MODELLING ELECTRIC VEHICLES AT RESIDENTIAL LOW VOLTAGE GRID BY MONTE CARLO SIMULATION

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ABSTRACT

In this paper, electric vehicles (EVs) are modelled as household electric appliances at the low residential electricity grid in order to analysis their impacts to the grid capacity by a Monte Carlo simulation. The aim of the research is at finding out more accurately the probabilities of possible overloads caused by EVs. A Monte Carlo simulation base model was developed to first represent random usages of electricity power at households, then the scenarios of EVs with various penetration degrees to households and different charging patterns are developed based on the settings given in the base model. Thus EVs' charging impacts on the low voltage electricity grid can be estimated with the scenarios, in supporting electricity distribution operators (DNOs) especially in their low voltage grid capacity planning. Pricing strategy of DNOs in influencing residential behaviors of charging EVs are also specified.

INTRODUCTION

The impacts of electric vehicles (EVs) on LV grid are uncertain in electricity grid asset capacity planning. At the consumption side, since different types of EVs with various battery characteristics are being developed or further improved, it is unpredictable which type(s) will be widely accepted and applied as popular transportation means. With the resulting different charging characteristics of EVs, combining with various transportation needs in households, the demand of electricity required for charging EVs on the LV-level is extremely uncertain. From the prospective of electricity distribution operators (DNOs) therefore, grid asset planning and pricing strategies are complex due to uncertain demand and irregular consumption behaviors.

This is especially true for the low voltage grid capacity planning, due to the fact that activities of individual households are highly different and EVs are high-power appliances in the households. Thus the impacts of individual charging patterns will be extremely high to the total loads. So how to address correctly the capacity needs caused by electric vehicles in the future LV grid asset management process?

In the research, based on the Monte Carlo simulation built for regular household behaviors at low voltage grid level [1], EVs are modelled as household electric appliances, and vast scenarios of charging EVs are generated in order to identify the impacts of EVs to the residential grid, and to test the sensitivity of penetration degree of EVs to the current grid capacity.

Vast scenarios are generated randomly by probabilistic distribution of EV charging patterns and different penetration degrees to the households. The EV Charging patterns generated in the Monte Carlo simulations are based on empirical mobility data of car-users in the Netherlands in 2008 [2]-[3].

The Monte-Carlo simulation can be helpful in providing insights in the load patterns of EVs and also be used for supporting DNOs on future low voltage electricity grid asset capacity planning.

METHOD

The scenarios of charging EVs at low residential voltage in the Monte-Carlo simulation and possible pricing strategies of DNOs can be illustrated as figure below:

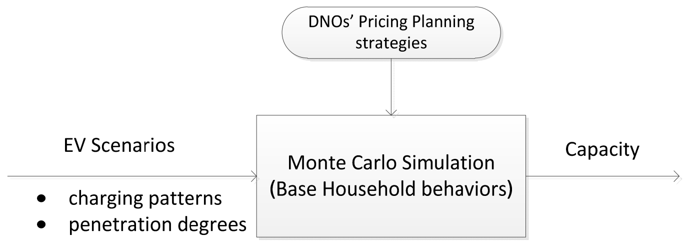

Figure 1. Modelling EVs for supporting DNOs on grid capacity planning by Monte-Carlo simulation

The outcome interest of DNOs in this research is focused on low voltage grid capacity needs, including mainly distribution sub-stations and cables. The highest peak load is critical in defining capacity needs. In the simulation modeling, more parcifically it is aimed at finiding the highest peak at time T (in step of minute) in daily 24 hours, and the probablities of overloads which may result in burnt-outs of cables or substations.

In order to find more accurately the probablities of overloads, a Monte-Carlo simulation with stochastically generated load profiles was built as base on modeling basical household electricity usage behaviors [1]. And the impacts of charging EVs at households will be simulated upon the base model.

EV scenarios are developed by different charging patterns and various assumed penetration degrees of EVs. The different charging patterns and penetration degrees are simulated individually and also in various combined ways in order to test their individual impacts and also intergrated impacts. The resulted increased capacity needs are restored for further analysis.

DNOs, as energy operators, can at the same time influence the consumers' charging behaviors with strategic and regulatory power. Possible influences to EVs' charging by pricing strategies are estimiated.

The influences are specified based on the same principle which different EV scenarios are generated. The pricing strategies thus ca be tested in their influces on EVs' charging behaviors, and the abilities of balanncing or shifting loads, or to find out how the current and available capacities can be used more in an optimum way.

In the following sections, the base Monte-Carlo simulation model, an exampled residential low voltage grid by the simulation model, the scenarios development and pricing strategies with their possible impacts are described respectively.

BASE MODEL (BY MONTE-CARLO SIMULATION)

In the base model, regular household behaviors of using electrical appliances are run with stochastically generated load profiles. This representes the daily electrticity consumption in a more realistic way then using aggreated and deterministic simulatainty factor. This is especially true for low voltage grid. And thus the impacts of having extra EVs at households can be found more actually as well.

In the Monte-Carlo simulation, eight household types are pre-defined based on number, age and working status of members in the households. Stochastic load profiles are generated for typical household types. Based on statistic Dutch household data, percentages of each household type are specified. Households are thus randomly generated based on percentage rate.

Commonly used 25 types of electrical appliances in Dutch households are stored in database, containing information of highest requested power usage, duration of time for each use.

The usage of appliances can be distinguished in three types in relation to its duration: 1. constant use: appliances such as fridge; 2. instant use: appliances such as coffee maker; 3. semi-constant use: such as air-conditioner.

For instant-used appliances, use time is specified as triangular distributions with approximate minimum, mean and maximum use time. For constantly used appliances, use time is specified as 24hrs. For semi-constant used appliances, use time specified only for the time when extra power is requested, as for the case of fridge, the time that extra high power caused by opening fridge door is specified. Stand-by power is set for constant and semi-constant appliances.

Penetration degrees of the appliances are pre-defined based on available statistics, market data and related researches. Not only a general penetration degree of each appliance is pre-defined, also penetration degrees of the appliance for different household types are assumed based on the characteristics of the households. Thus, for each generated household, certain appliances are 'installed' based on the penetration degrees accordingly.

Probability distributions are pre-defined for all the installed appliances in the households in their power usage, frequency to be used during the day and duration time of each use.

And the power usage is recorded with minute as time step. Random applications of household electrical appliances are thus modelled by Monte-Carlo simulation method.

AN EXAMPLE OF SIMULATED LOW VOLTAGE GRID

Low voltage of residential electricity distribution grids are directly linked to households, thus modelling these low voltage grids often tend to be very detailed in technical parameters, thus are not easy for supporting robust strategic planning. To simplify the modelling process, but at the mean time, also keep the modelling results accurate enough in power flow analysis, a sub-grid concept is developed [5].

As an example, one sub-grid type containing 30 to 50 large-size households is modelled in the simulation modelling environment. It assumed that this sub-grid is located in a region of semi-detached large-size apartment block instead of studios (which thus normally tend to contain families instead of single working adults). And household types chosen for this sub-grid are:
1. (H3) working couple without children;
2. (H4) working couple with children;
3. (H6) couple but one stay household with children.

The ratio set for three household types are 4:3:2. The figure shows radio-layout of the 37 loads under one distribution substation.

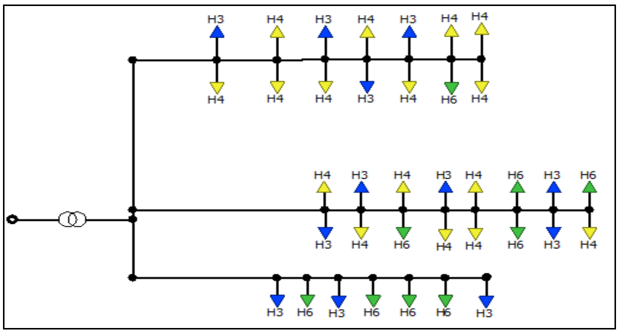

Figure 2. An example of grid layout with large-sized household types in simulation

EV APPLIANCE

Based on the household base model, EV is simulated and is treated as one household appliance. In the research, only full battery-engined EV is considered.

According to the base model settings, EV is taken as instant use appliance. In the same settings for other common household electricity appliances, EV appliance is simulated with following attributes :

1. Power usage : in triangular distribution (unit :watt)
2. Duration of charging : in triangular distribution (time unit : minute)
3. penetration degree : in percentage
4. frequency of being charged in different charging periods : in triangular distribution (unit : number)

The penetration degrees of EVs are estimated in different levels according to household types. Household types with children and more working adults tend to have higher penetration degrees.

EV SCENARIOS

The EV scenarios are developed based on estimated electricity needed for charging EVs. To estimate the expected needs, the data by Mobility Research Netherlands is used [2], and other research results are referred to such as [3,4].

The scenarios are developed by mainly following logics:

1. charging patterns (including charging start-time, charging rate and charging time)
2. penetration degrees.

Charging Patterns

Starting Time

Starting time of charging EVs is set in two ways:1. start charging immediately after arriving at home; 2. charging after 11:00pm.

Based on distribution of arrival time found in [4], in the model, simplified arrival period is set between 16:30pm to 20:00pm.

Charging Rate

Fixed charging rates are considered in the research. Two charging rates are used in developing scenarios [4,5]:
1. low rate of 3kW; 2. high rate of 10kW.

Charging Time

EV efficiency of 5km/kWh is assumed in the simulation modelling. The principle assumed is the EVs are charged at households and not at charging point or station until EVs' batteries are full. Based on data of distance driven found in [4], charging time is assumed with approximate triangular distribution of (min, mean, max) in (10mins, 300mins, 540mins) for low charging rate, and (10mins, 120mins, 300mins) for high charging rate.

Penetration Degrees

Penetration degrees are set with following ranges :0.1 to 1 in step of 0.1.

Generation of Scenarios

Simulation modelling generates EVs charging profiles randomly. For each step of penetration degree (0.1 to 1), also for both low and high charging rate, random scenarios of up to 1000 are generated in the Monte-Carlo simulation.

DNOS' PRICING STRATEGIES

DNOs can use pricing strategies to influence household EVs' charging behaviors, and thus to balance the peak loads. By setting different prices for various periods during the day, consumers may be either encouraged or discouraged in using electricity in pre-defined periods. Thus peak loads can be shifted to other periods or being balanced.

In the research, two possible results after DNOs applying pricing strategies are modelled corresponding to the scenarios logics:
1. shifting charging start time;
2. reducing charging amount by reducing charging time at households;
3. reducing charging amount by decreasing charging rate at households.

Shifting Charging Time

Charging start-time will be shifted to after 11:00pm, from 10% of households onward up to 100% in step of 10%.

Reducing Charging Time

Charging time will be reduced in 10% to 50% of previous settings.

MODEL RESULTS

In a given grid layout, the EVs are randomly generated for all households based on set penetration degrees. Simulation runs for each household and generates load profiles representing its daily electric usage. EVs' charging load profile can be highlighted as one appliance. In the shown exampled figure below, aggregated load profile of a single household (of type H6) is represented by red lines, and EVs charging profile is indicated by a blue line:

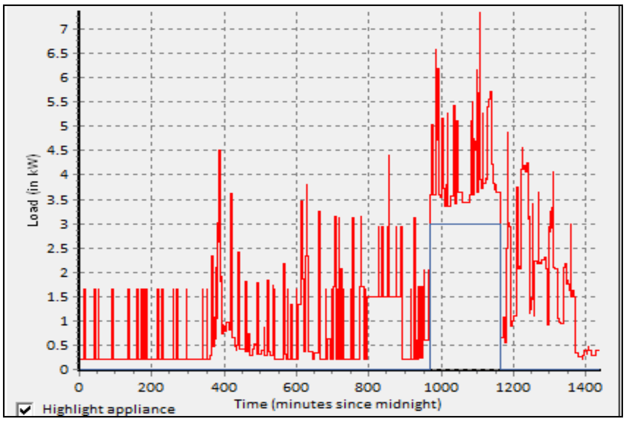

Figure 3. Highlighted EVs' charging load in a single household load profile

The aggregation of load profiles at distribution transformer can also be shown as the exampled figure below. In this example, the influence of pricing strategy is also included. The layout of modelled grid is shown in figure 2, and the settings for charging EVs are: 1. penetration degrees are 0.7 for all the three household types; 2. low charging rate at fixed 3kW; 3. most of households are shifted to charge during night time after the influence of pricing strategy, and the new charging starting time is about 15% of households chose to charge right after arrival, and about 85% charge during night after 11:00pm.

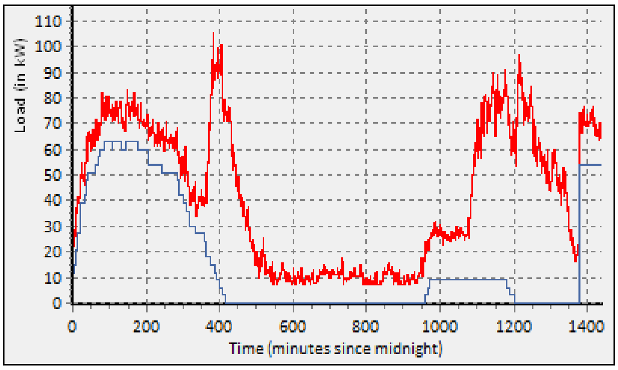

Figure 4. An example of aggregation of transformer loads

The probability of overloads can be calculated based on the simulation results. Following the above settings, the result is shown after 1000 runs with 180kW limit at transformer. It can be seen that the mean of peak loads is 166kw, the maximum peak load is 242kw, and in total, about 7.6% probabilities are overloads.

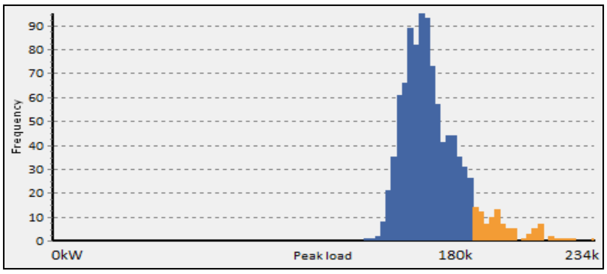

Figure 5. An example of aggregated peak loads

VALIDATION

The base model will be validated by two steps: validation of the base model and validation of EVs' charging profiles. Aggregations of household loads will be compared with empirical transformer loads provided by Enexis B.V., NL. The EVs' charging results will be validated with real sampled data at individual households.

CONCLUSION

In the research, modelling EVs as household appliances by a Monte-Carlo simulation is described, and the charging scenarios of EVs are randomly generated in a vast way aiming at analysing EVs' charging impacts on residential low voltage grid capacity. Charging scenarios are generated stochastically with different penetration degrees and charging patterns. DNOs' pricing strategies are also estimated in their influences on EVs' charging patterns, the impacts of which also will be analysed for supporting DNOs in their strategic planning process.

Acknowledgement
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REFERENCES

[1] W.Du, P.W.G. Bots, J.G.Slootweg, 2011, "Monte Carlo Simulation of Generating Stochastic Load Profiles in Electricity Distribution Grid Asset Planning', CIRED conference

[2] DVS, 2009, "Mobiliteitsonderzoek Nederland 2008", het onderzoek, Ministerie van Verkeer en Waterstaat / Rijkswaterstaat

[3] R. Verzijlbergh, Z. Lukszo, J. Slootweg, and M. Ilic, "The impact of controlled EV charging on residential low voltage networks," 8th IEEE International Conference on Networking, Sensing and Control.

[4] R. Verzijlbergh, Z. Lukszo, E.Veldman, J. Slootweg, and M. Ilic, "Ev charging profiles derived from driving statistics," IEEE Power & Energy Society General Meeting 2011.

[5] W. Du, P.W.G. Bots and J.G. Slootweg, 2010, "Supporting the Development of Robust Strategies for Asset Replacement in Electricity Distribution Grid", 3rd International Conference on Infrastructure Systems, Shenzhen, PRC.