REDBACK TECHNOLOGIES

Using solar and load predictions in battery scheduling at the residential level

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Energex
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Who we are

Incorporated in April, 2015 with 2 Employees. Today Redback employs 40 people, with 34 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.

Agenda

- Who we are
- Our product
- Saving money by scheduling
- Literature review
- Linear program
- Assessment
- Conclusion
- Future work

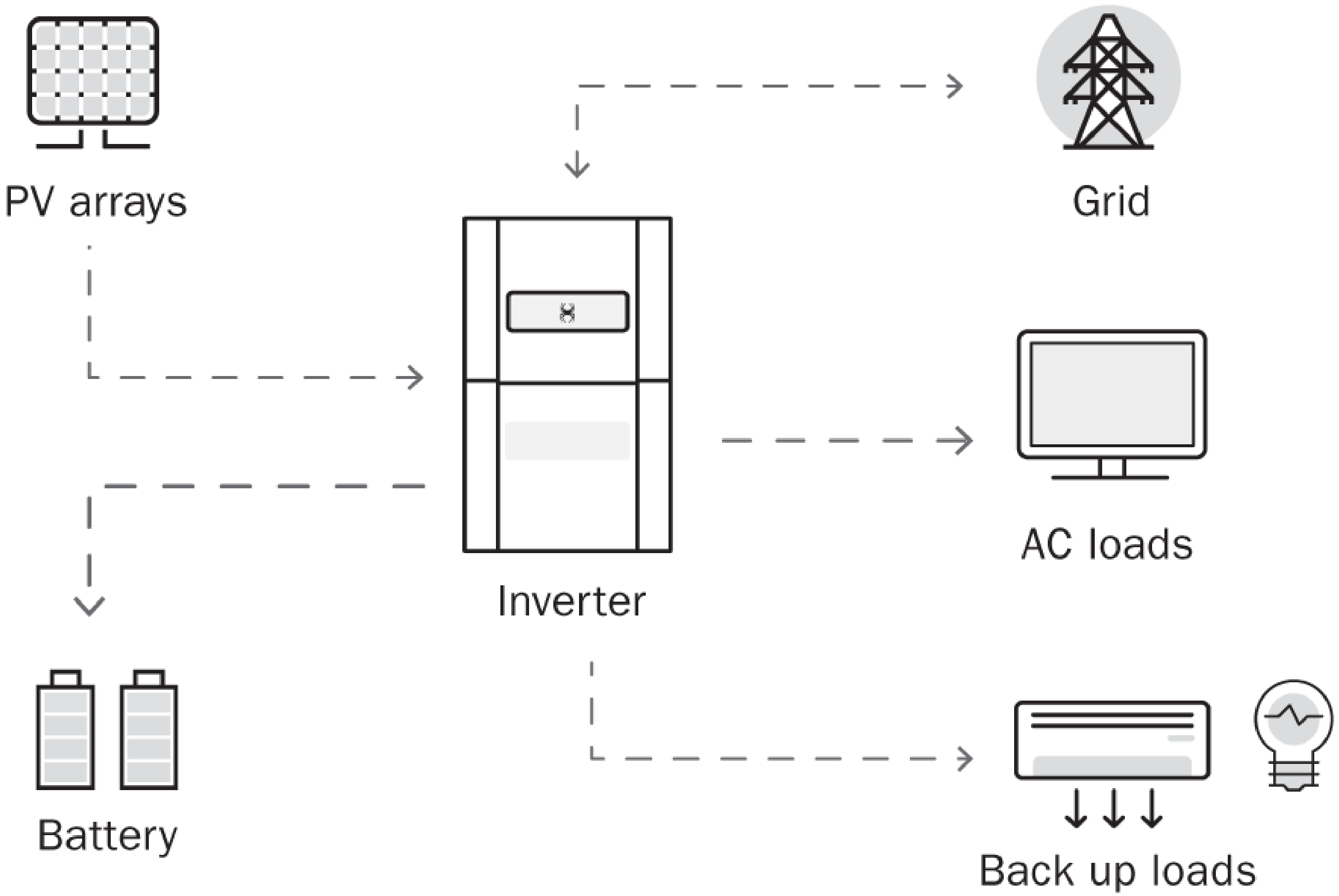
Redback Technologies

- Australian manufacturer of smart solar inverters
- Inverters to store, monitor and manage a home’s solar energy
- Based in Brisbane (Indooroopilly) and Suzhou
- Customers can choose battery (e.g. lithium ion, zinc bromide, lead acid)
- Customers choose inverter panel size and type
- Agnostic to battery type
- Ability to schedule relays (IoT)
- Inverter models: SH4600, SH5000 – maximum AC power to grid

Redback Technologies

- About 500 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



Battery scheduling

The default approach

- The “default” 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 “default” approach

It’s not the optimal approach
We want to lower the customer’s energy bills

- Default 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 “default” with Redback inverters is:
  - Inverter can be commanded to maintain a charge or discharge rate, or set back to “default” at any time (depending on connectivity)
  - These commands can be ignored if they would violate battery State of Charge boundaries

Improve default approach

- Objective for Redback is to save customers money over the default 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

Literature Review

Nottrott, Kleissl, and Washom (2011)
Nottrott, Kleissl and Washom (2012)
Nottrott, Kleissl and Washom (2013)
Hanna, Kleissl, Nottrott, and Ferry (2014)

- “OFFON” approach
  - Battery undergoes one daily full charge cycle at 80% depth of discharge
  - Constant charge rate during off-peak, constant discharge rate during peak
  - Easy with a predictable load e.g. industrial, commercial
- “RT” approach – real-time dispatch
  - Charge to full capacity during off-peak periods
  - Discharge to meet customer’s actual net load in real time

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Hanna, Kleissl, Nottrott, and Ferry (2014)

- Nottrott et al's focus was on reducing monthly peak rather than energy cost
- Performed modelling with actual load and solar forecasts (15 minute resolution from commercial provider)
- "Trigger" used to reassess mode of operation if load spiked or solar failed to meet prediction
- Battery command resulting in level below minimum State of Charge (SoC) characterised as "failure"
- Thus the system was deemed not yet ready for commercial operation
- However, in reality: depends on inverter response to commands, size of system, forecast error, PV to load ratio, and time of use tariffs

Literature Review

Ratnam, Weller and Kellett (2013, 2015, 2016 and 2017)

- “An optimization-based approach to scheduling residential battery storage with solar PV: assessing customer benefit”
  - Linear program to minimize cost, or
  - Quadratic program to reduce back-flow into distribution network in peak i.e. “minimize the impact of the residential energy system on the grid”
- Assumed perfect load and solar forecast
- Residential data set from AusGrid available for 300 homes – heavily cleaned and filtered

Literature Review

Davy and Huang (2016)

- Using day ahead solar radiation forecasts and assumed knowledge of household electricity demand
- Known time of use tariffs and feed-in tariffs
- Software and examples provided
- Using MiniZinc modelling language (CSIRO and Data61 tool)
- Penalty applied for battery state of health

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)
  - National Weather Service (GFS)
  - European Centre for Medium-range Weather Forecasts (ECMWF)
- Assimilation/analysis step

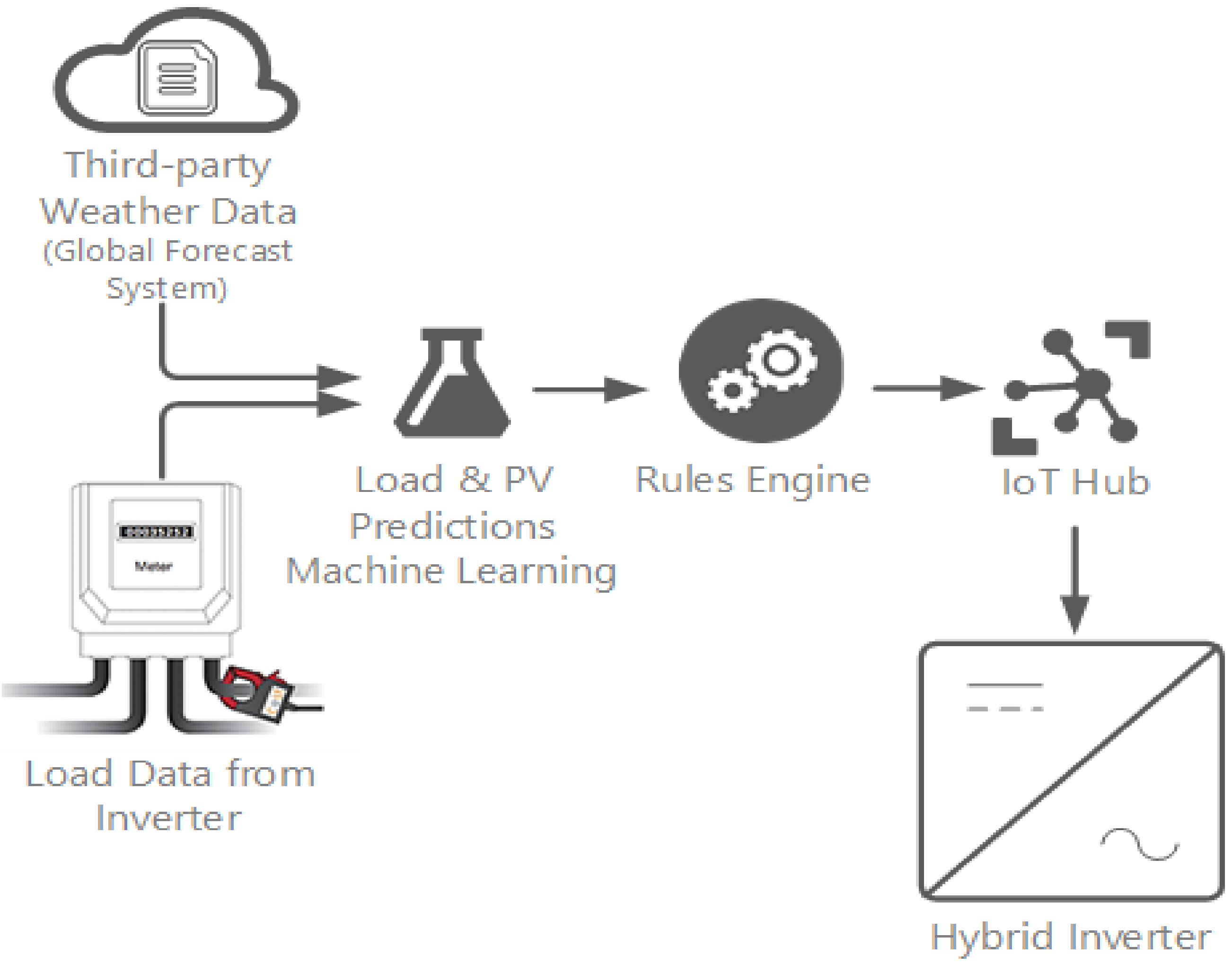
Spatio-temporal resolution of NWP forecasts

- Gridded global forecast
- BOM ACCESS-C (for existing customers)
  - 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

Other providers

- Weather Underground / Weather Company (IBM)
- Weatherzone
- Solcast

Diagram



Third-party
Weather Data
(Global Forecast
System)
Load & PV
Predictions
Machine Learning
Rules Engine
IoT Hub
Load Data from
Inverter
Hybrid Inverter

Prediction of solar and load

For each location

- 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

- Mean Absolute Error rate for day ahead predictions for solar and load is approximately 20% (across all inverters)
- 25^{th} percentile is approximately 16% for PV and 11% 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. 24-48 hours ahead)
- Variables
  - Load and solar predictions for given time period (hourly)
    - It may help to use 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

Linear programming approach

For each hour in the forecast $h \epsilon \{1, \dots . H\}$
t_h = Tariff $/kWh for hour h (covering peak, shoulder and off-peak pricing)
f_h = Feed in tariff $/kWh for hour h

Linear program is as follows (all values in kWh)
Minimise objective function:

$$\sum_{h=1}^{H} t_h\, I_h - f_h E_h$$

I_h = import from grid in hour h
E_h = export to grid in hour h
S_h = state of charge at end of hour h
B_h = battery flow for hour h (positive is discharge, negative is charge)

Linear programming approach

Limits on state of charge for the battery: $S_h >= 0$, $S_h <= 6.5$

Limit on import from grid: $I_h >= 0$

Limit on export to grid: $E_h >= 0$, $E_h <=$ export limit for hour for inverter

Limit on battery flow in each hour: $B_h <= -4.8$ and $B_h >= 4.8$

Balance equation: $L_h – P_h = B_h + I_h – E_h$

State of flow per hour: $S_h = S_{h-1} – B_h$

Outcome

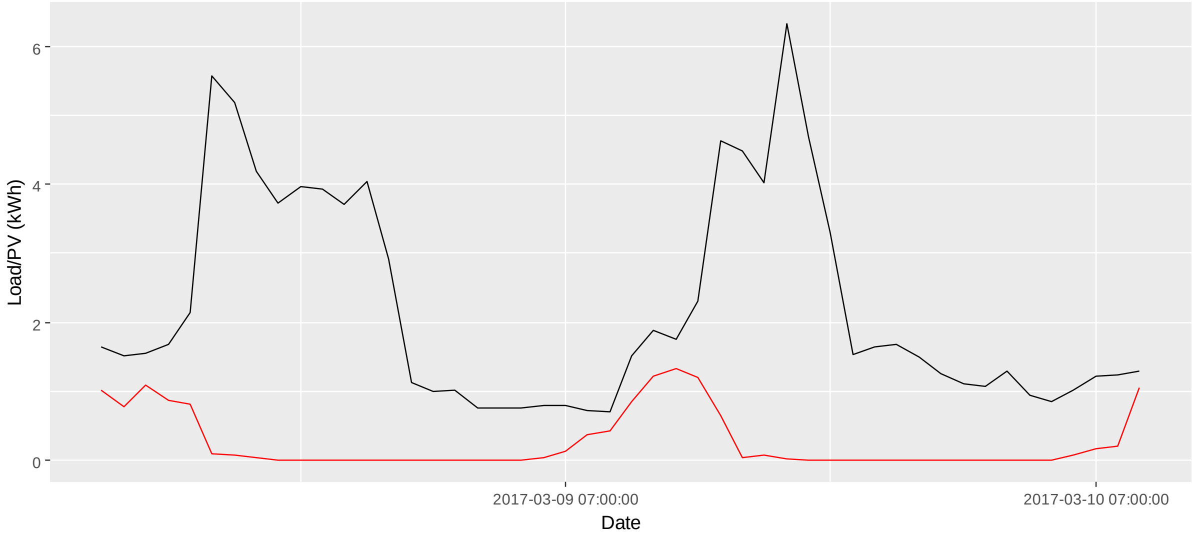
When should each inverter charge and discharge

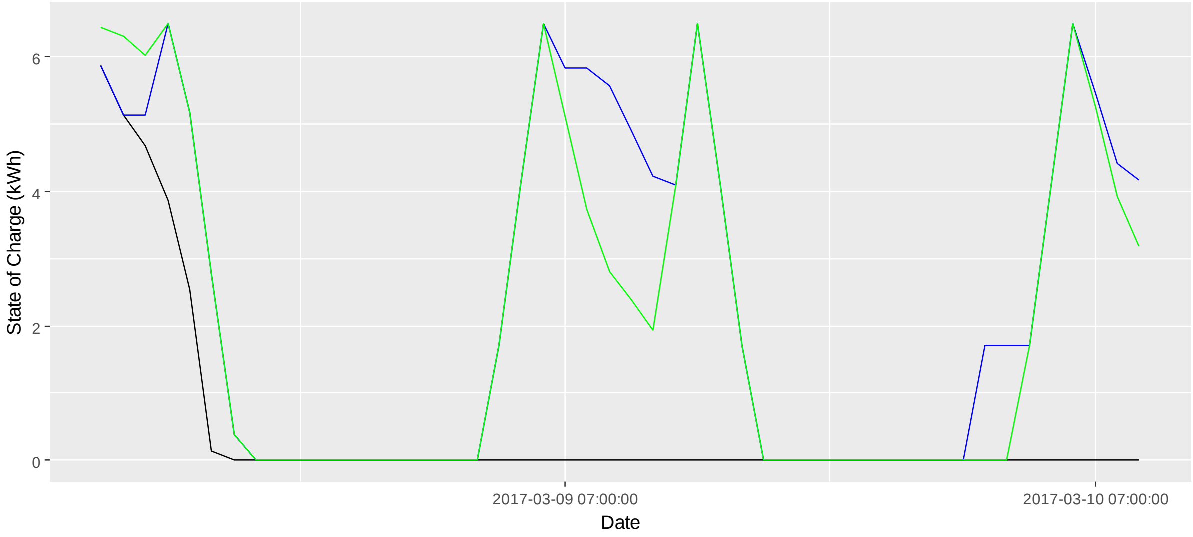
- Generally with a time-of-use tariff where the peak price is very high relative to the off-peak, it is optimal to attempt to fully charge the battery before the peak begins, with a combination of grid and solar depending on how much solar is forecast
- Depending on load forecast and time-of-use tariff values and boundaries, it may still be optimal to import energy during peak
- Choose hours based on time of day (before shoulder or peak start) and PV to load relativity
- With aggressive tariffs, use default approach in peak hours

Sample output

Low PV to Load ratio

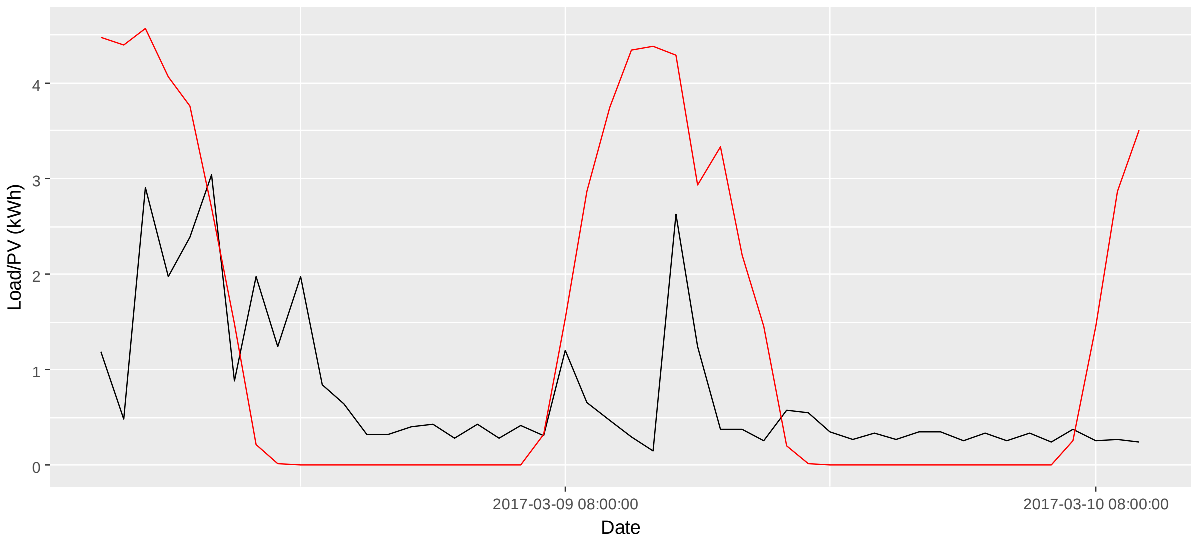
- Where PV to Load ratio is very low – default approach is wrong as it will never charge the battery
- Load – black line, PV – red line; Default – black line, LP – green line, LP with perfect forecast – blue line
- Start with full battery

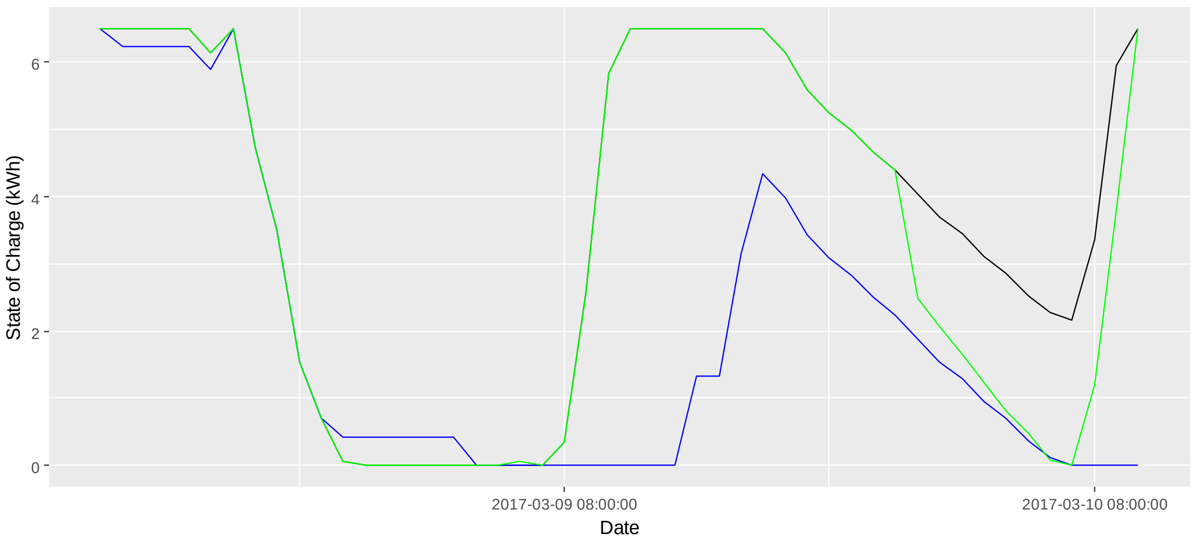




Sample output

- Normal case – PV to Load ratio 0.9
- Load – black line, PV – red line; Default – black line, LP – green line, LP with perfect forecast – blue line
- During the off-peak period (prior to 8am, 10th March), LP meets Load demand fully using the battery; default inverter meets Load using grid power.

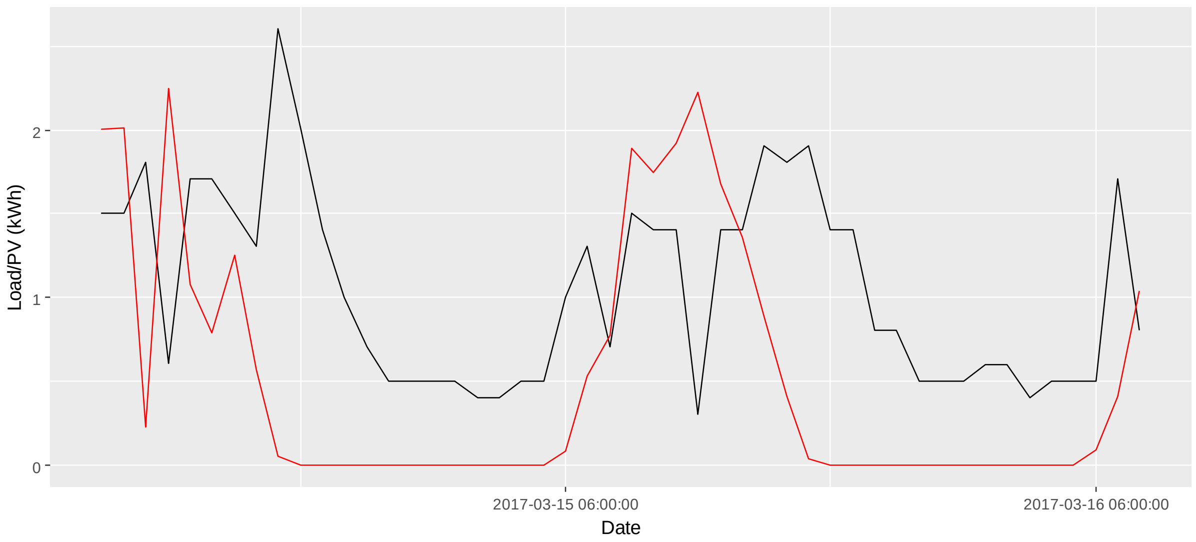


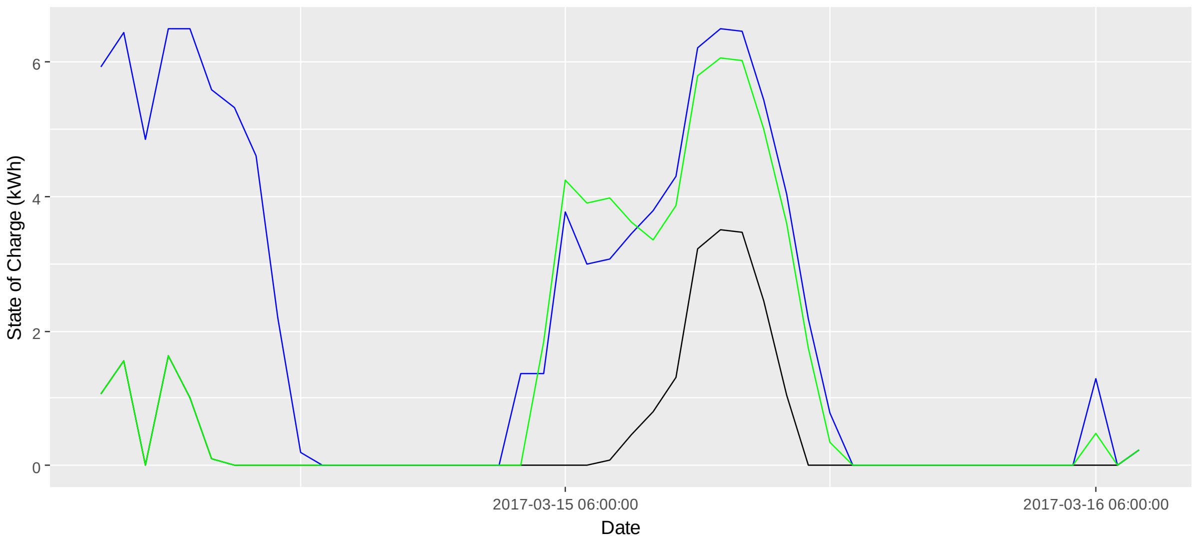


Sample output

Normal PV to Load ratio – load increasing

- Normal case – PV to Load ratio 0.72
- Load – black line, PV – red line; Default – black line, LP – green line, LP with perfect forecast – blue line
- At the start of the peak period (2pm), the LP mode is aware that there will be significant Load to be met during the peak period, with corresponding rapidly declining PV output. The “default” mode doesn’t have this knowledge and does not consider tariff differences between shoulder and peak periods.





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
- Over a 100 day period, using hourly simulation, the optimisation saves 18% over the default approach (with an aggressive tariff), compared to 30% if a perfect PV and load forecast was available
- With tariffs where the peak and off-peak prices are closer together, savings are lower

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 forecast error rates at given sites (e.g. MAPE)
  - 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
- Improve “trigger” mechanism
- State of health considerations should be evaluated and taken into account
- Battery efficiency can be estimated more effectively
- Avoiding back flow to grid may be a concern in future

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Thankyou

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