Intelligent Optimal Control of Sustainable Small Grids for Battery Life Extension

Solar pump-based village microgrids-potential for tackling the energy/water/food nexus in Punjab

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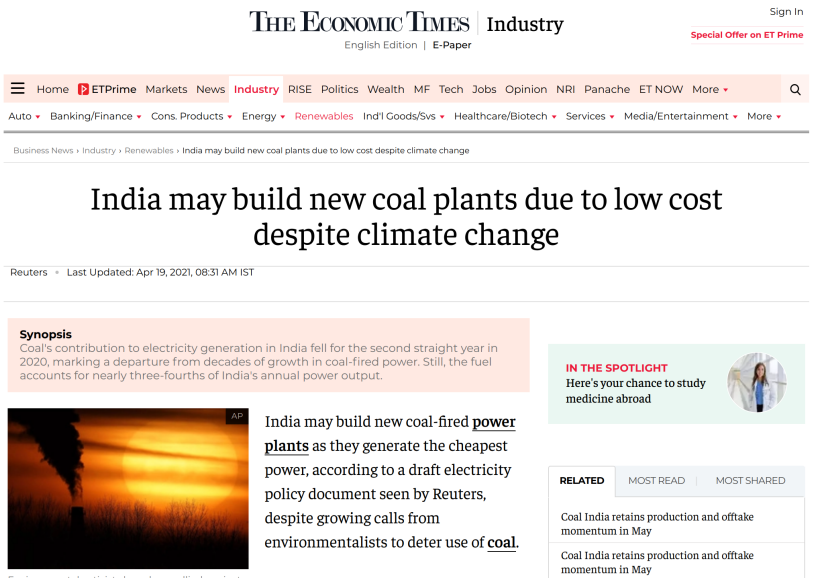
Outline

- Current context
- Mini-grids
- Control solutions
  - Model Predictive Control
  - Deep Reinforcement Learning
- Conclusions and Openings

Access to Power

Electricity is a major challenge.

There is a need for more power.



India Times

- Economic growth
- Urbanisation
- Transition to digital society
- Electrification ...

Access to Power

Electricity is a major challenge.

Many issues are not solved.


the Blackout report

Nigeria Power Grid Collapses For Second Time This Year

May 13, 2021 Chris Owens 0 Comment Power News

The power grid across Nigeria completely collapsed on Wednesday morning (12 May) plunging much of the country into a blackout.

- Black Out (local or nation-wide)
- Connection to the Grid
- Prices

Access to Power

Electricity is a major challenge.

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High winds cut power to thousands of Skye and Uist homes

10 March

Portree on Skye was among the places affected by the power cut

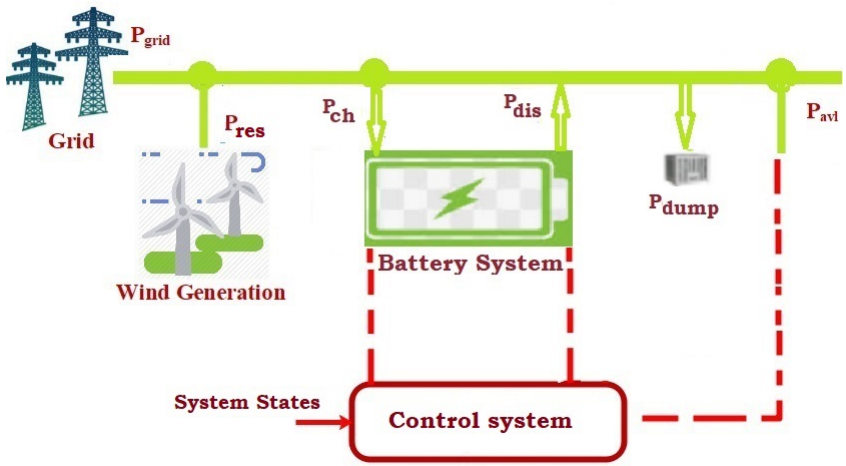
Thousands of properties across Skye and North and South Uist were left without power after high winds on Tuesday.

It happens everywhere !

Mini grid

A mini grid is essentially :

- Means for generating power
- Means to save power (to manage intermittency)
- Means to use power
- Sized for a household/village



There is a global need for :

- Producing more (clean) energy
  1. Grids more efficient
  2. Grids more economically attractive

Power Balance

A mini grid is :

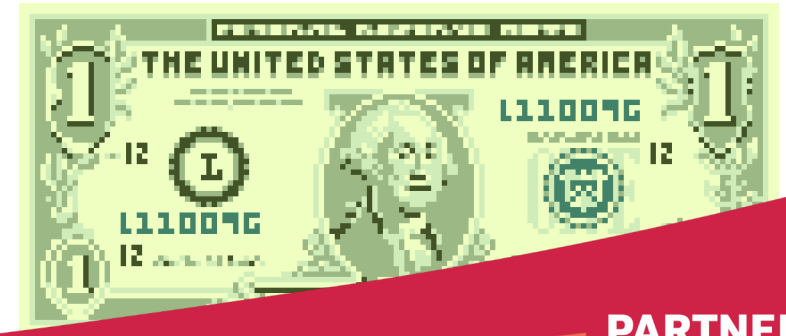
- Receiving power from the renewable sources : P_{re}
- Providing enough power to meet the consumer needs : P_{load}
- Buying/selling power to the grid : P_{grid}.
- Charging/discharging the battery : P_{batt}

and the power balance is :

$$P_{load} = P_{re} + P_{batt} + P_{grid}$$

The objective is to optimize the management of P_{batt} and P_{grid}.

So more users will desire one



Maximizing revenues

We want to optimize

- profits
  - sell (when high prices)
  - minimize buying (except when low prices)
- sustainability/investment via battery management
  - increase lifetime
  - identify correct sizing
  - less heating/risks with second hand battery
- delivery to the consumer (loads, grid and REs are all intermittent)

Importance of the batteries

The price of the energy system storage is an important part of the grid - up to 40%[1].

It is expected to go down, but batteries are still pricey and have a large environmental impact.

- How to make the storage more affordable ?

  Improve sizing, better usage, reduce operating and management costs

- How to make the storage more sustainable ?

  Minimize the needs of change

It has a direct impact for funding bodies/stakeholders !

[1] : Energy Storage Grand Challenge Cost and Performance Assessment,Publication No. DOE/PA-0204, US Dpt of Energy.

Challenges and constrains of Energy Management Systems

- Fast controller

  So it remains cheap/can work on different situations

- Cheap actuators/sensors

  Mostly metering, eventually connected

- Limited access to sensors/information

  So it is realistic

My belief : Data-driven methods are the best solutions !

- Physics informed But it is hard and expensive !
- Black Box But what do we know and understand ?

Situations can evolve during usage !

Focus on batteries : two methodologies

My point of view :

- Take into account the health of the battery
- Minimize the risks associated to second hand batteries

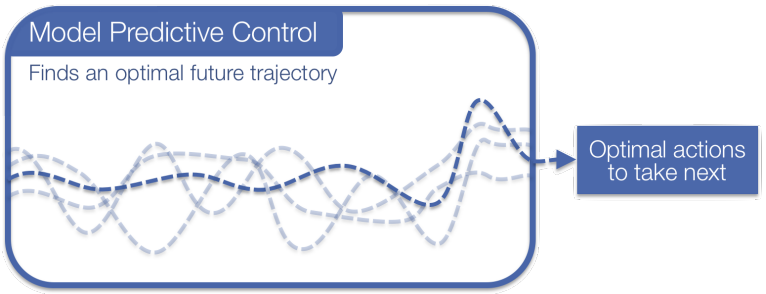
I use mainly two methods

- Model Predictive Control - how a grandmaster plays chess.
- Deep Reinforcement Learning - how to learn how to be a grandmaster.

To help/inform previous methods, we also work on the physics of cooling, using physics-based simulations.

Model Predictive Control (MPC)

It is similar to how the grandmaster plays chess.



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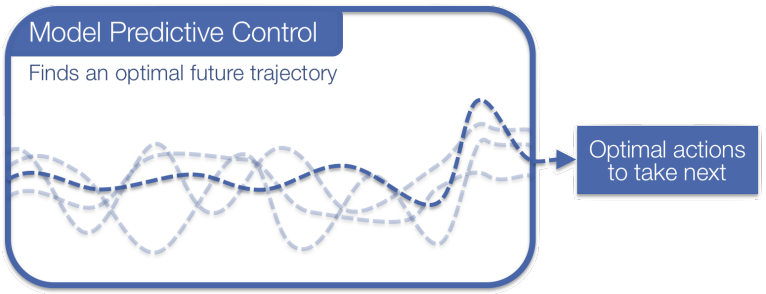
1. The grand master imagines the few possibles outcomes based on the board state.
2. He selects the movement that results in the best outcome.
3. The opponent plays and updates the board state.



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3. The opponent plays and updates the board state.

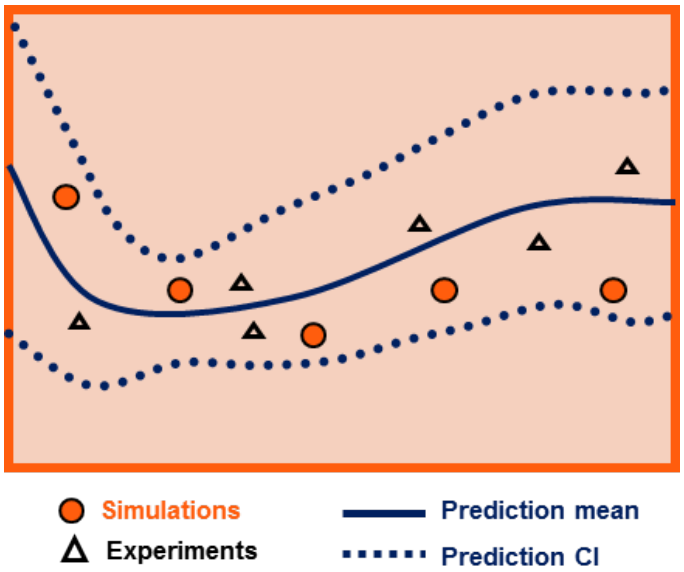
1. The algorithm identifies the best sequence based on current knowledge and predictions.
2. The controller apply the first item of the sequence.
3. It loops when the knowledge is updated.

Limits of MPC

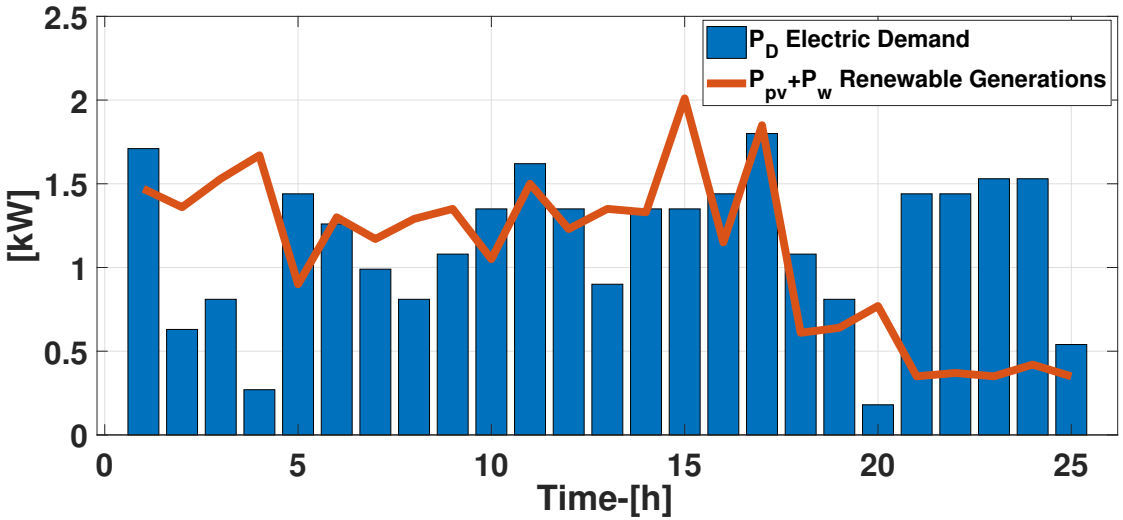
MPC is a very robust approach.

However, MPC can perform poorly when

- someone does not follow the rules attack
- the rules/model are unknown/changes
- the model is expensive to compute
- the board/state is not well known/uncertain



Numerical Results [ECC2021,CDC2021]



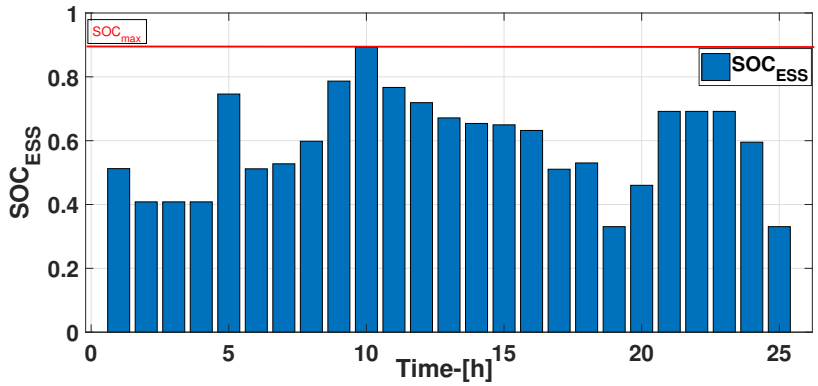
Considered control objectives are :

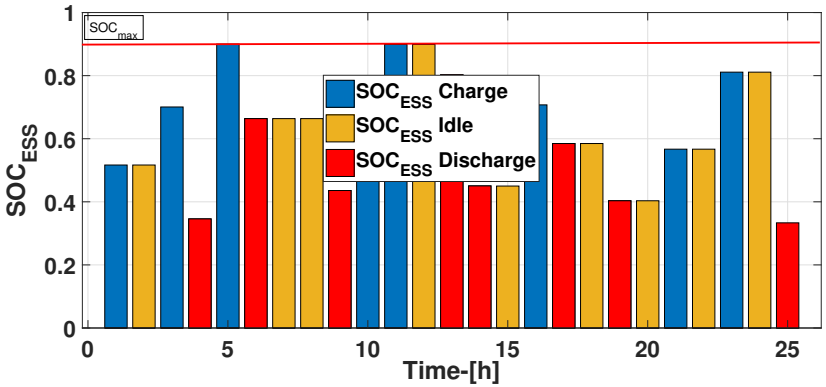
- user electric power demand satisfaction
- revenue maximization
- minimizing battery operating costs

Constrains :

- exceeding/missing power variations
- unreliable main grid

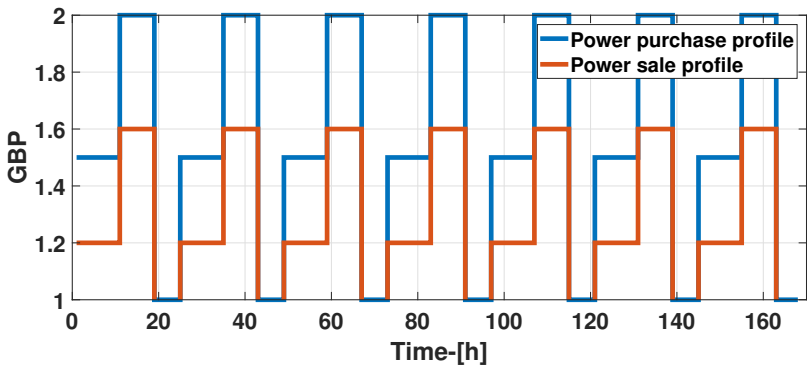
Battery SOC Results [ECC2021,CDC2021]

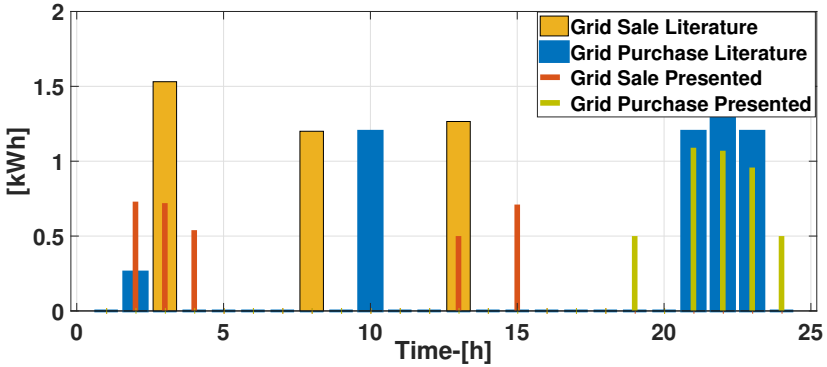




1. charging/discharging events are unavoidable
2. idle state up to **37.5%** of the time.
3. **savings in battery life cycles - maximizing its lifetime**.

Energy Market Participation [ECC2021,CDC2021]



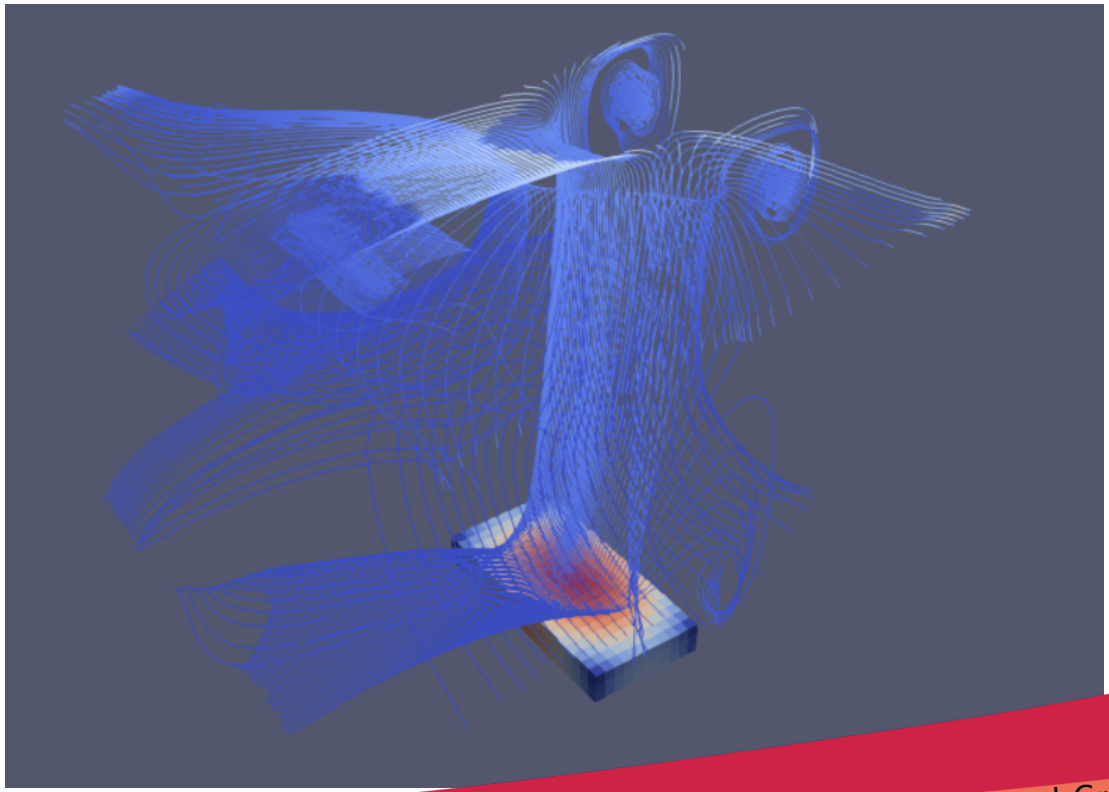


1. More interaction with the market
2. proposed strategy main advantages :
   - profit maximization by exchanging power with the grid as per the energy price profiles
   - **battery life extended upto 3 years**

Saving batteries [ECC2021,CDC2021]

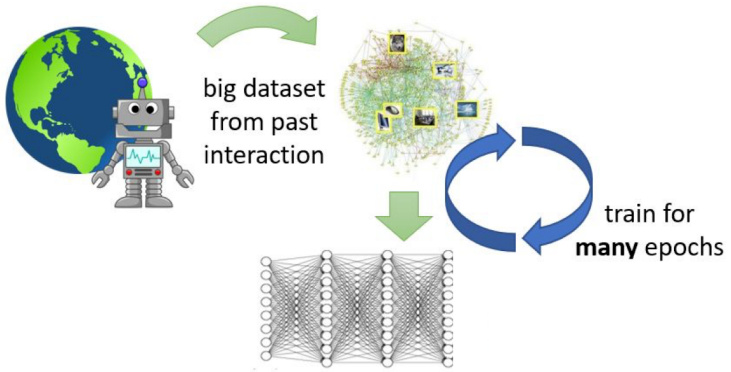
The battery life is extended up to 27%.

It also means reducing the heat and fire hazard for second hand batteries.



Deep Reinforcement Learning (DRL)

It is similar to how the grandmaster learns how to play chess.



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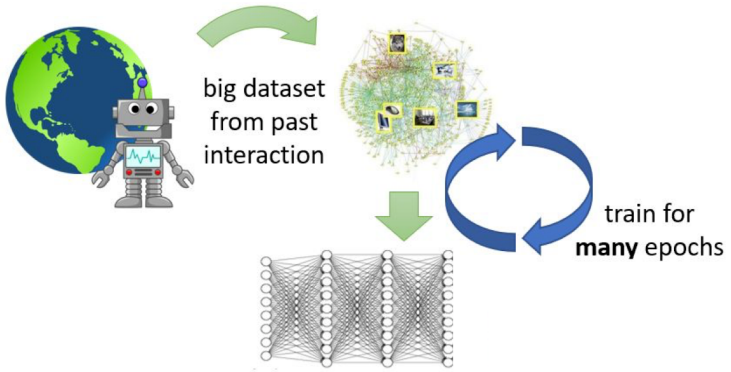
2. The opponent plays and updates the board state.
3. The grandmaster takes notes if the evolution of the board seems positive or not.
4. They continue until the game is finished ; the grandmaster notes the outcome of the game.



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4. They continue until the game is finished ; the grandmaster notes the outcome of the game.

1. The algorithm identifies the best movement based on current knowledge. Knowledge about allowed movement is used/updated. Note that is it mostly about recognising a situation rather than predicting the outcomes.
2. It loops until the states evolve.
3. Immediate Rewards are taking into account.
4. Final Rewards are (eventually) taking into account.

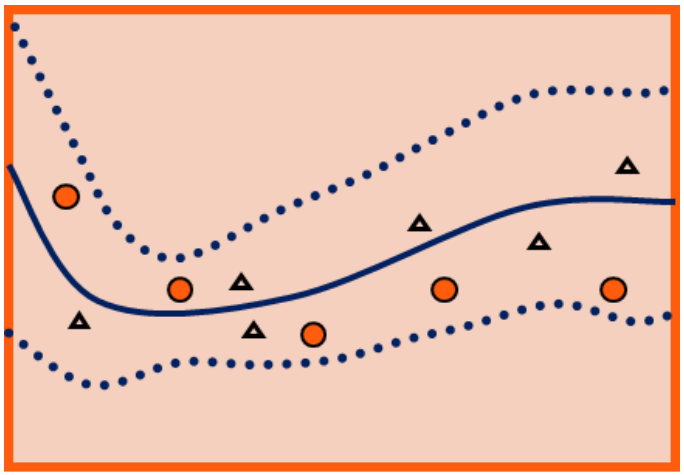
Strengths and Limits of DRL

DRL can be an uncertain approach

- Optimality is not guaranteed
- Learning phase is long

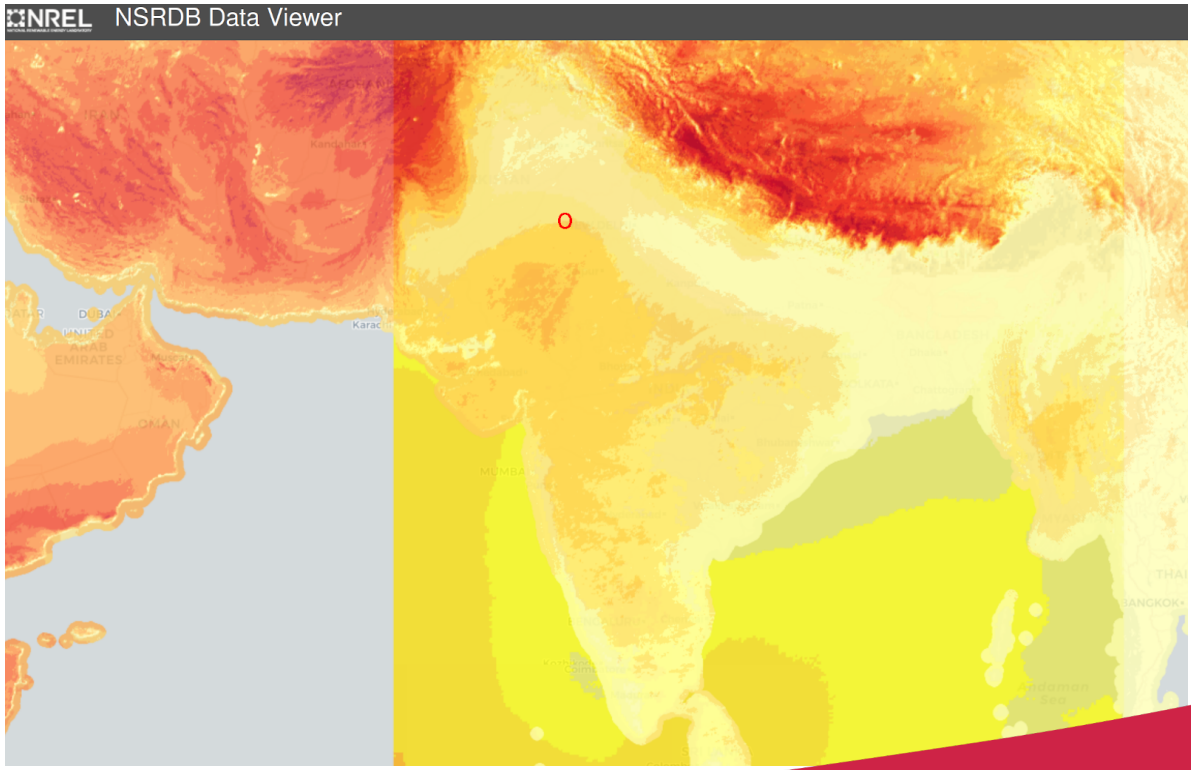
However, the strength correspond to the weaknesses of MPC

- the rules/model are learnt, so they can change
- the model is cheap to run
- the board/state does not need to be well known



Source of data

- Load comes from the PJM Hourly Energy Consumption Data
- Production comes from the US National Solar Radiation Database, the data point is Panjab.



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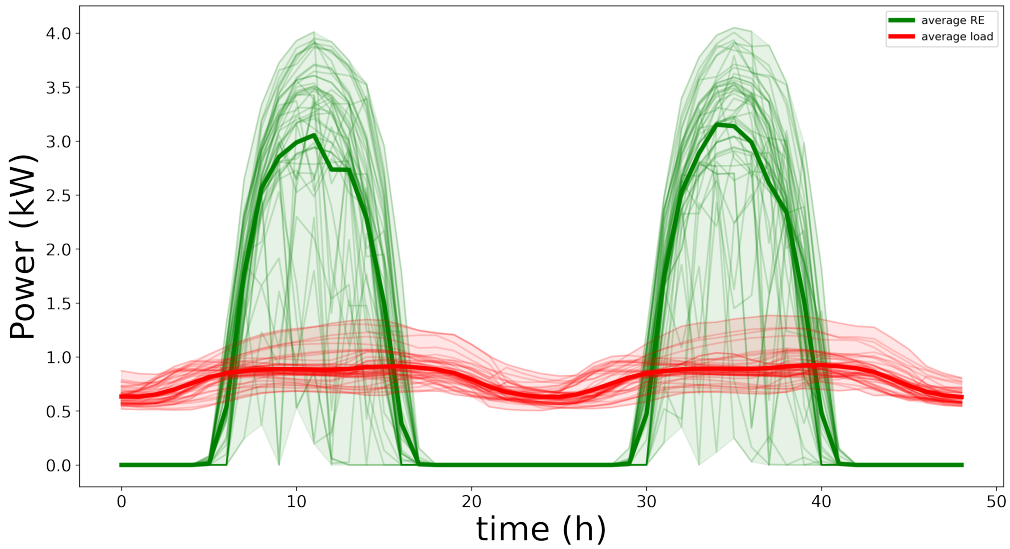

Considered control objectives are :

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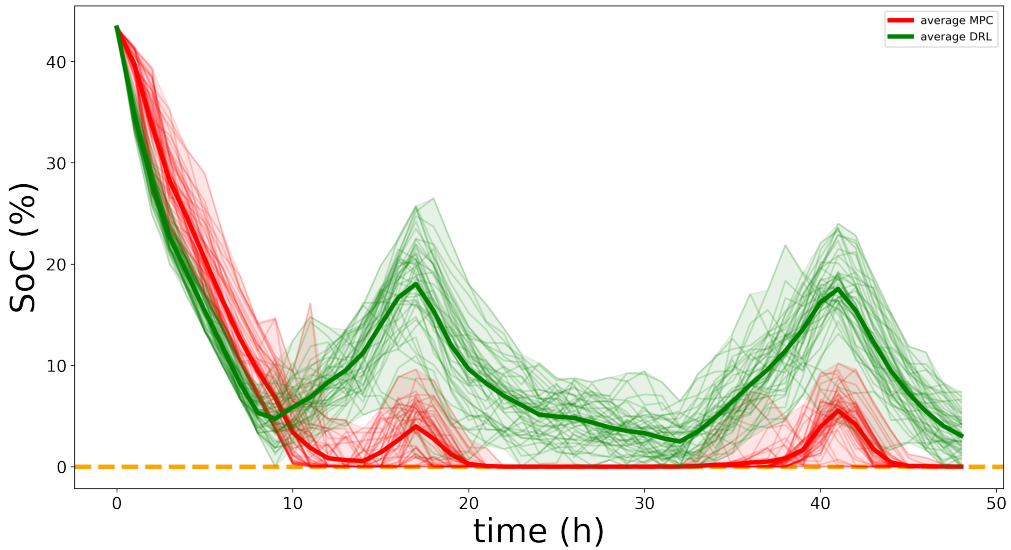
- revenue maximization
- soon : minimizing battery operating costs

Constrains

- exceeding/missing power variations
- soon : unreliable main grid

States of Charge

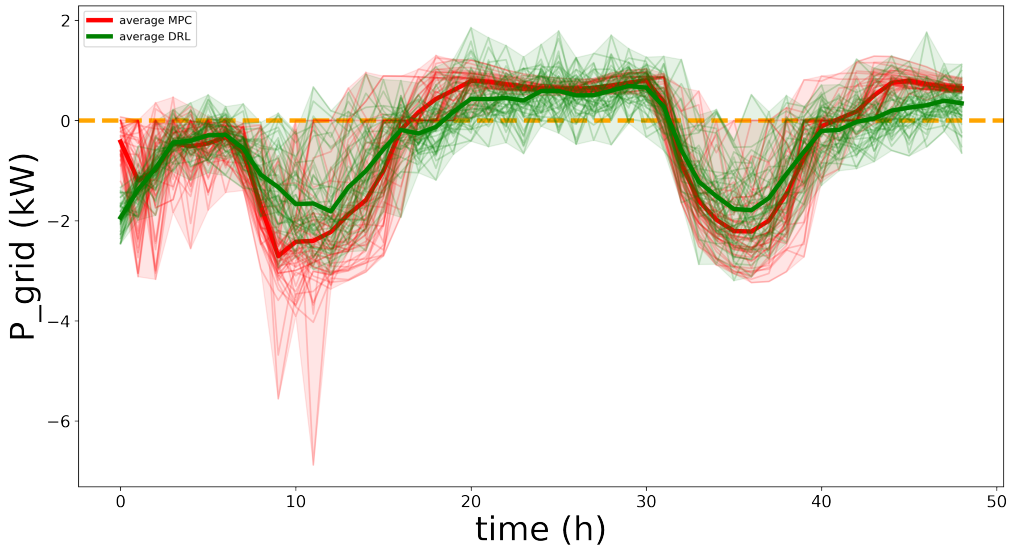


By its overall predictive nature, the DRL tends to take into account the worst possible scenarios, and hence still keep the SoC not at zero.

It also has a longer horizon that MPC.

It means a more resilient grid, able to respond to unpredicted/able demands.

Energy Market Participation



By its predictive nature, the DRL tends to

- sell 38% less
- buy 16% less

Identical performances and Considerable speedup

Once trained, the DRL allows to have quick system. It means the on-site requirements remain cheap.

	time (sec)	Value ($)
MPC	34.9 ± 3.8	27.9 ± 9.8
DRL	0.05 ± 0.003	28.5 ± 9.4
diff	6955%	3.8%

The speed up is around 7000%, and the overall performance are slightly increased.

Conclusions and openings

AI-powered control can

- maximize profits
- increase battery life by 30%
- manage unreliable or intermittent grid/RE
- positively affects sizing and investment cost
- improve sustainability

Once designed, the control can be inexpensive.

Some open questions

- Design the market prices to influence farmers habit
- Model risks of attacks
- Extreme events

Any questions ?