# CONTROL FOR SMART GRID APPLICATIONS

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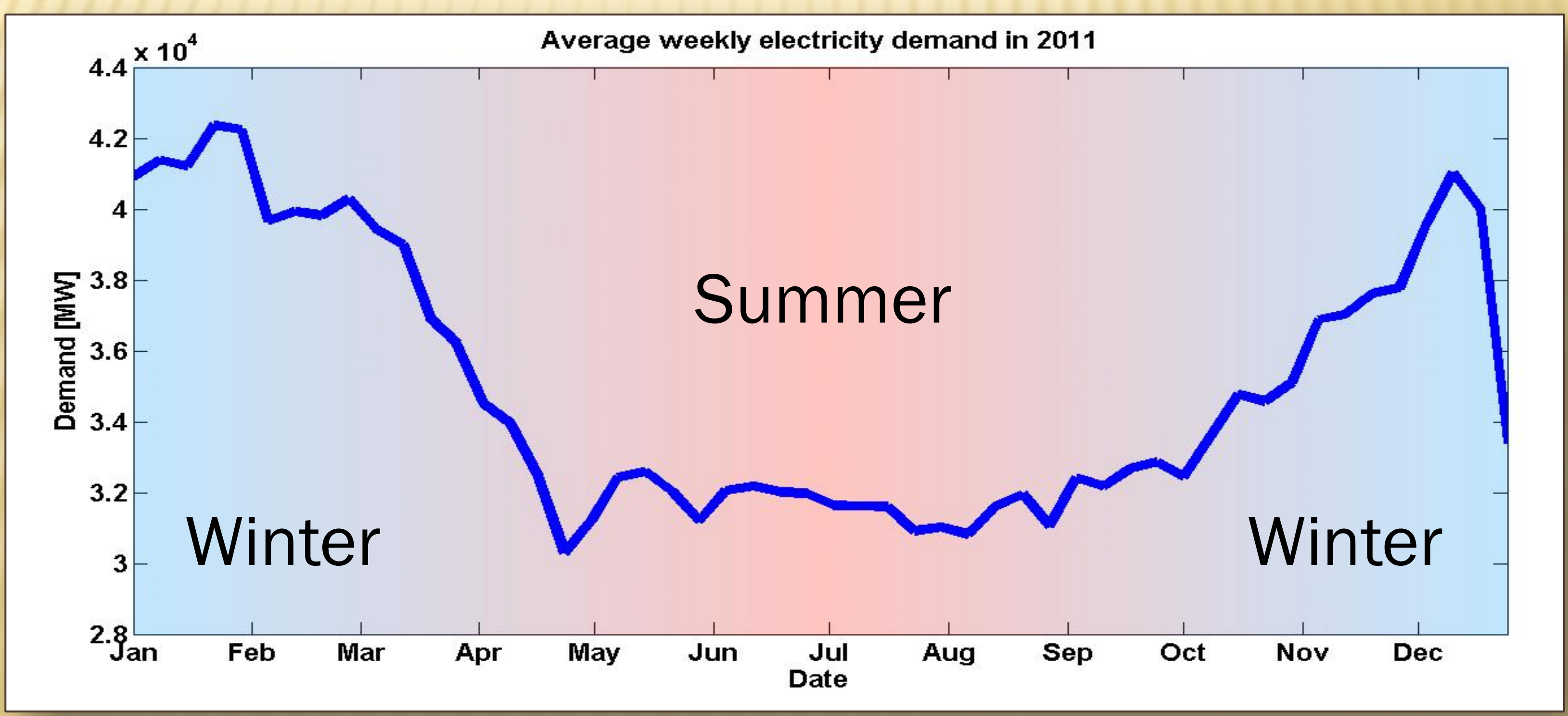
# THE ELECTRICITY GRID IN 2020

- European Union agreement to increase electricity generation from renewable energy sources by 15% between now and 2020
- Scottish government wants “to meet an equivalent of 100% demand for electricity from renewable energy by 2020”
- **What would an entirely renewable grid look like in 2020? What will the problems be? How can we help solve them?**

# DEMAND AND SUPPLY

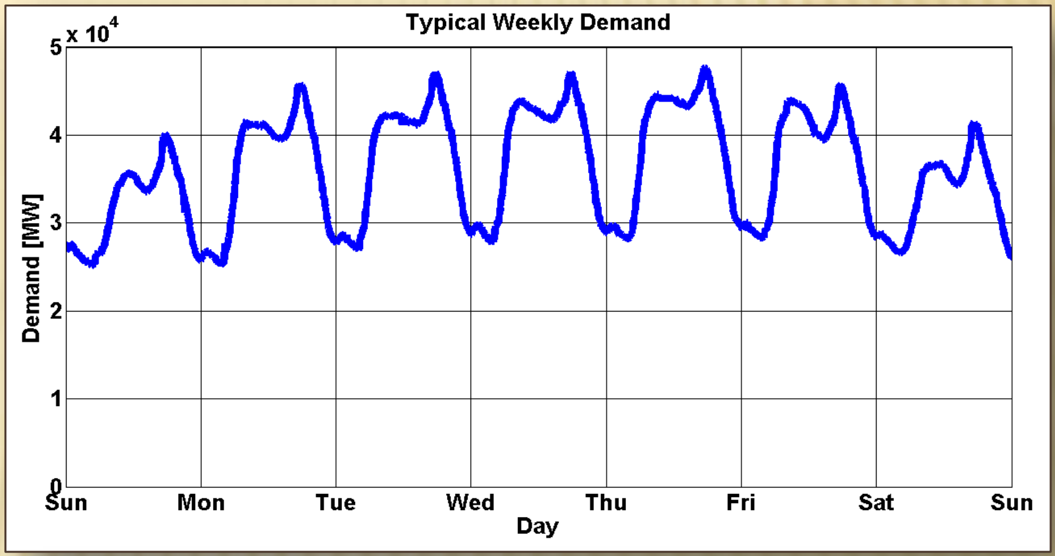
# WHAT WOULD DEMAND LOOK LIKE?

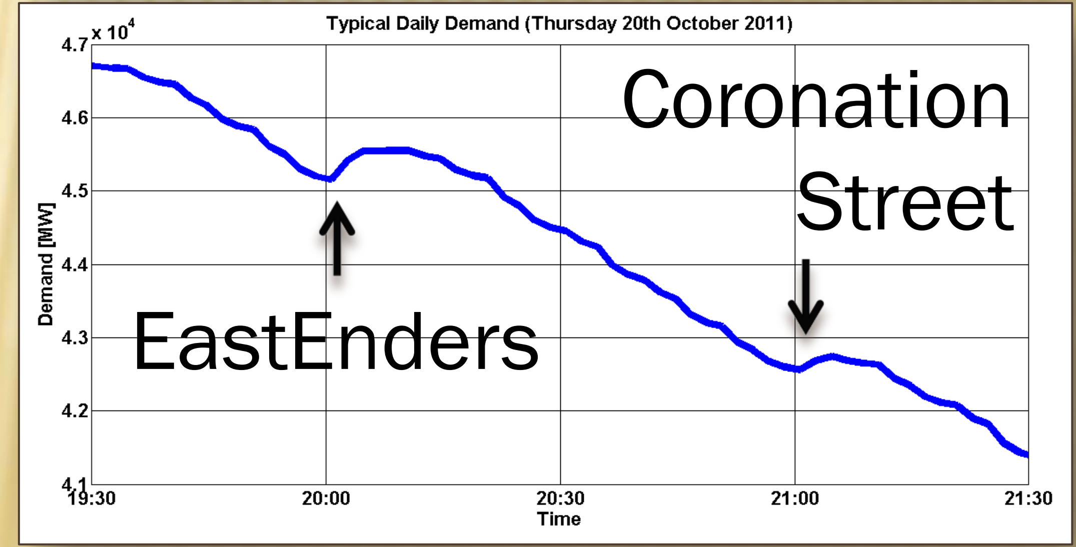
- Demand in 2020 should follow similar patterns to demand in 2011
- I obtained demand data for 2011 from UK National Grid
- Most usage in winter, least in summer



# WHAT WOULD DEMAND LOOK LIKE?

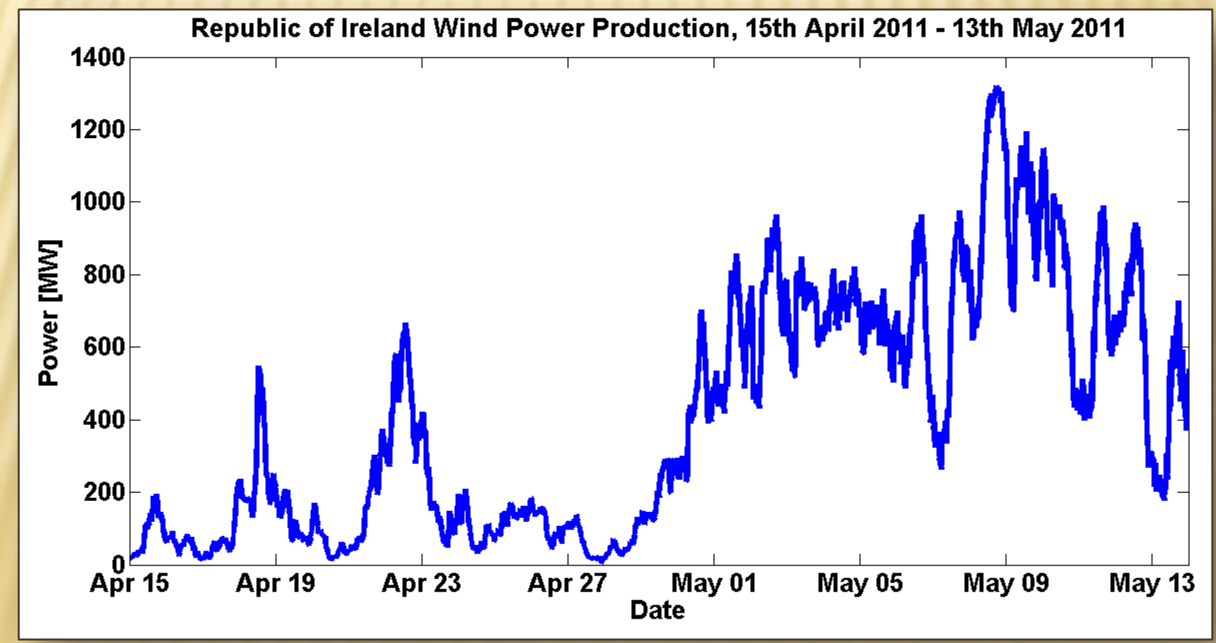
- Weekly demand follows a pattern
- Occasional demand spikes on **second, minute and hour bases**
- ‘TV pickups’ result in spikes in demand as viewers turn their kettles on for a cup of tea
- **Reasonably predictable** in the long term



# WHAT WOULD SUPPLY LOOK LIKE?

- No one really knows, but we can guess that it would involve lots of wind turbines and solar panels
- Let's assume **50%** of the UK's electricity in 2020 will come from **wind**
- I obtained data for Irish wind production from EirGrid
- Scaled data so that **total production = total demand**

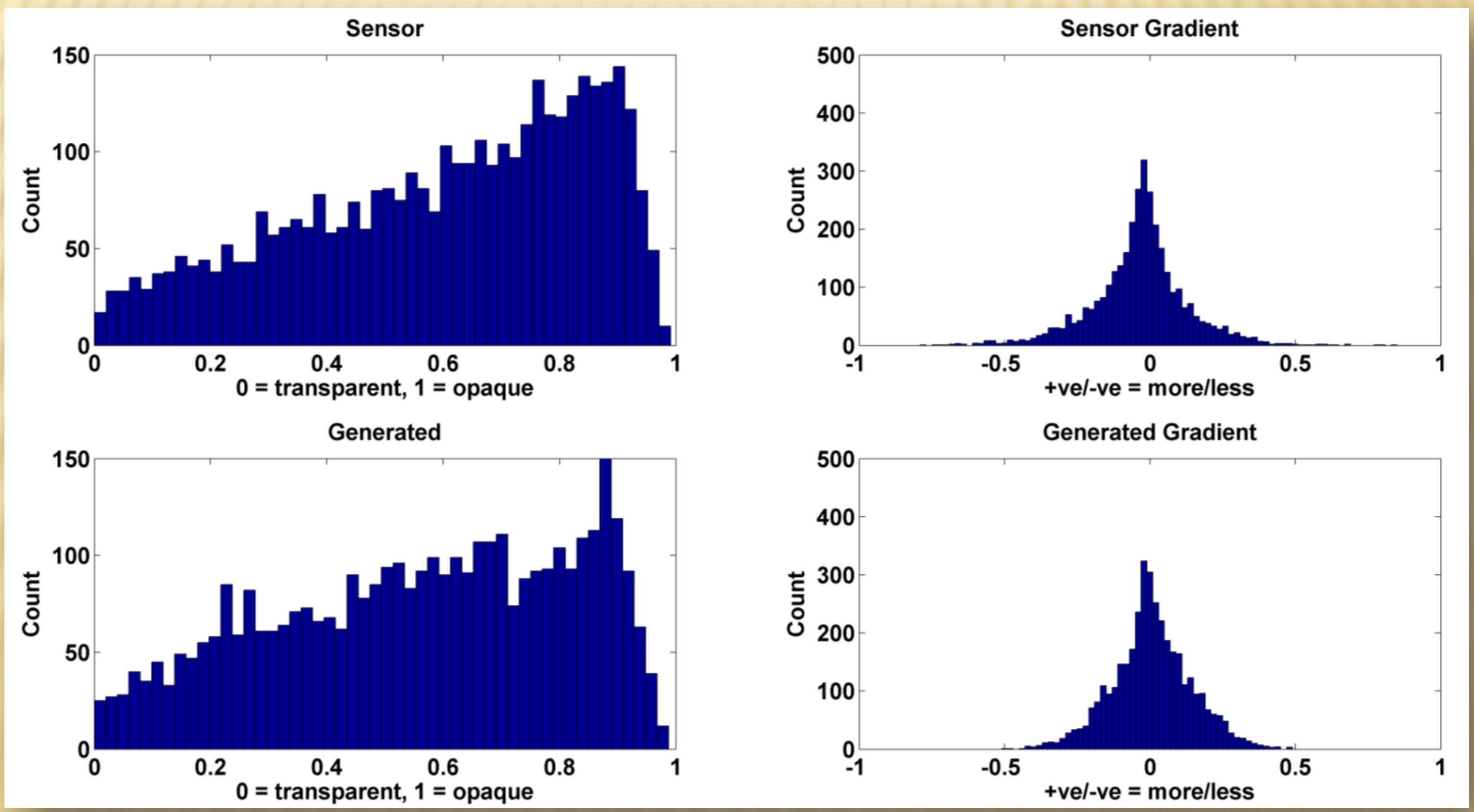


# WHAT WOULD SUPPLY LOOK LIKE?

- Let's assume the other **50%** comes from vast areas of solar panels
- We created a **simulation** of solar power production using 2011 solar irradiance measurements for Glasgow provided by the Met Office
- Scaled area of solar panels to produce enough average supply to meet average demand

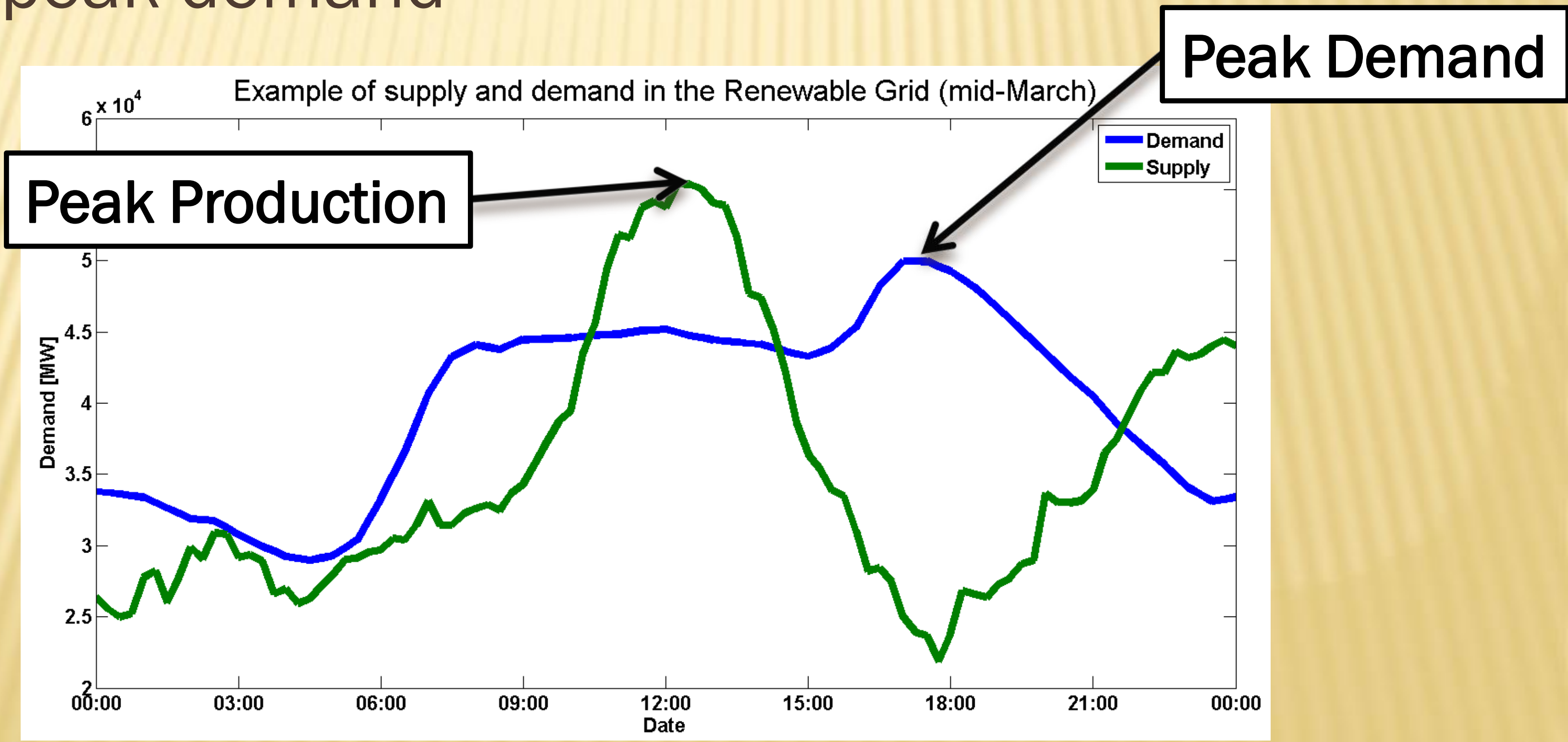
# WHAT WOULD SUPPLY LOOK LIKE?

- The ‘cloudiness’ factors, and their rates of change, were modelled on the real data



# WHAT WOULD SUPPLY LOOK LIKE?

- **Stochastic** energy production across all time scales
- Peak generation **does not necessarily coincide** with peak demand



# MITIGATION CONCEPTS

# HOW WE CURRENTLY MITIGATE

- **Inefficient gas generators** are brought online to cover extra demand for short periods of time
- Longer periods are covered by **pumped storage** (e.g. hydroelectric dams)
- **We can import power** from France, Ireland and the Netherlands

- As a last resort, we can **shut down heavy industries**
- This works now for small and predictable fluctuations in demand, but this won't work for the anticipated fluctuations present in a future grid

Cruachan Dam, Scotland
440MW Capacity

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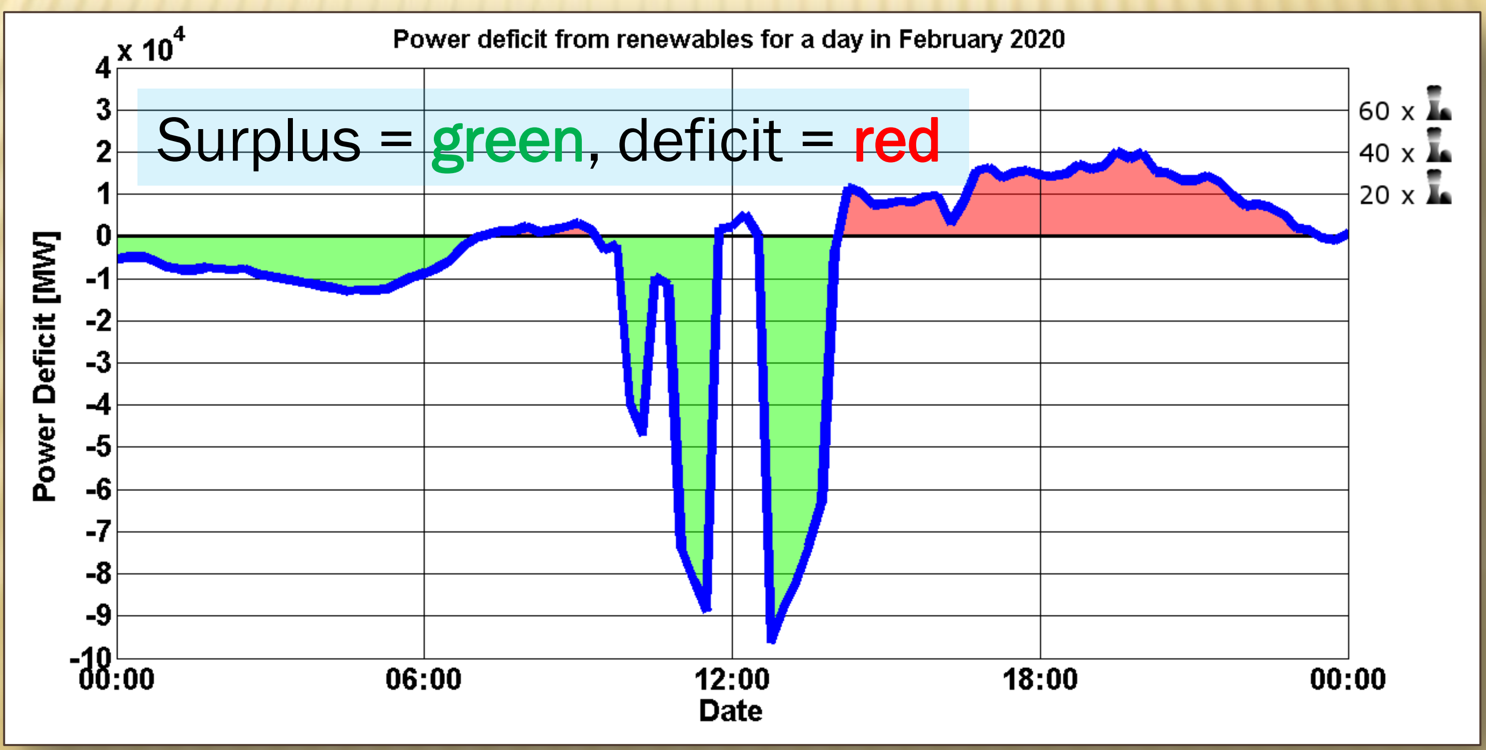
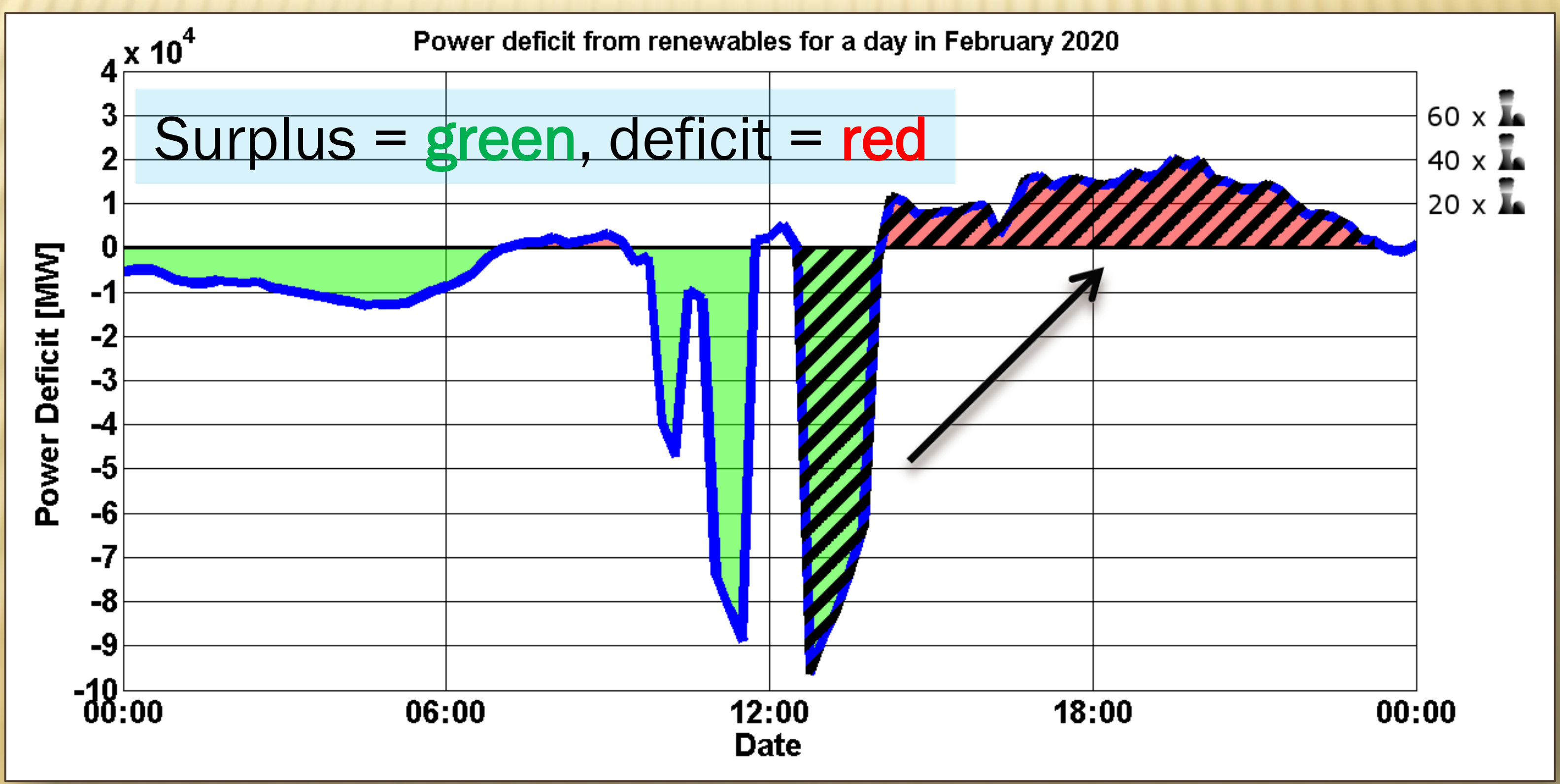
# A RENEWABLE GRID WITHOUT MITIGATION

- How would the 'renewable' grid behave?
- We simulated it based on our wind and solar models
- This showed **long periods of supply deficit** in times of low wind and/or sunlight



# A RENEWABLE GRID WITH MITIGATION

- We want to **move the area under the curve** when there is too much supply to when there is too little



# BUT HOW DOES THIS SAVE ANY ENERGY?

- Well actually, we aren't
- We are **buffering** surplus production to use during times of deficit production
- The benefit of this is that we can **reduce the number of conventional power plants we need** to cope with peak fluctuations
- A typical new 500MW nuclear power plant (like Hunterston B) costs in the region of **£15-20B to build** [1]

[1] http://en.wikipedia.org/wiki/Economics_of_new_nuclear_power_plants#Capital_costs

# WHAT CAN WE USE AS BUFFERS?

- These can be any device with the ability to **store energy**
- For example: pumped storage, flywheels, electric cars, laptops
- We decided to investigate **laptops** as a means of buffering!
- They are very common, are typically used on a daily basis, and have a buffer of the order of a few hours so they are worth exploring

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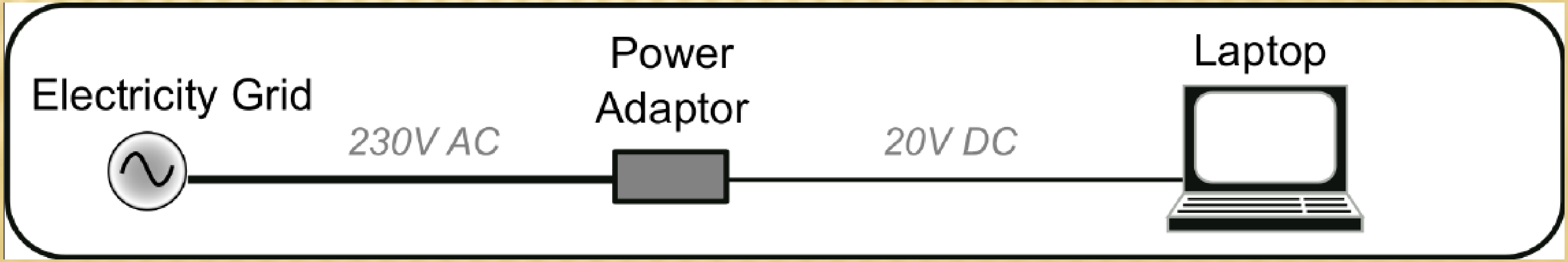


# HOW DO WE KNOW WHEN TO USE BUFFERS?

- In order to effectively mitigate fluctuations, we need to know **when to take power** and **when not to take power** from the grid
- The National Grid provides alternating current at a frequency of around 50Hz
- The actual frequency is determined by the **proportion of demand to supply**

We have a grid health probe in every room!

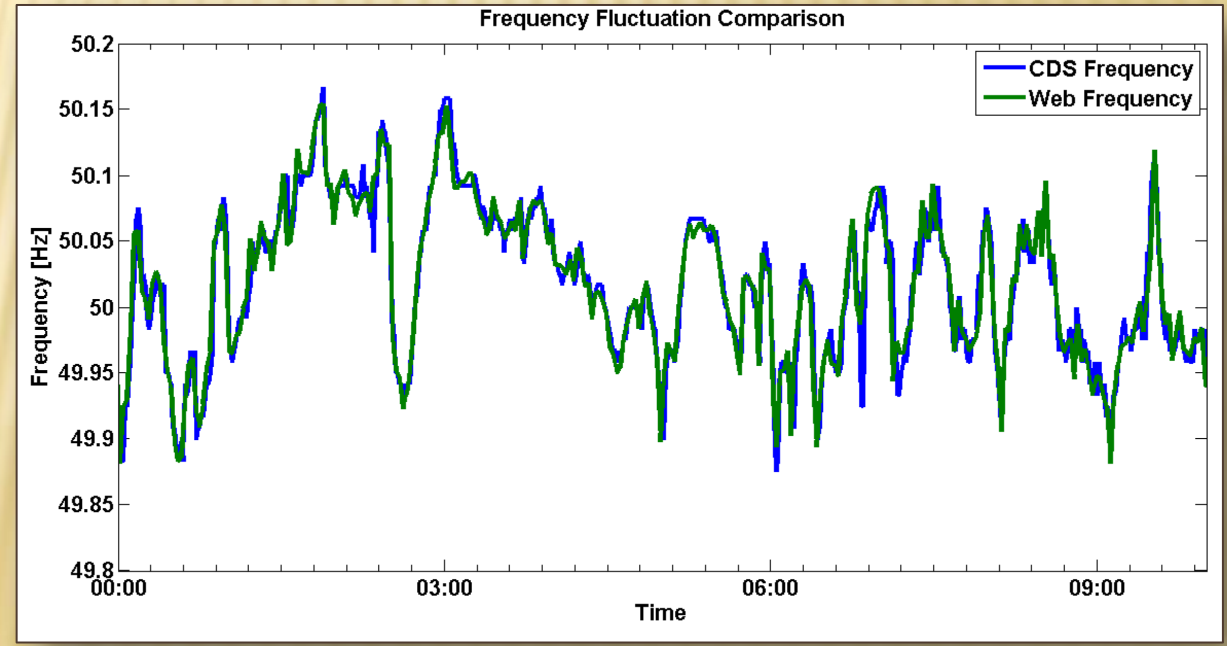
# MEASURING THE GRID FREQUENCY

- We used the Glasgow IGR's **Control and Data System** (CDS), a real time Linux-based control system
- With this we measured the grid frequency
- We also used this for the world's first prototype of a **smart charging laptop**!

# MEASURING THE GRID FREQUENCY

- To demonstrate the CDS, we measured the grid frequency for 24 hours at 1kHz
- We simultaneously logged the frequency reported by the National Grid on their website

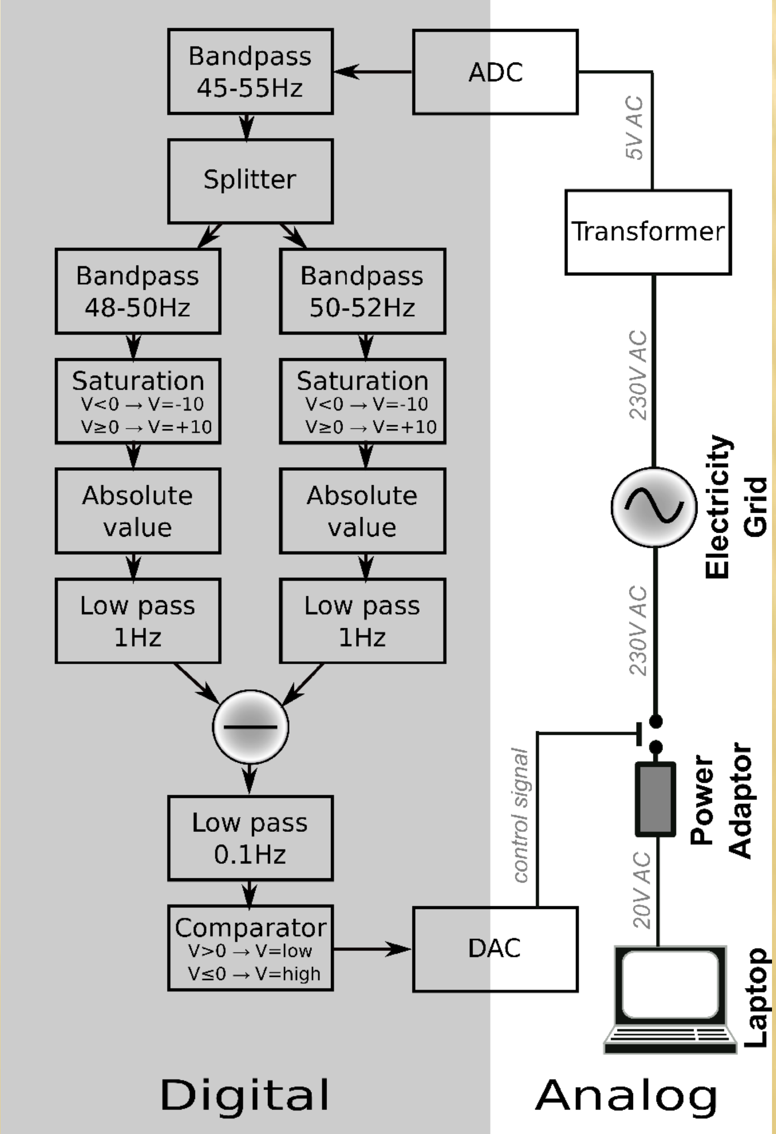
They match up well!



# THE 'LAPTOP AS A BUFFER' CONCEPT

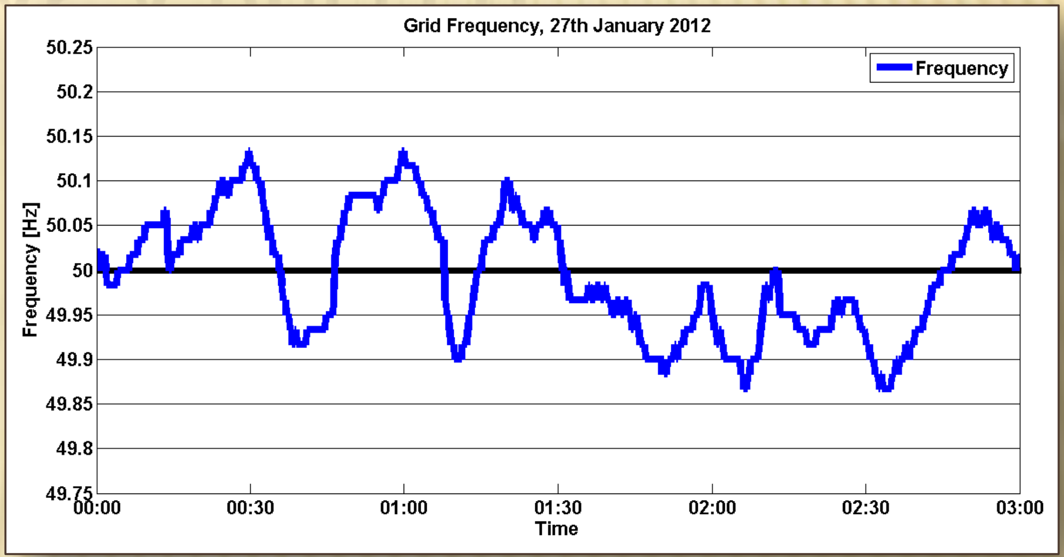
# USING A LAPTOP AS A BUFFER

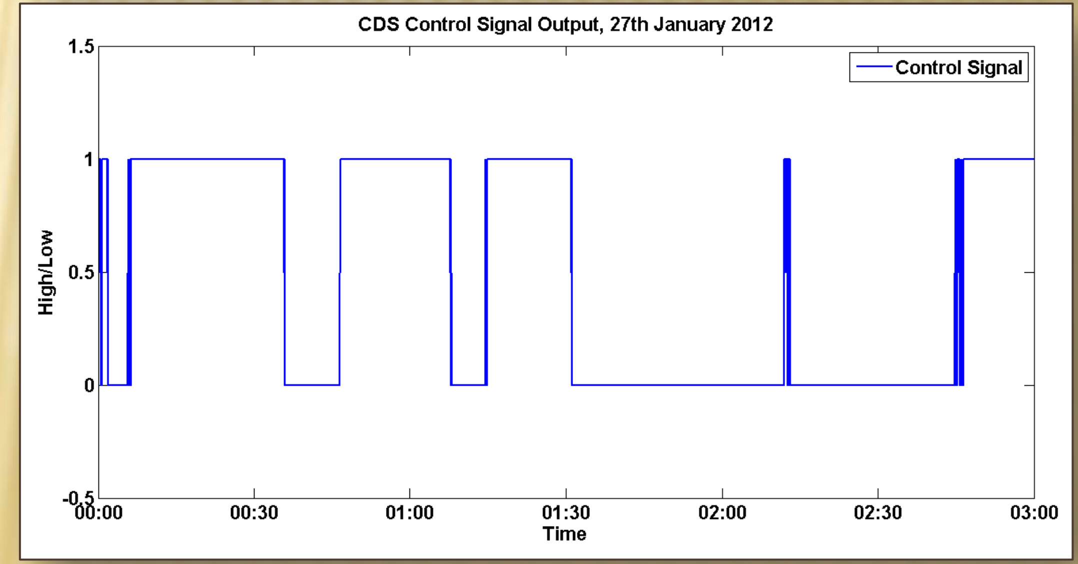
- Inferring frequency using only AC voltage measurements requires computationally expensive Fourier transforms
- The CDS was not designed to perform ‘real time’ FTs
- But we only need to know whether the frequency is ≥50Hz or <50Hz, so we can use a much simpler **differential band pass filter** method
- Only when the **frequency is ≥50Hz** will the relay allow the laptop to charge



# USING A LAPTOP AS A BUFFER

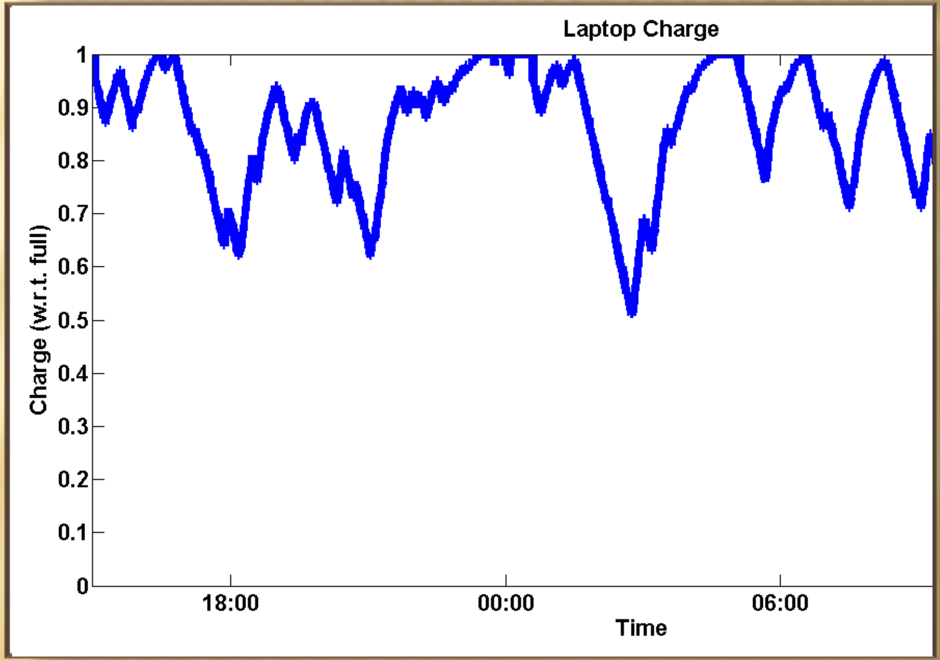
- The band pass method appears to work well!



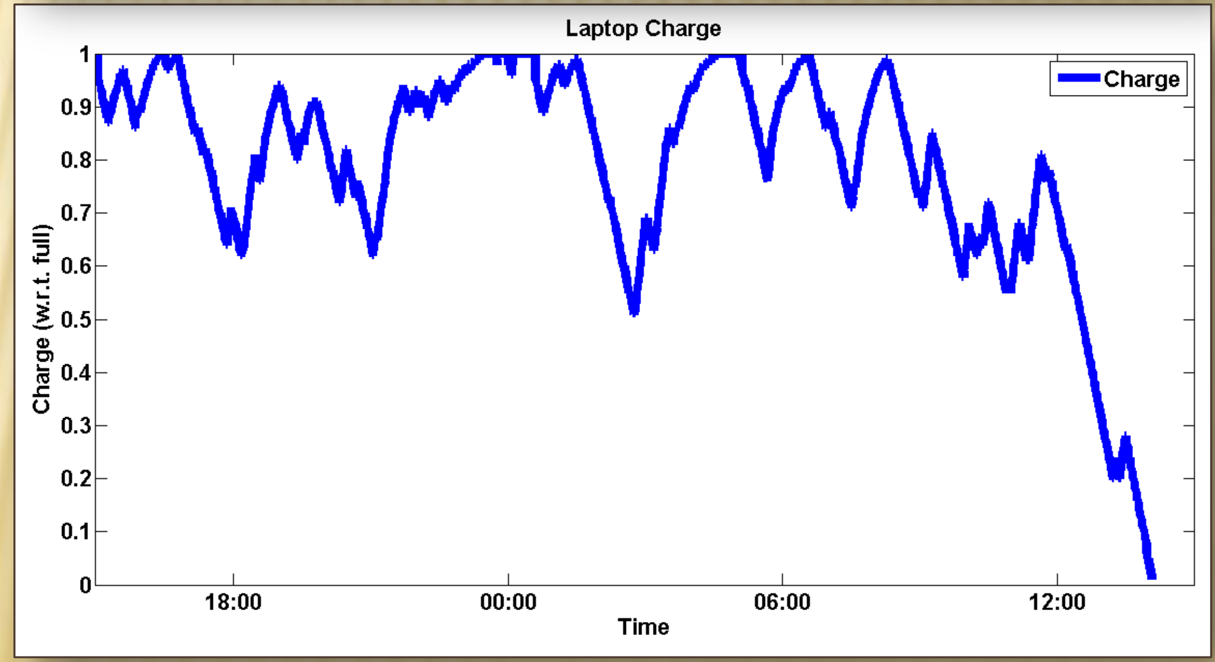
# USING A LAPTOP AS A BUFFER

- We wrote a Linux terminal script to log the laptop's battery charge level and plugged it into the CDS system
- The laptop seems to have worked well…



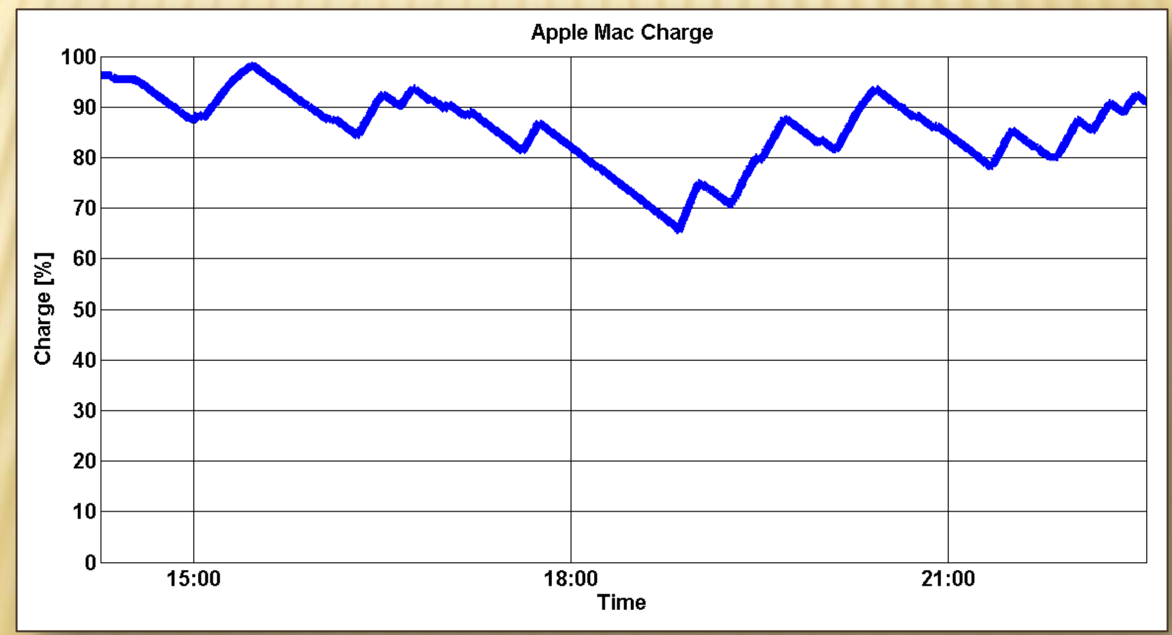
# USING A LAPTOP AS A BUFFER

- ...However, **it only managed to stay on for 23 hours** before switching off. A long period of grid frequency <50Hz caused the battery to drain.



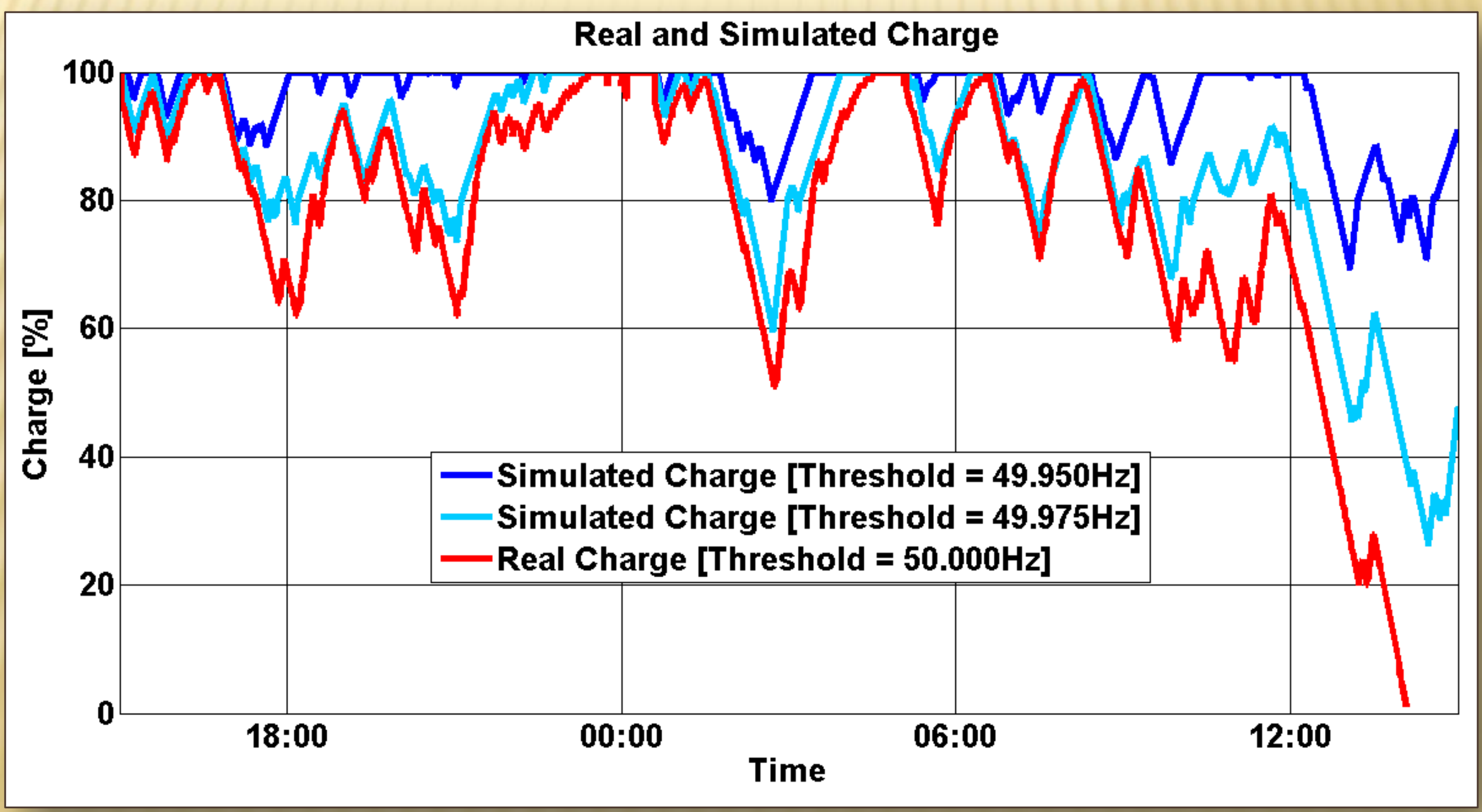
# MAINTAINING LAPTOP CHARGE

- We ran the system on an Apple laptop for 7 hours as well – it managed to **stay on throughout**
- The Mac charged **much more quickly** than it drained
- It also had a **longer battery life** (i.e. larger buffer)
- On other laptops, **lowering the frequency threshold below 50Hz** would achieve a similar effect



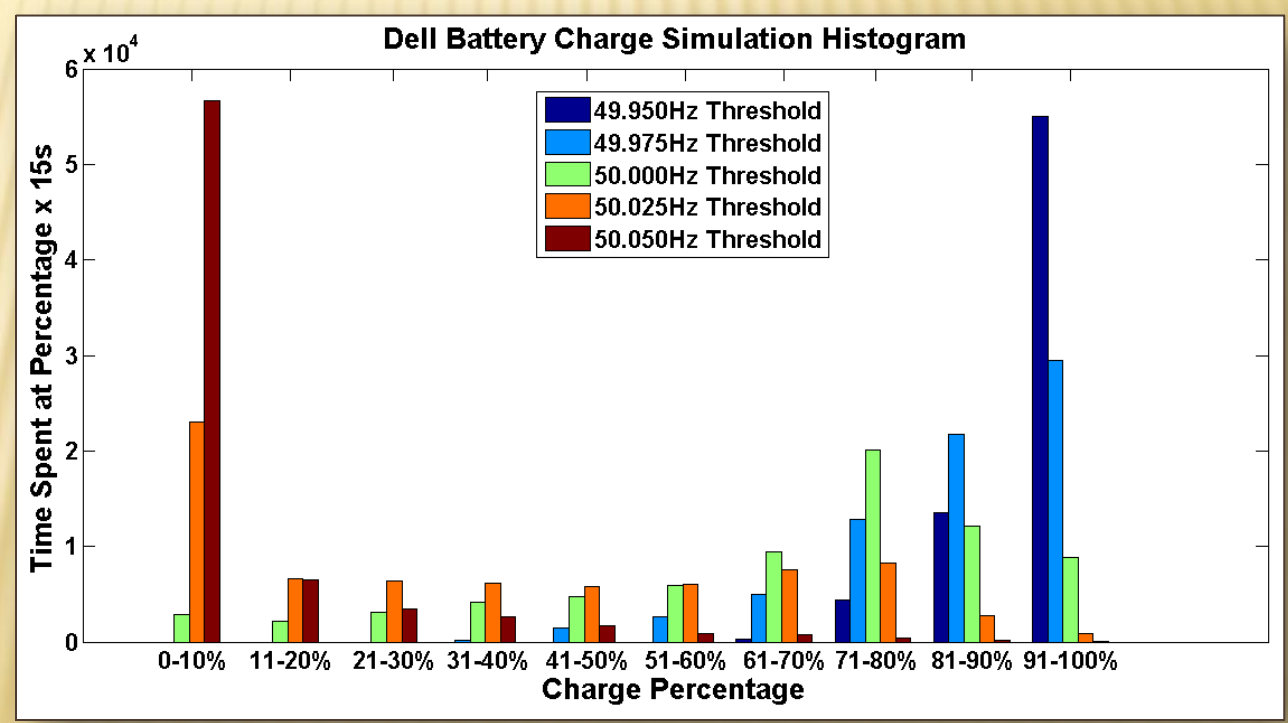
# MAINTAINING LAPTOP CHARGE

- We could run the system with many different frequency thresholds to find the best one, but it is **easier to simulate** the effects



# SIMULATING THE EFFECTS ON A LAPTOP

- I created histograms of simulations of the laptop running on the control system using **5 different frequency thresholds**, using 2 weeks of frequency data
- Frequency thresholds around **49.975Hz** keep the laptop at least 30% charged almost always
- It's a trade off between **keeping the laptop usable** and mitigating **as much fluctuation as practical**



# MINIATURISING THE CONTROLLER

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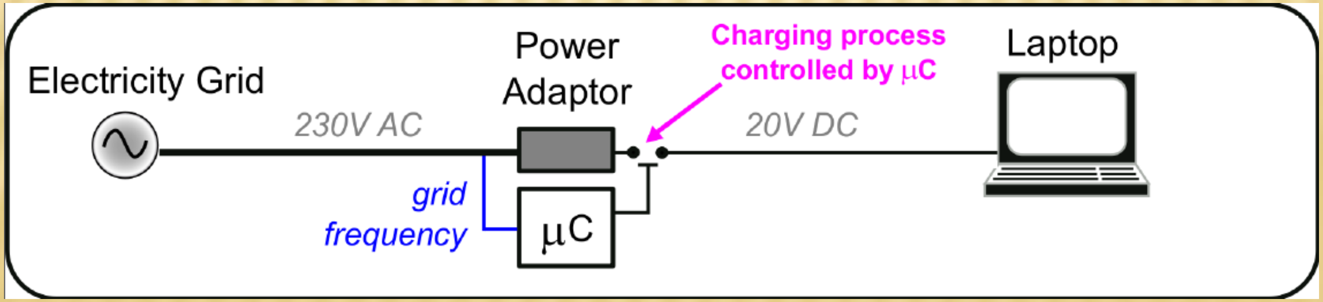
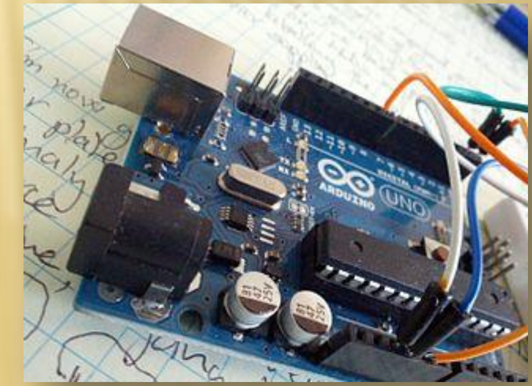
- The CDS isn't going to fit in your pocket!
- Ultimately the logic could be integrated onto the existing circuitry within devices
- To demonstrate the feasibility, we built a miniaturised controller with an Arduino



# MINIATURISING THE CONTROLLER

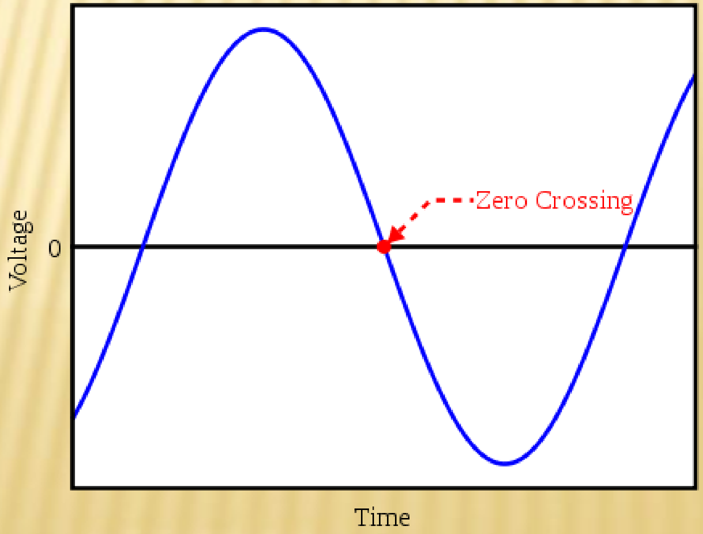
- The method by which we sensed the grid frequency had to be adapted due to the limited processing power of the Arduino
- It also makes sense to choose a less computationally intensive technique
- Remember, we only care about whether the frequency is **above or below 50Hz**
- Still no need for Fourier Transforms

# MINIATURISING THE CONTROLLER

Ideas:

- Counting zero crossings
- Numerical band pass filters
- Many more...

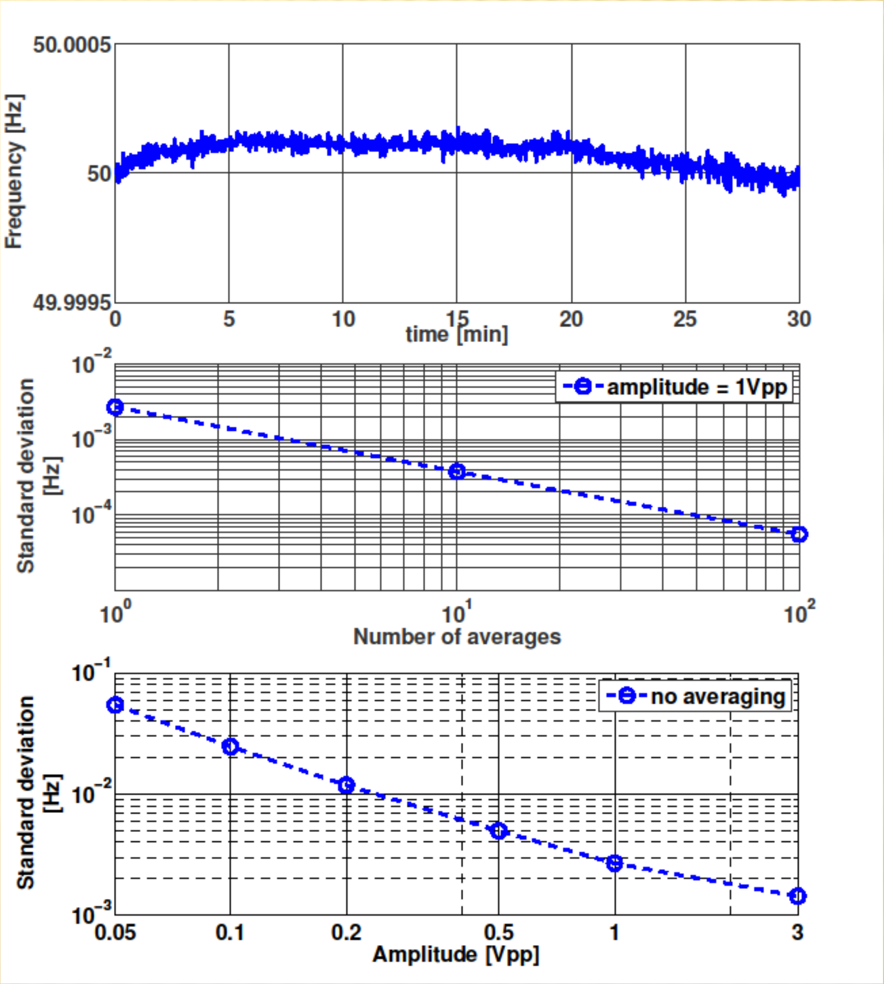
We chose to implement the zero crossing method.



# MINIATURISING THE CONTROLLER

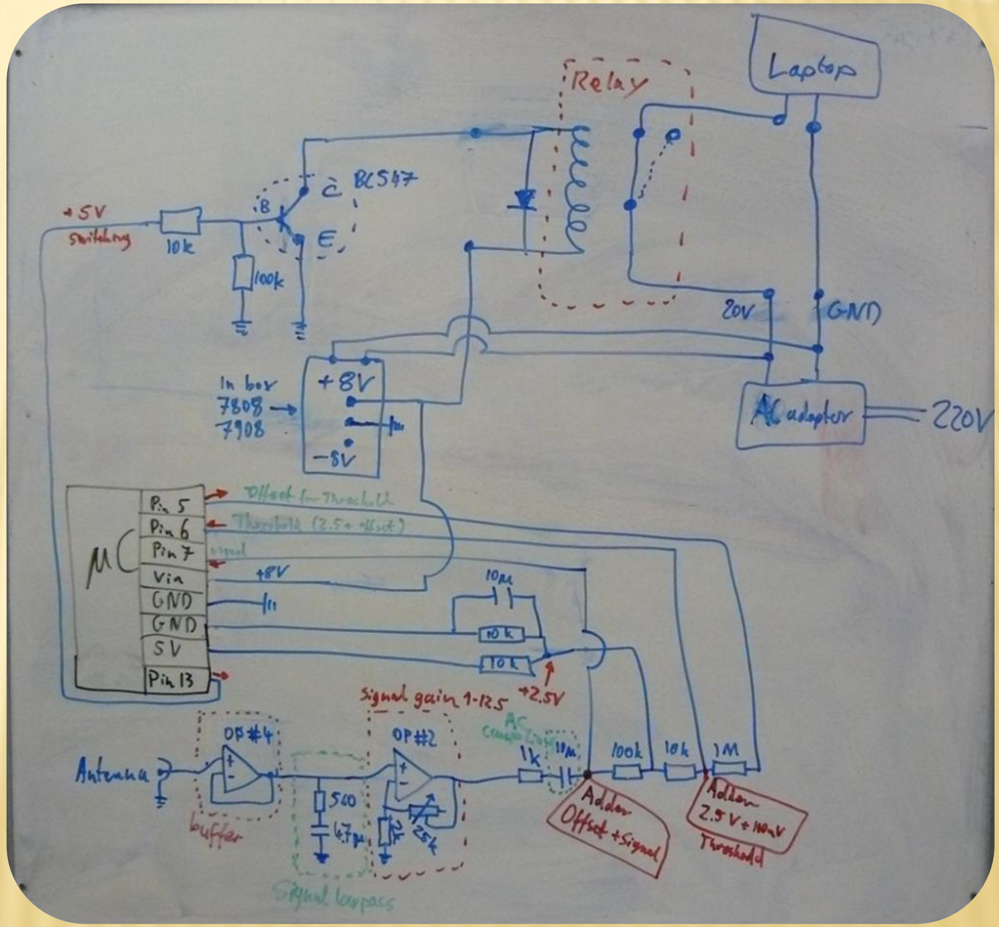
This involves:

- Counting the number of sign changes in a given number of clock cycles,
- Dividing the number of sign changes by the measurement time,
- Then averaging over multiple (e.g. 100) measurements to obtain greater accuracy.
- *1 average gives an accuracy of 2.5mHz*
- *100 averages gives an accuracy of 0.05mHz*



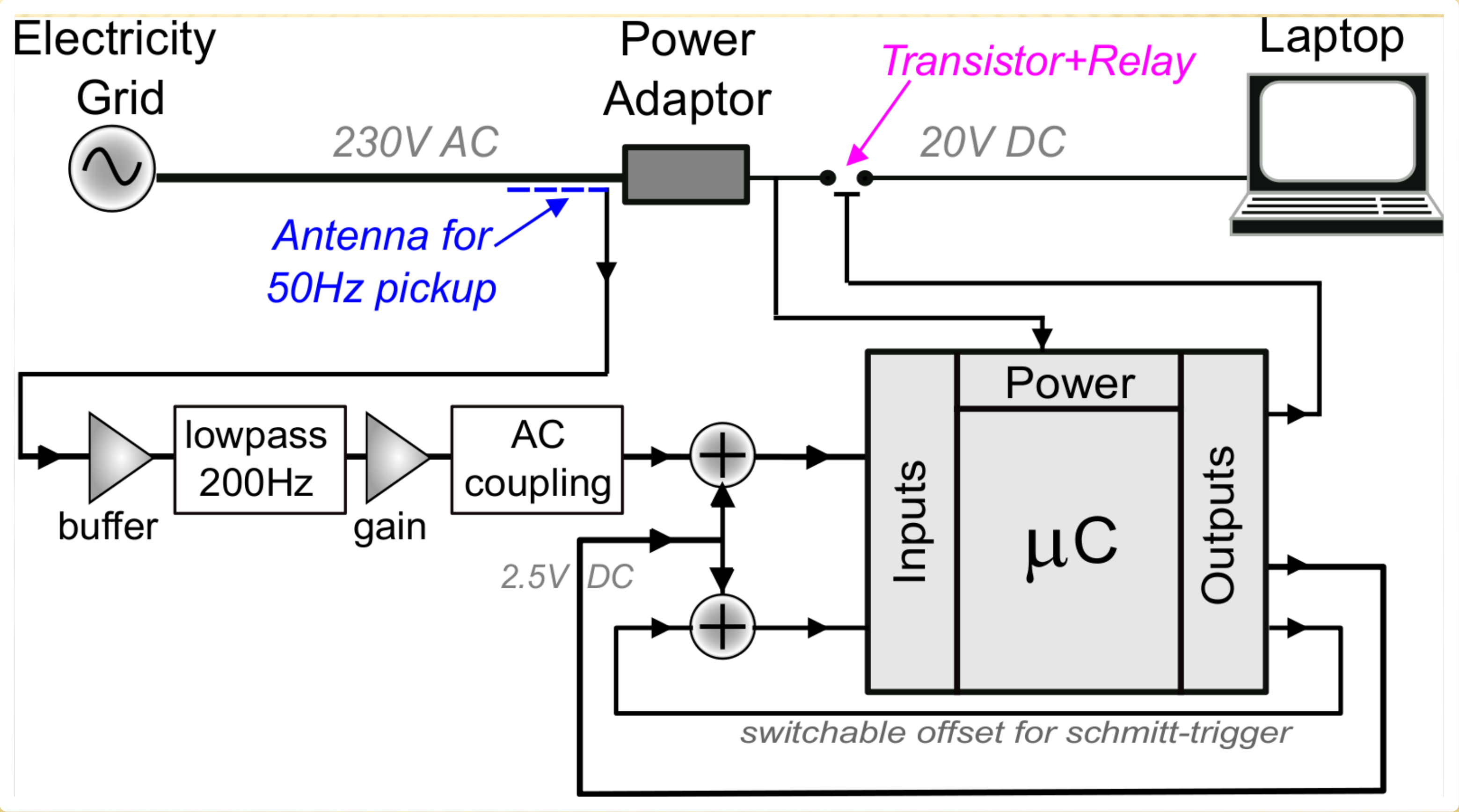
# MINIATURISING THE CONTROLLER

- Our time measurement relied on the 16MHz crystal in the Arduino, which we needed to characterise. It is actually 15.98MHz.
- Different thresholds depending on whether the laptop is charging or not can be used to prevent ‘bouncing’
- Slow transients limit the accuracy to 0.1mHz (ambient temperature?), but this is far better than we need



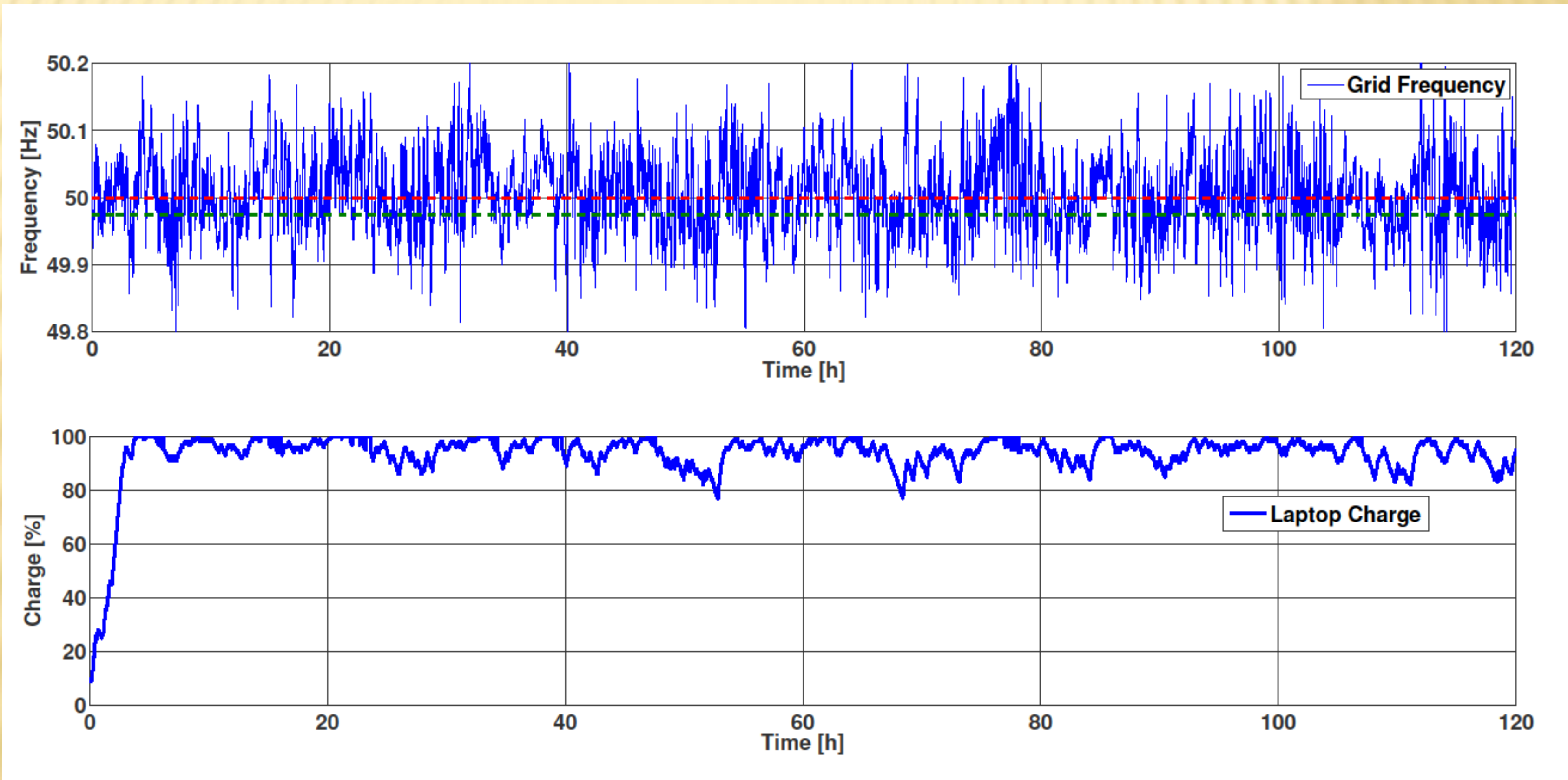
# MINIATURISING THE CONTROLLER

- Crucially, the whole system is powered from the laptop's own charger! A true demonstration of portability!



# MINIATURISING THE CONTROLLER

Six days of continuous measurement:



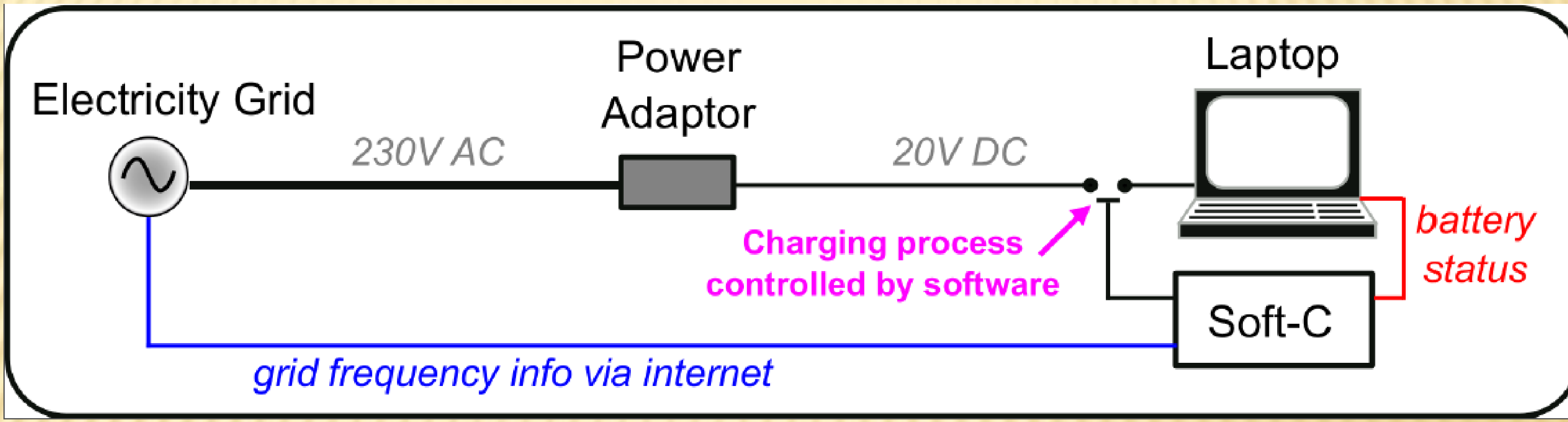

It works!

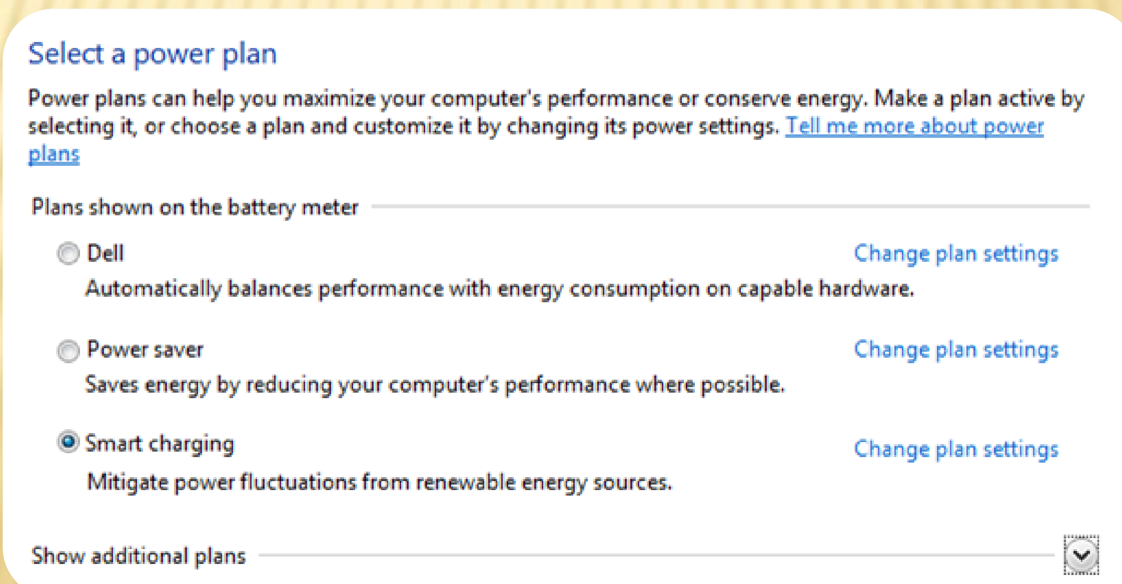
# ADVANCED CONCEPTS

# ADVANCED CONCEPTS

- Algorithms can be improved over the simple on/off switch
- User could specify that they want at least 80% charge in the battery as of 8am each day, regardless of the state of the grid
- The user could specify that they only wish to mitigate in extreme circumstances, in which case the algorithm would scale its response based on the size of fluctuation
- Predictive mitigation – machine learning?

# ADVANCED CONCEPTS



# For further information…

If you want to find out more, please read our paper, available on arXiv!

Cornell University Library



Computer Science > Other Computer Science

## Smart Charging Technologies for Portable Electronic Devices

Stefan Hild, Sean Leavey, Christian Gräf, Borja Sorazu

*(Submitted on 25 Sep 2012)*

In this article we describe our efforts of extending demand-side control concepts to the application in portable electronic devices, such as laptop computers, mobile phones and tablet computers. As these devices feature built-in energy storage (in the form of batteries) and the ability to run complex control routines, they are ideal for the implementation of smart charging concepts. We developed a prototype of a smart laptop charger that controls the charging process depending on the locally measured frequency of the electricity grid. If this technique is incorporated into millions of devices in UK households, this will contribute significantly to the stability of the electricity grid, help to mitigate the power production fluctuations from renewable energy sources and avoid the high cost of building and maintaining conventional power plants as standby reserve.

Subjects: **Other Computer Science (cs.OH)**
Cite as: arXiv:1209.5931 **[cs.OH]**
(or **arXiv:1209.5931v1** **[cs.OH]** for this version)

http://arxiv.org/abs/1209.5931

# WHAT IS THE LARGE SCALE EFFECT?

# WHAT IS ITS LARGE SCALE EFFECT?

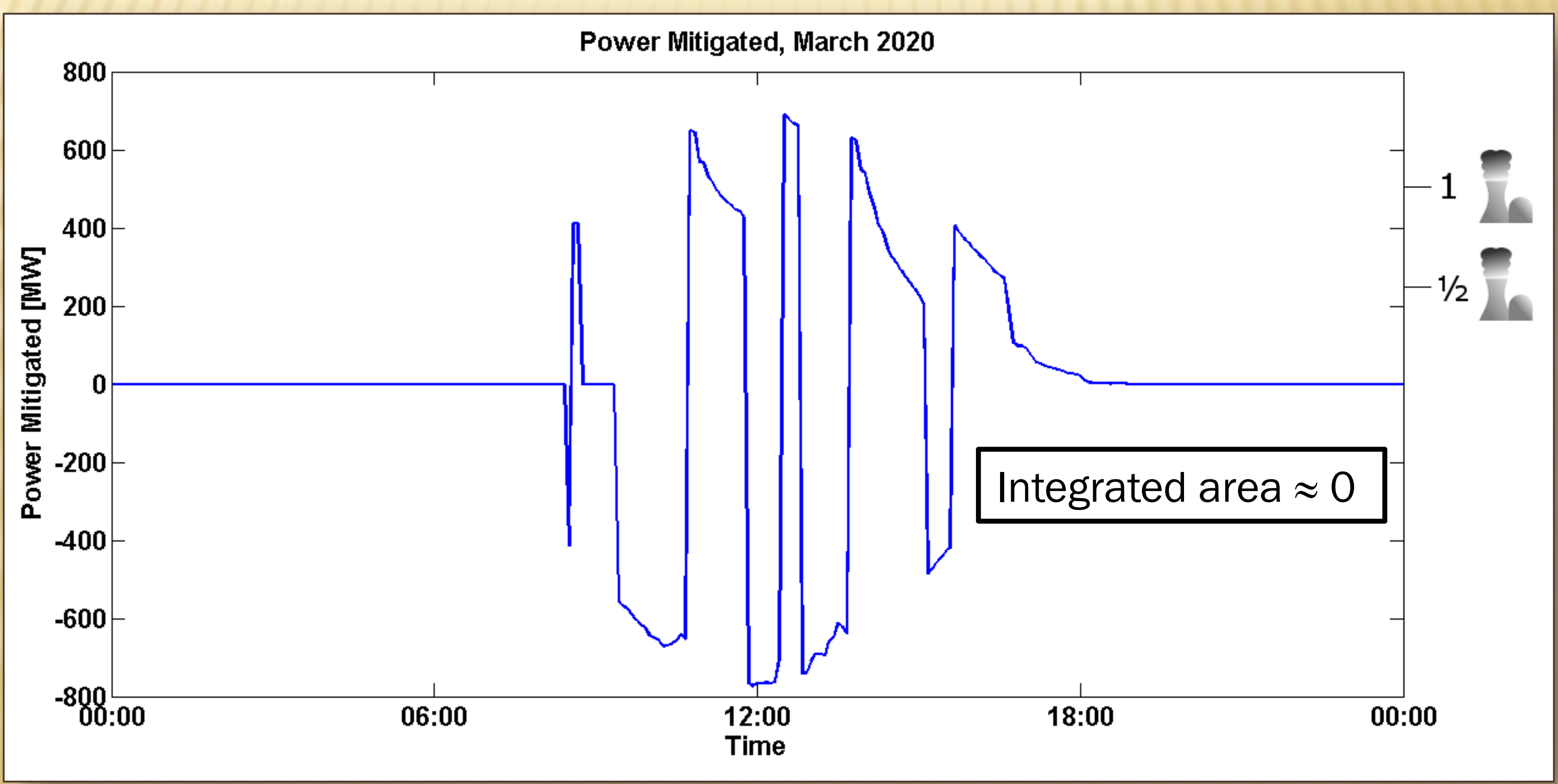
- Simulated effect of **20 million laptops** using the system
- Different laptops have different **daily usage patterns, charge capacities and charge rates**
- Each entity in the simulation **represents 20000 laptops**, for the sake of performance: matrix entities number 105 million as opposed to 2 trillion!

# LARGE SCALE LAPTOP EFFECT ASSUMPTIONS

- Some assumptions: most usage occurs between **8am and 4pm**
- On average, laptops charge from 0% to 100% in **slightly over 1 hour**
- Laptop charge level is flatly distributed between **0% and 100%**
- Laptops are typically in use between **3 and 9 hours** a day
- Calibrated **Gaussian distributions** using these assumptions

# LARGE SCALE EFFECT ON THE GRID

- Let's see how power mitigation would look in March in 2020
- It would cover about 1.5 x a large nuclear power plant's output



# THE BIG PICTURE

- Ultimately, laptops with dynamic demand management are **not going to entirely solve** the problems the 2020 grid might face
- However, they form part of the big picture
- The solution will involve a combination of many forms of ‘dynamic demand management’ (such as fridges, vehicles, etc.) as well as supply-side methods
- The **principles** developed during the project can be applied to **any kind** of dynamic demand system, not just laptops

# CONCLUSIONS

- Characterisation of grid frequency behaviour
- First prototype of laptop system
- Full time domain simulation of an ‘all renewable’ grid in 2020
- Miniaturised version of smart laptop charger
- Future: ‘matchbox’ SMT version of smart charger
- Advanced charging algorithms
- Extension of concept to other devices such as mobile phones, electric vehicles, etc.

Thanks for listening!