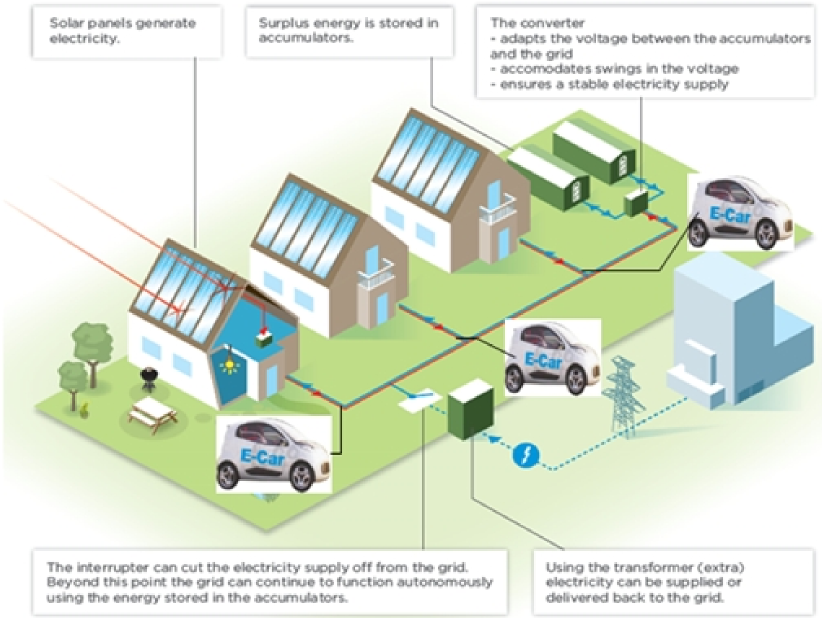
Chapter 1

The future of the energy network

Times are changing in the energy sector with rise of solar panels and electric cars. Network operator Endinet asked the study group under which circumstances the energy network will remain stable. The mathematicians used a real suburb in Eindhoven and discovered that not everyone can have everything.

Endinet provides the physical delivery of electricity. A task of this network company is to balance energy consumption and production. Consumers should experience no power failures or spikes in their voltage. Until recently energy transport was one-way-traffic: a few big power stations delivered energy to many small consumers. But now households are starting to generate their own energy with solar panels and the superfluous energy flows back into the network. And there is a second big change coming in the scheduling of energy usage. Traditionally the energy demand was high during the day and low during mid night (which is why some energy companies offer a cheaper night-rate). But electric vehicles are slowly becoming more popular and consumers will need to charge their cars at night. Can Endinet keep the balance in the energy network with these two new developments?

Specialist asset management Sharmistha Bhattacharyya brought a real-life example to the SWI2012: a small part of the network in Eindhoven. Thirty-one houses on a feeder. What would happen if all these houses had a solar panel and an electric car? Bhattacharyya asked three specific questions about this network of the future. In the first place, can it harvest all the solar energy? Secondly, can it deliver all demand when electric vehicles are charging? And finally, would it be useful to put in an extra cable in the ground to make an extra connection in the network?



Start simple

Studygroup veteran Chris Budd (University of Bath) was excited to work on these questions: “Energy is a big problem and it is impossible to predict the future. We just do not know what is going to happen energy-wise.”

Budd and some other members of the team had experience with the equations for power systems. “We spent the first day training the rest of the group on these equations and the basic techniques. We started with a very simple model with just one house. We solved this case both analytically and with simulations. Everyone caught on very fast.”

Because the future is so unpredictable, the group decided to focus on simulations and run different scenarios. They subdivided the tasks: one group focussed on the software for the simulations, a second group worked on the solar panels and the third group studied the electric cars. Budd: “It makes sense to model solar panels and electric cars independently. Solar panels only work when there is sun and most cars will be loading at night. So they offer a strain on the network at different times.”

Avoid broken televisions

The constraints on the network however are the same for both problems. First of all the voltage should always be between 207 V and 253 V, otherwise computers and televisions of the consumers might break down. The voltage may also not change too rapidly, the maximal allowed variation between two consecutive peaks is 3%. Furthermore, the current must stay below a certain limit, otherwise the isolation around the cables might melt. And finally, Endinet wishes to minimize the power losses in the network.

Every consumer has a different power demand, but a typical household uses an average of 400 W with a peak load of 1000 W in the early evening. Furthermore, people use more energy in the winter than in summer. To give an idea of this usage: a laptop uses 45 W, a normal light bulb 60 W and a fridge 150 W. Charging an electric vehicle takes 3500 W, so this is really a heavy load on the electricity network.

Think about cloudy days

On a bright, sunny day a solar panel delivers around 3000 W, more than enough for a normal household, the surplus energy is transported back to the network. The main problem is that purely sunny days are scarce (especially in The Netherlands). The production of a solar panel varies rapidly when clouds drift by: in ten minutes it can jump by 600%. Recall that two consecutive voltage peaks in the energy network could not vary more than 3% and it is clear that it is not trivial to transport the energy from the solar panels. A mathematical complication is that these variations happen for all the solar panels in a neighborhood simultaneously. If one solar panel is clouded, the ones next to it will probably be as well. Therefore the panels can not be seen as independent variables.

The mathematicians tried different combinations of household loads and solar panel placements. For each possibility they simulated four characteristic days: cloudy and sunny days in both winter and summer. When less than 70% of the houses had a solar panel, there was not a single problem. The network was robust, no matter how the panels were distributed over the neighborhood, or how the individual household loads varied. However, when more than 90% of the houses had a solar panel, the network inevitably failed. In this case it was impossible to prevent voltage jumps. For the in between cases the stability of the network mainly depended on how the solar panels were distributed.

The inhabitants of the Peruvian Taquile Island decided to use solar panels instead of generators.

Baby you can charge my car

So the network can handle solar panels, as long as there are not too many. What about the electric cars? In the worst-case-scenario, everyone would come home from work at 6:00 p.m. and plug in their car to charge. But the early evening is exactly the time with the highest peak in energy demand from households. In this scenario the network will definitely fail. A scheduling strategy for charging cars is necessary.

Based on the average mileage of cars, the study group assumed that it would take three hours to fully load one vehicle. In their model each household owns one car that arrives at 6:00 p.m. and needs to be charged before 7:00 a.m. the next morning. The mathematicians devised a greedy algorithm that always tries to charge a car at the location with the highest voltage. With this strategy the network could charge almost all the cars at once. Within six hours every car was fully charged. Even though it is technically not possible to charge two cars per household (the capacity is too small for that), the mathematicians wondered whether the network could handle is. The greedy scheduling became more elaborate, but it was possible to charge all the cars in nine hours. So in theory, each household could have two freshly charged cars waiting in the morning.

A hybrid car is charging its battery.

Add the cable

The final question from Endinet was about the addition of an extra cable. With this extra cable a number of households could get their energy from more than one source, which might make transport more efficient. The question was whether this extra cable would result in sufficient less power loss to justify the investment of putting it in the ground. Mathematician Keith Myerscough (CWI) enjoyed the realistic feel of this problem: “This question was about a real suburb in Eindhoven. I got the feeling that Endinet wanted us to decide whether or not this extra cable is necessary.”

The answer to this question was a clear “yes”. The extra cable approximately halves the power loss in the network, independent on the number of solar panels. During their presentation the mathematicians emphasized that this result would be hard to generalize, it depended strongly on the structure of the grid in this suburb.

Down-to-earth

A few weeks later we call specialist asset management Yolanda Knops at Endinet to ask if they have already installed the cable. She starts laughing: “That cable has been in the ground for years. We wanted to give the study group an interesting problem, but it would be too labour intensive to model an entire suburb. Therefore we gave them a small part of the network and removed the cable to make it more challenging. We wanted to give them a real feel of our problems.” Endinet was curious how the mathematicians would tackle their problems, would they come up with completely new techniques? Another main goal was to strengthen the ties with the university and show researchers the common questions in the energy field. Knops: “We are a down-to-earth company, we would never outsource the decision about adding a new cable.”

The mathematicians did not discover some new revolutionary technique, but Knops is also down-to-earth about that: “We are already using a lot of mathematics, so it is not surprising that the solutions from the study group are familiar to us. Their work is correct, only the finer points are missing. But that is logical since they only had a few days. In hindsight, we might have formulated the problem slightly different and given the group a ready-made model. Now it took them a lot of time to get started. It would have been interesting to see what other charging strategies they would have come up with if they had had more time.” Her colleague Sharmistha Bhattacharyya adds that the enthusiasm of the group was fantastic: “They asked many questions about the consequences of solar panels and electric cars for the network. Especially because they could correlate the given problem with the realistic situation that might occur in their own homes or neighborhood.”

Team Endinet

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