little communication: indicating the need of a vehicle to charge and signal of the substation to start the charging process. However, this does not take into account that some users have more urgent requests then others, as they soon need to depart again. The complexity rises with a *pooling of free capacity* strategy, where all the power available from the substation is evenly distributed. No one has to wait with this strategy but charging power of all vehicles has to be recalculated and communicated with every vehicle connecting or disconnecting. The benefit of this strategy is that it may be considered more just, but it still neglects the needs of some users having urgent requests for energy. This can be overcome by a *pooling with priorities* strategy, which takes into account amount of energy needed of every vehicle, time of arrival and departure, power available etc. Even more complexity is added in order to store and process these data sets.

Location of intelligence

Depending on the goal pursued by a control strategy, its intelligence (communication, calculation) may be implemented at different points in the system.

Centralized control

Taking the participation in reserve power markets as an example, a centralized control is required. This control system has to receive commands from the operator of reserve power and forward it to the different electric vehicles available for charging or discharging. As these vehicles may be distributed over a large area (e.g. Germany or possibly Europe), the system may not be able to take into account the state of all LV grids where cars are connected. Centralized control systems may be implemented at DSO levels as well, e.g. within a substation sending out signals to reduce charging power when the transformer is overloaded. Centralized systems in this way are defined as systems where one central (but possibly redundant) unit makes the required calculations, takes decisions and sends out commands that are to be executed.

Decentralized control

Decentralized control on the other hand is characterized by multiple intelligent units (possibly all vehicles) that gather and exchange information in order to optimize the overall system's performance. Quite often this is referred to as multi-agent-systems (MAS).These strategies are very suitable to also take into account user's needs or other properties that are directly available to the algorithm (voltage can be measured, SOC, current etc.) while at the same time reducing the need for communication. However, there is a lack of direct control by clearly defined commands and therefore it may be easier for the user to manipulate the algorithm. Therefore, a more sophisticated system of incentives for the user to cooperate may be required, which is described in the following section.

DECENTRALIZED CONTROL MECHANISM WITH MULTI AGENTS

A decentralized control scheme offers flexibility with respect to scalability of a system, e.g. number of electric vehicles to be controlled or adding new control instances [6]. Due to this fact decentral processing of information for reduction of grid impacts through an adequate scheduling of charging processes of a significant number of electric vehicles offers a suitable option for future grid operation. Hence, the following sections deal with multi agents related to the scheduling of electric vehicles.

Multi Agent Systems

Multi Agent systems consist of multiple autonomous entities having different information and individual preferences such as user and technical requirements. Agents are characterized through incomplete information and thus only have a restricted knowledge on the environment and therefore limited capabilities to solve a global problem. Besides, data is processed and distributed in a decentralized way, which makes the approach applicable to very complex and distributed problem solving. It therefore enables to split large problems, which are hardly solvable with centralized approaches due to its complexity or huge amount of information to be processed such as in the case of coordination of charging processes of widely distributed electric vehicles. Besides, a decentralized approach also enhances the flexibility of an entire system through interoperation of multiple systems allowing for an adaptive system size through a cooperative way. A realization of multiple systems might be introduced at substation level with a mutual communication in order to achieve a certain goal, for instance, maximization of stored wind power taking into account the very local technical limitations (thermal stress etc.) respectively.

The modularity of a decentralized coordination scheme also enhances reliability and robustness of a system as information is exchanged between agents (substations or electric vehicles) and in case of failure only a certain part is not capable to operate.

In this particular case a central entity is introduced gathering and distributing information at substation level, which might be seen as the main coordinating agent receiving global information. This approach demonstrates a combination of a central unit with decentralized agents, which is described in the following section.

Coordination approach for electric vehicle charging

In order to transfer an agent based coordination mechanism into a context of electric mobility and electricity grid the goal need to be determined first, which however, is easily extendable to another or even multiple goals. The scope of this paper lies within an adequate consideration of technical limitations and incorporation of individual preferences into a scheduling algorithm, which also takes into account a centrally initiated process such as described in section one (e.g. ecological charging: synchronization of charging processes with wind), which then is processed through a multi agent approach in a decentralize way. As such the coordination mechanism demonstrates a combination of a central mechanism combined with a distributed processing. However, initiation of autonomous coordination of scheduling is to be implemented through a mechanism, which has to fulfill certain requirements listed below:

- Actions in real time
- Easy to implement
- Reduced data traffic
- Inclusion of individual preferences

In order to cope with uncertain events such as grid failures or sudden increase in wind power, adaption of the system state through initiation of charging in order to increase or decrease consumption has to be realized within short time whilst at the same time considering all technical limitations, e.g. voltage level along lines, thermal stress on assets and overall system stability. Besides, in order to keep additional expenses related to implementation of a coordination mechanism small compared to a conventional grid expansion required without control the complexity is to be kept as small as possible, which requires an easy to implement algorithm. Additional expenses arising through implementation might be compensated with reduced grid expansion due to better utilization of assets, which however are not in scope of this paper. Inclusion of autonomous entities such as owners of electric vehicles requires consideration of individual preferences, which are derived from characteristic behavior, which differs in terms of individual ecological preferences. These preferences differ in terms of willingness to pay for a more ecologically power (wind power) and represents real attitudes of customers. In order to avoid a simultaneous action of customers to avoid thermal stress of assets a resource allocation algorithm is required, considering these individual attitudes, which in fact result in different charging behavior. In this case restricted resources are technical limitations of a distribution grid. In order to remain within the technical boundaries (transformer loading, voltage) allocation of resources is realized through a negotiation between agents, which is based on an auction algorithm and introduced in the following section.

Coordination through auctioning

Coordination through an auctioning mechanism transmits the decision of processes onto the agent in this case an electric vehicle. Agents' reaction is then dependant on his abilities, properties as well as options for actions. The algorithm presented is based on a Vickrey auction [3], accepting the highest bid. In order to ensure a safe and reliable grid operation incorporation of another entity is necessary, which represents an auctioneering agent, who at the same time observes technical limitations. The auctioneering agent receives and ranks all bids according to height of offers provided by participants and compares all requests (charging power of electric vehicles) with technical limitations.

Agents properties are incorporated according to [7] in terms of their behavior towards bidding, where an cool-headed agent takes a risk and waits a little until it bids higher prices with shortening of the remaining departure time, a careful agent chooses the opposite strategy and puts higher bids to increase his probability to charge. A neutral agent has a linear dependency of placing bits related to time remaining to departure.

CONCLUSION AND RECOMMENDATIONS

The paper provides a brief impact analysis of some common strategies suggested for incorporation of electric vehicles into electricity grids in order to cope with upcoming limitations related to a synchronization of charging processes with global aims such as storage of power generated by wind. For this purpose a brief understanding of central and decentralize control schemes is given. As the complexity increases with the number of charging processes to be scheduled a central control algorithm is neither capable of taking into account local grid requirements nor incorporating individual user preferences. Hence, a multi agent based approach is presented to distribute the resource allocation problem dividing the global problem into sub problems, which are then computed at a local level including local grid characteristics. This makes a combined approach of centrally initiated charging processes and a decentralized allocation of available resources possible. The complexity is reduced as multi agents provide downsizing of the entire problem. As a transition towards smart grids is expected a decentralized arranged scheduling mechanism might be implemented enhancing grid operation and increasing efficiency.

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