REDBACK TECHNOLOGIES

Aspects of data science at Redback Technologies

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Who we are

Incorporated in April, 2015 with 2 Employees. Today Redback employs 47 people, with 38 employees based in Australia. Redback is located on the University of Queensland's Long Pocket Campus. University of Queensland is an investor behind the company and has developed an IP collaboration and commercialization agreement that sees Redback leveraging UQ technology across the fields of Electrical Engineering, Information Technology, Economics, Business and Policy.

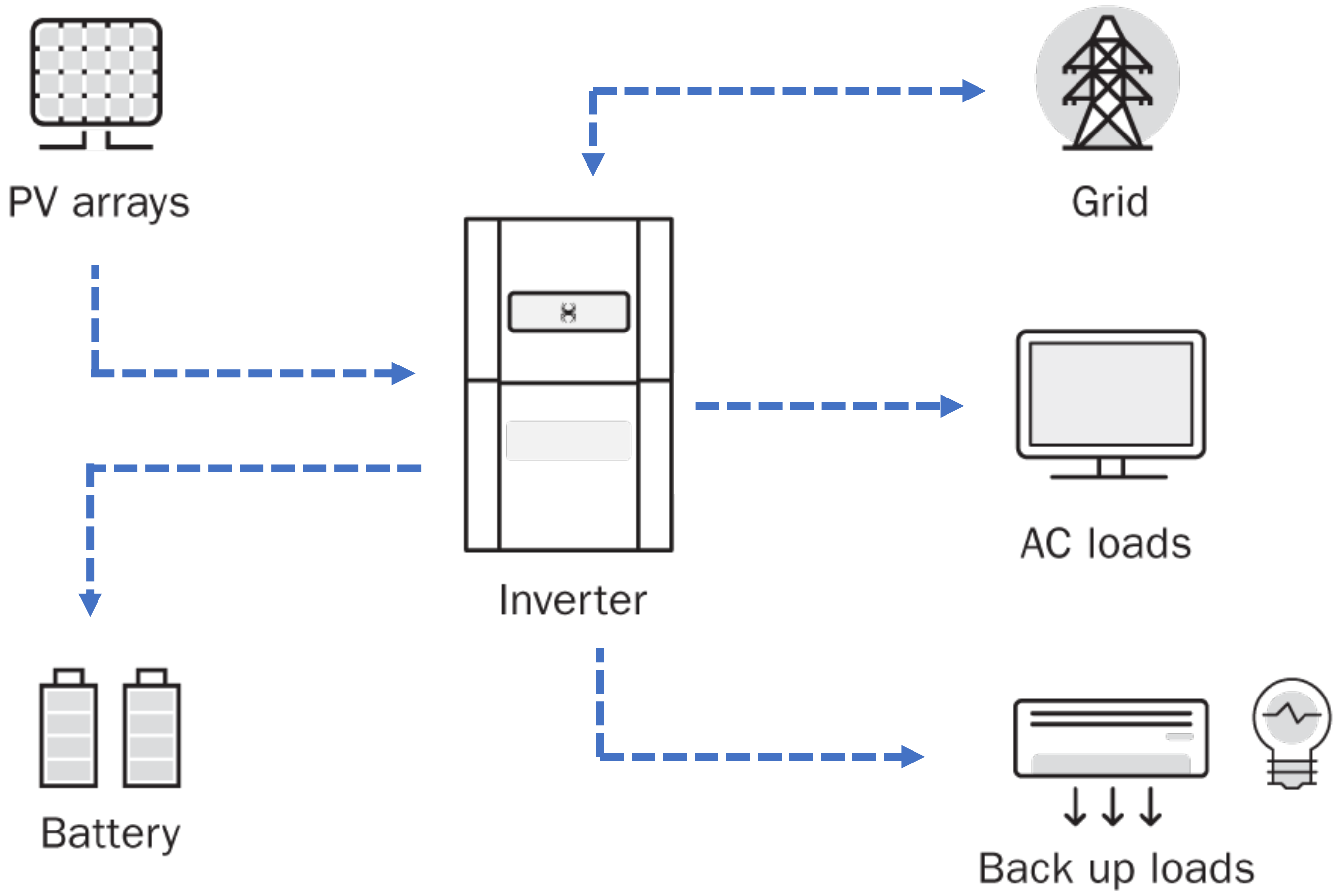
Redback Technologies

- Australian manufacturer of smart solar inverters
- Inverters to store, monitor and manage a home's solar energy
- Based in Brisbane, Australia and Suzhou, China
- Customers can choose battery type (e.g. lithium ion, zinc bromide, lead acid)
- Customers choose inverter panel size and type
- Agnostic to battery type
- Ability to schedule relays (IoT)
- Redback Technologies Research Centre at the University of Queensland, incorporated in August 2018; collaborators welcomed

Redback Technologies

- About 1,300 active sites across Australia and NZ
- Load and solar data is sent to cloud storage over wi-fi whenever possible
- Different measurements on the inverter for accuracy and calibration – instantaneous values at one minute intervals and internal counter updated at five second intervals
- Data can be available at resolution of approximately one minute

Diagram



Schematic of inverter with associated electrical loads, battery and grid connections

Battery scheduling

- The “automatic” approach for instantaneous energy management used in the Redback inverter
- First, load is met (in order) by:
  - Solar energy
  - Battery energy
  - Grid energy
- After this procedure is applied, any left over energy is sent (in order) to:
  - Battery
  - Grid

Limitations of “automatic” approach

- The approach does not know about:
  - Time of use tariffs at the household
  - Location of inverters – sunrise, sunset times
  - Location of inverters – weather forecast (radiation, clouds etc)
  - Past load and PV data
- The alternative to “automatic” with Redback inverters is:
  - Inverter can be commanded to maintain a charge or discharge rate, or set back to “automatic” at any time (depending on connectivity)
  - These commands can be ignored if they would violate battery State of Charge boundaries

Improve approach

- Objective for Redback is to save customers money over the automatic approach while never losing money (over long-term)
- Forecast errors may lose money at a particular inverter in the short term
- These errors are much more costly in peak
- Ideally we would have a command based on a perfect load and PV forecast at a fine resolution (e.g. 10 to 15 minute resolution)
- Load and PV forecast can be useful 24-48 hours into the future

Forecasting solar and load

- At Redback, the properties of each inverter (e.g. size, orientation, shading effects) are in general not known and must be derived from observations
- Cloud detection and prediction e.g. using cameras not viable
- Numerical weather prediction (NWP) approaches
- NWP providers
  - Bureau of Meteorology (BOM) in Australia
  - National Weather Service (GFS) from United States
  - European Centre for Medium-range Weather Forecasts (ECMWF)
- Assimilation/analysis step

Spatio-temporal resolution of NWP forecasts

- Gridded global forecast
- BOM ACCESS-C
  - 1 to 36 hours (hourly) at 0.015 degree resolution, 6 hourly updates
- ECMWF
  - 1 to 240 hours (3 hourly) at 0.1 degree resolution, 6 hourly updates
  - Free for academic use
- GFS
  - 1 to 384 hours (hourly to 120) at 0.25 degree resolution, 6 hourly updates
  - Perl script for geographic subregions and variable selection
  - Free access

Prediction of solar and load

- Model built for hourly forecast of load and solar at each inverter location
- Using GFS data and solar forecasts where available (updates at 00, 06, 12, 18 UTC)
- Solar approach based on variables from GEFcom2014 (Global Energy Forecasting Competition 2014, solar track)
- For example, temperature, humidity, time of day, Julian date for load, plus solar radiation, cloud cover, precipitation, wind speed vectors, and pressure for solar
- Load – weekend/holiday variables may assist
- Quantile random forest or moving average (load)
- Distance weighting to account for points not in centre of grid squares

Accuracy of predictions

- NMAE (Normalized Mean Absolute Error) rate for hour ahead predictions for load is 40% and for PV is 26% (50^{th} percentile of inverters)
- 25^{th} percentile is 23% for PV and 31% for Load
- Error rate for PV improves with larger PV system size

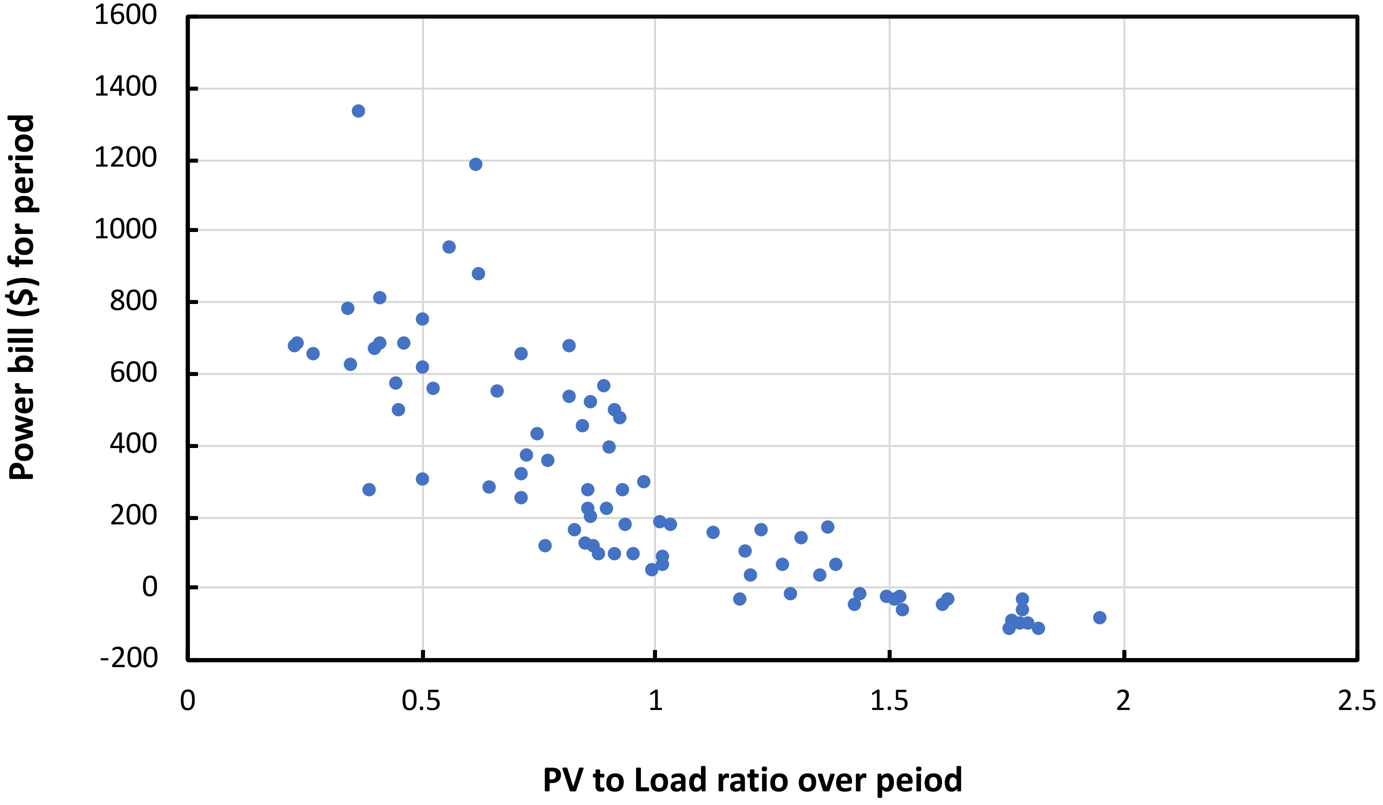
Linear programming approach

- Objective function: minimize cost of energy purchased from grid (minus cost of solar exported to grid) over given time period (e.g. 24 hours ahead)
- Variables
  - Load and solar predictions for given time period (hourly)
    - We also consider using quantile forecasts to bias the input e.g. instead of 50th percentile load and solar – 60th percentile Load and 40th percentile PV – avoid unnecessary grid import
  - Time of use tariffs and feed in tariffs for each period
  - Efficiency value for battery and inverters (or assume constant)

Linear programming approach

- Constraints
  - Kirchoff’s law – Load – PV = Battery Flow + Grid Flow
  - State of charge limits of battery (minimum and maximum)
  - Charge and discharge rate limits of battery and inverter
  - Penalty values to preserve state of health of battery
- Output
  - Battery flow variable for each period

Results



Bill with perfect forecast versus PV/Load ratio of data (tariff 1)

Tariff descriptions

Tariff	Description	Off-Peak Price (c/kWh)	Shoulder Price (c/kWh)	Peak Price (c/kWh)
1	Usage - Peak usage per day - Between 7am & 11pm, Monday to Friday AEST, Usage - Off-Peak usage per day (if applicable) - All other times	20.3	-	37.8
2	Usage - Peak usage per day - Between 7am & 11pm, Monday to Friday AEST, Usage - Off-Peak usage per day (if applicable) - All other times	16.6	-	31.2
3	Usage - Peak usage per day - Between 7am & 11pm, Monday to Friday AEST, Usage - Off-Peak usage per day (if applicable) - All other times	17.1	-	35.7
4	Usage - Peak usage per day - Between 7am & 11pm, Monday to Friday AEST, Usage - Off-Peak usage per day (if applicable) - All other times	18.2	-	36.0
5	Usage - Peak usage per day - Between 7am & 11pm, Monday to Friday AEST, Usage - Off-Peak usage per day (if applicable) - All other times	15.1	-	34.9
6	Peak Between 2pm and 8pm, Monday to Friday (excluding public holidays), Off-peak Between 10pm and 7am, Monday to Sunday, Shoulder Between 7am to 2pm and 8pm to 10pm Monday to Friday, 7am and 10pm Saturday/Sunday and Public Holidays	15.2	25.0	54.9
7	Peak 1pm to 8pm, Mon-Fri (excluding public holidays), Off Peak All other times, Shoulder 7am to 1pm and 8pm to 10pm, Mon-Fri	17.8	32.3	42.1
8	Peak 7am to 9am and 5pm to 8pm, Mon-Fri, Off-peak All other times, Shoulder 9am to 5pm and 8pm to 10pm, Mon-Fri	18.6	33.8	36.1
9	Max 7am to 9am & 5pm to 8pm, Mon-Sun, Economy All other times, Mid 9am to 5pm & 8pm to 10pm, Mon-Sun	14.4	19.0	27.5
10	Peak Between 4pm and 8pm, Monday to Friday (excluding public holidays), Off-peak Between 10pm and 7am, Shoulder Between 7am and 4pm & Between 8pm and 10pm Monday to Friday - Between 7am and 10pm Weekends	20.3	25.6	36.0

Outcomes by tariff over 83 inverters (c/kWh)

Tariff	No solar	No battery	Automatic	PV persist	PV & Load persisted	50-50	Load persisted	60-40	Persist last hour	Perfect forecast
1	34.48	14.93	10.83	10.22	10.21	10.11	10.11	10.08	9.90	9.73
2	29.19	11.78	8.69	8.20	8.19	8.11	8.11	8.09	7.94	7.83
3	31.41	13.01	9.49	8.83	8.81	8.73	8.72	8.68	8.51	8.39
4	32.02	13.44	9.80	9.21	9.19	9.10	9.10	9.07	8.90	8.76
5	30.65	12.44	9.04	8.25	8.21	8.15	8.12	8.07	7.88	7.79
6	29.03	10.96	7.41	6.84	6.78	6.77	6.72	6.66	6.52	5.69
7	27.85	10.09	7.34	6.77	6.73	6.70	6.67	6.62	6.48	6.21
8	26.97	9.70	7.30	6.75	6.72	6.67	6.65	6.62	6.48	6.34
9	20.00	5.99	4.75	4.36	4.34	4.34	4.32	4.31	4.25	3.75
10	25.84	10.39	7.61	7.59	7.62	7.53	7.58	7.58	7.51	7.10
average	28.74	11.27	8.23	7.70	7.68	7.62	7.61	7.58	7.44	7.16

Number of inverters for which different approaches save money

Tariff	PV persist	PV & Load persisted	50-50	Load persisted	60-40	Persist last hour
1	68	66	78	76	76	78
2	69	68	79	77	78	79
3	73	72	80	77	80	80
4	70	69	79	77	79	80
5	77	76	81	81	81	80
6	79	79	82	81	82	82
7	76	75	80	79	80	80
8	74	74	80	79	80	79
9	83	83	83	83	83	83
10	36	28	51	37	36	53
Total	705	690	773	747	755	774

Outcome

- Generally with a time-of-use tariff where the peak price is very high relative to the off-peak, it is optimal to attempt to fully charge the battery before the peak begins, with a combination of grid and solar depending on how much solar is forecast
- Choose hours based on time of day (before shoulder or peak start) and PV to load relativity
- Use default approach in peak hours

Caveats

- Where the PV to Load ratio is very high it is not possible to significantly beat the theoretically “perfect forecast” optimal schedule as the “default” approach is very similar
- Where the average PV or Load value is too low, the measurement error and variability in the values becomes too high to produce an optimal schedule – another approach (e.g. OFFON) may be appropriate
- Reliable connection needed – need a way to escape from schedule if connection drops
- “Trigger” needed to escape from schedule if a load spike or solar power drop occurs

Conclusions

- The approach is successful, depending on some factors
- Using hourly simulation, the optimisation saves 1-10% over the default approach (with an aggressive tariff), compared to 7-23% if a perfect PV and load forecast was available
- Feed-in tariff rate and peak+shoulder to off-peak price ratio affects savings

Conclusions

- Careful attention needs to be given to
  - Selection of which inverters are appropriate for approach
    - Absolute values of PV and Load mean values
    - PV to Load ratio
  - Time zone boundary of tariffs versus forecast period
  - Actual predictions need to be used, not just “best available”
  - Optimisation technique used to choose hours
  - “Trigger” approach
  - Actual “time of use” tariffs in effect
  - How reliable the customer’s connection is and whether inverter data is credible

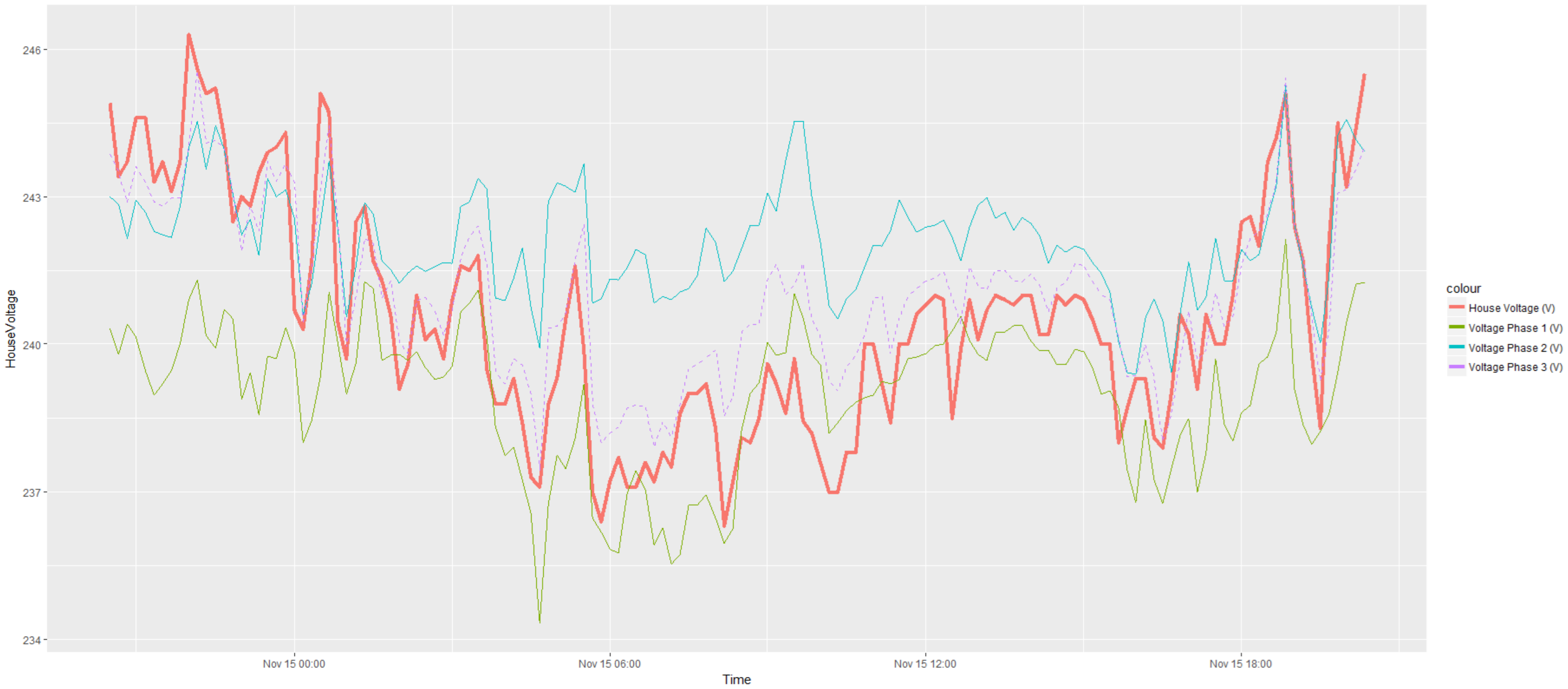
Future work

- Integrate other forecasting approaches – ensembles do better
- Improve forecast accuracy of solar and load
- Use approach to recommend battery and panel size to new customers
- Improve data quality and cleaning
- Use “trigger” mechanism
- State of health considerations should be evaluated and taken into account
- Battery efficiency can be estimated more effectively – dynamic programming
- Avoiding back flow to grid may be a concern in future

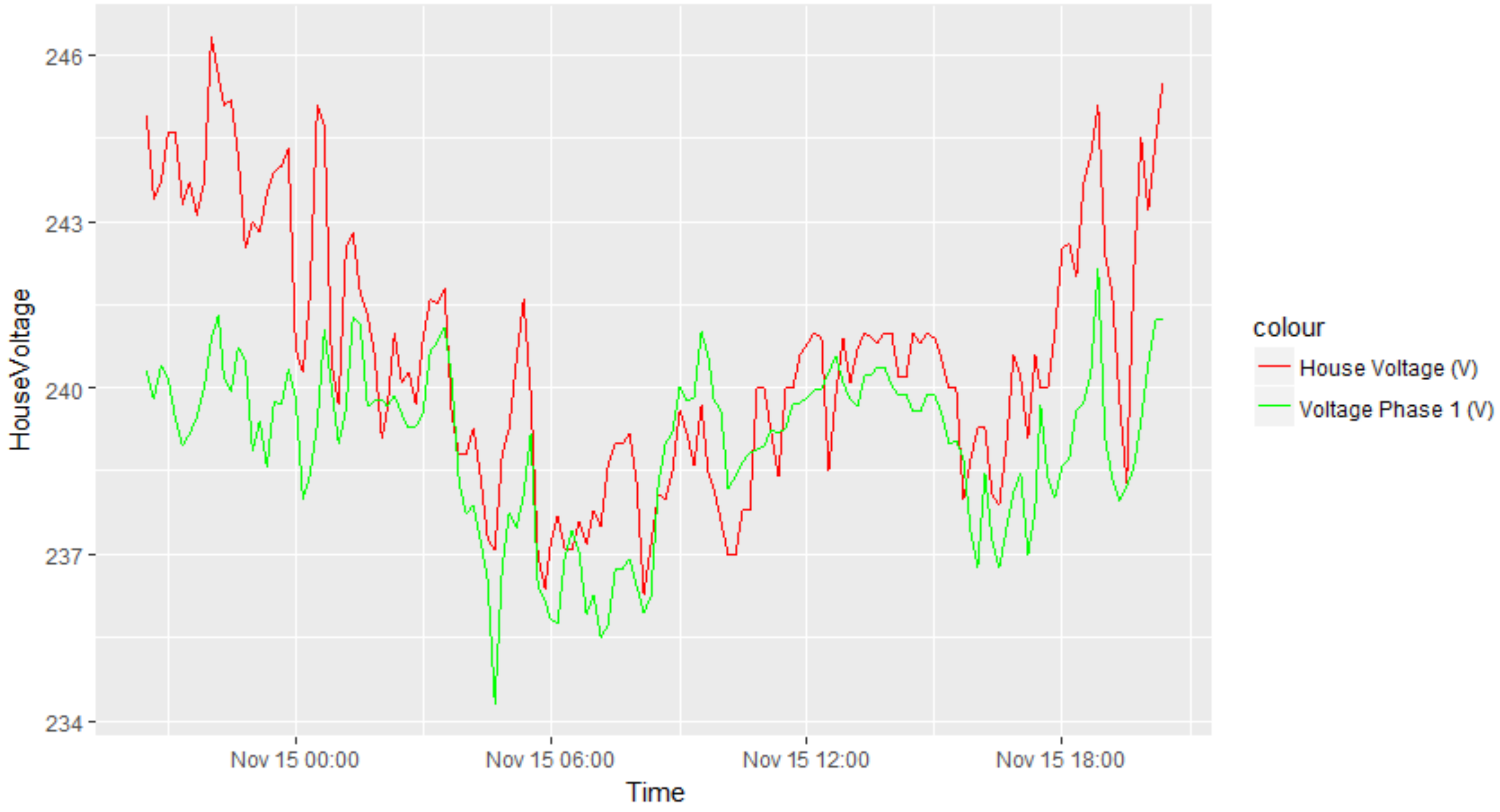
Data science in Redback Technologies Research Centre

- Detecting residential neutral faults
  - Setting up an example home network in the Renewable Energy Laboratory at UQ St Lucia
- Load and PV forecasting at the distribution transformer level
- Phase identification using time-series voltage or current data
  - Cluster analysis of houses into three phases
  - Can be supervised (with knowledge of DT voltage/current) or unsupervised
  - Various approaches – Pearson correlation between time-series voltage/current data or sum of energy concept

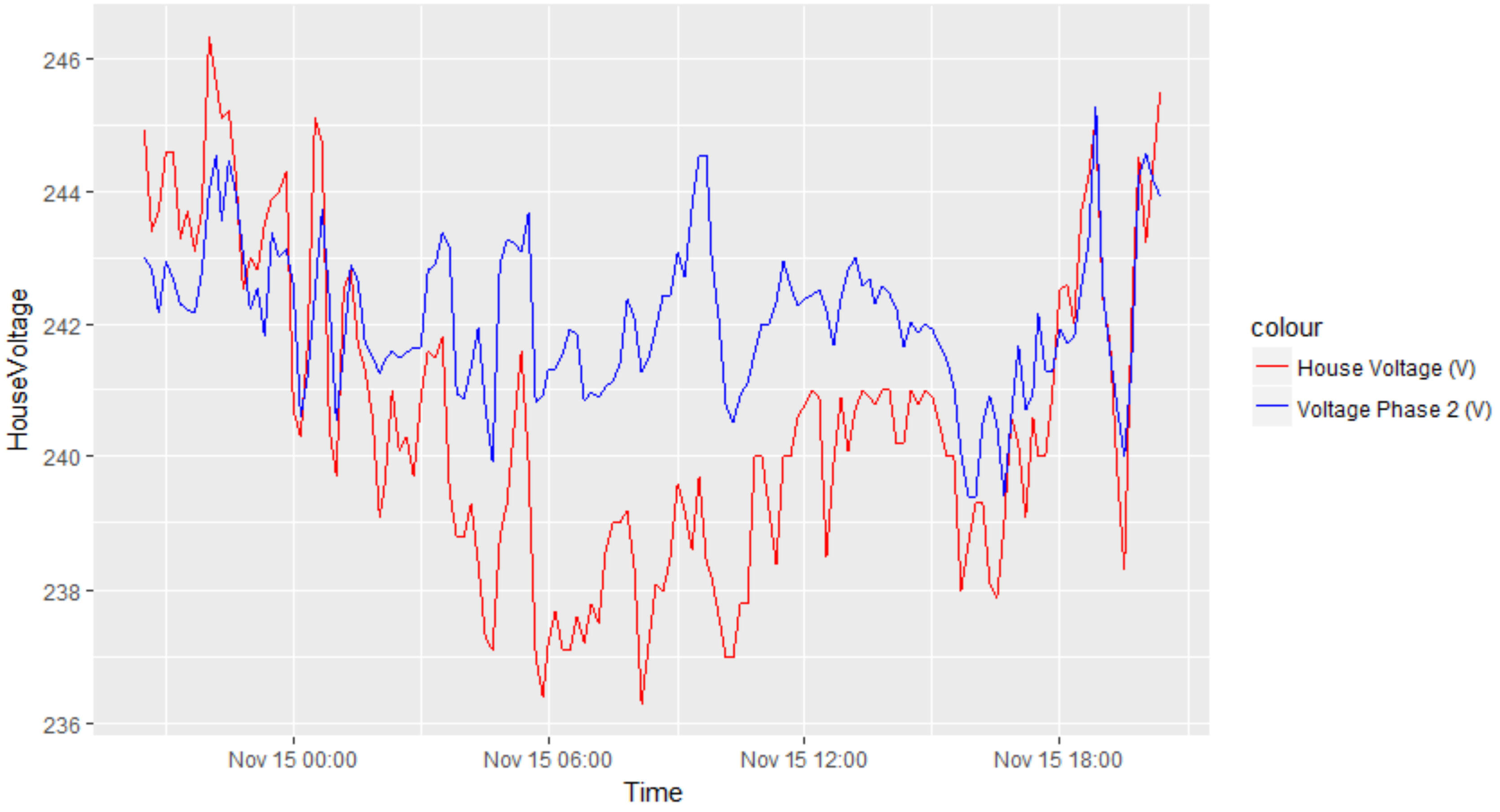
Phase identification – with DT data



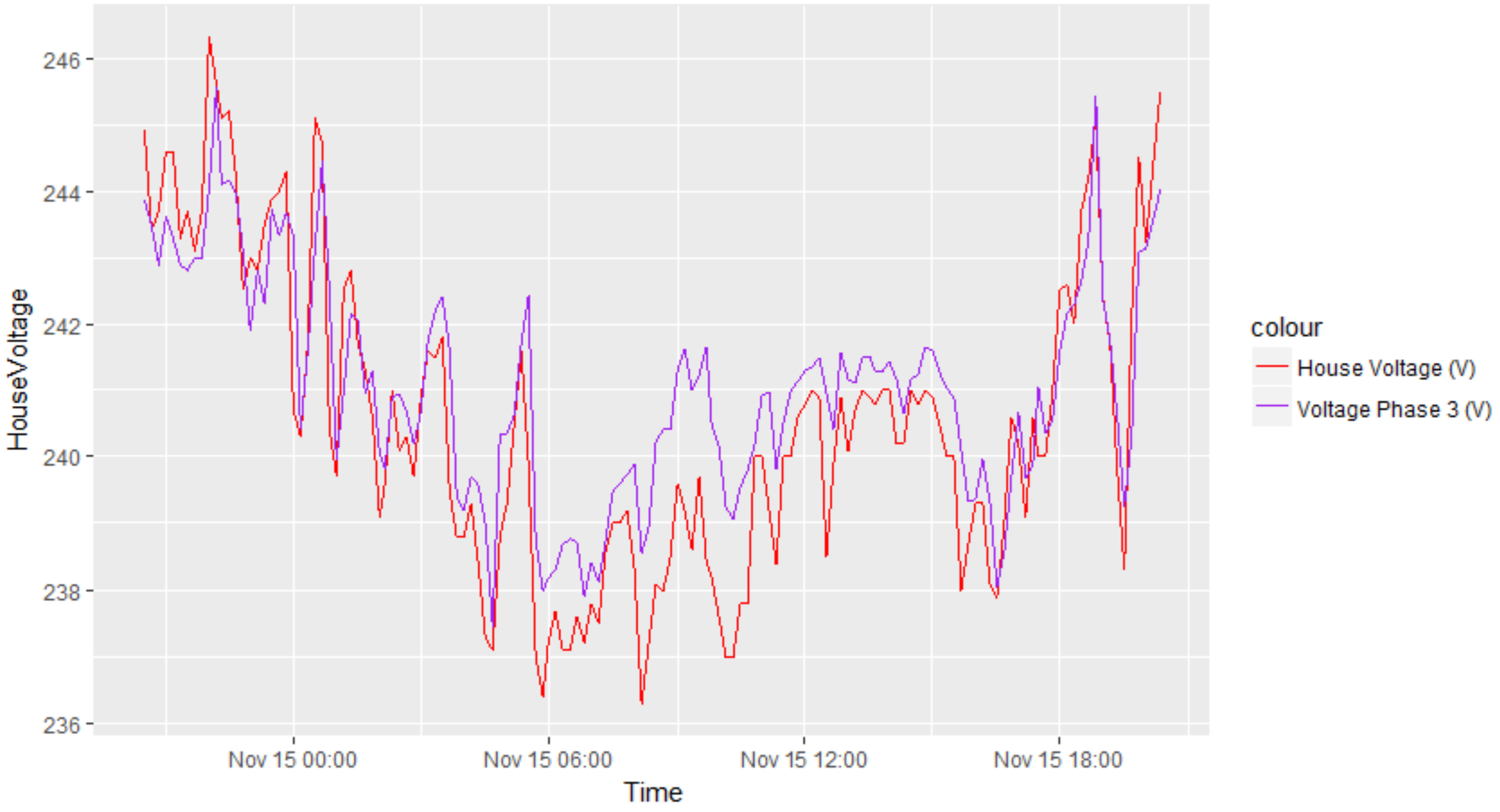
Phase identification – with DT data – phase 1



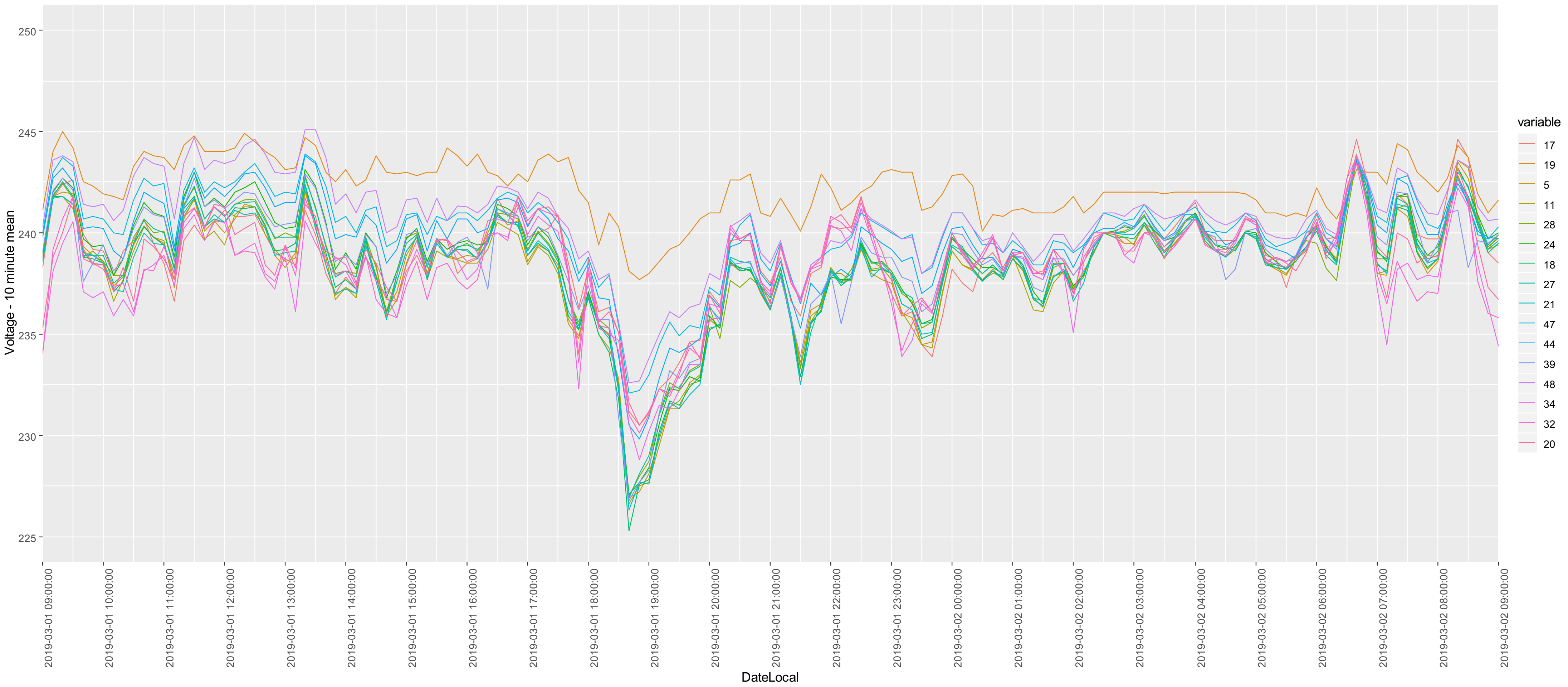
Phase identification – with DT data – phase 2



Phase identification – with DT data – phase 3



Time series voltage plot



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Thank you

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