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

F. Gueniat florimond.gueniat@bcu.ac.uk 5-7 January 2022

Birmingham City University



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MPC [

Deep Reinforcement Learning

Conclusion







Outline

- Current context
- Mini-grids

Contraction of the state of the

- Control solutions
 - Model Predictive Control
 - Deep Reinforcement Learning

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Conclusions and Openings



Conclusion

attractive grids objectives focus on batteries my challenges

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Access to Power

Context

outline

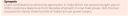
Electricity is a major challenge.

There is a need for more power.

THE ECONOMIC TIMES | Industry Fromh Edition 1 E-Danes E Home DETPrime Markets News Industry RISE Politics Wealth MF Tech Jobs Opinion NRI Panache ETNOW More Auto + BankingFinance + Cons.Products + Energy + Renewables Indi GoodsSvs + HealthcareBictech + Senices + MediaEntertainment + More

India may build new coal plants due to low cost despite climate change

Routers - Last Updated: Apr 19, 2021, 08:31 AM IS





plants as they generate the cheapest power, according to a draft electricity policy document seen by Reuters, despite growing calls from environmentalists to deter use of coal

India may build new coal-fired powe

India Times

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Coal India retains production and offsale Coal India retains production and official

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

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Deep Reinforcement Learning Conclusion

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Access to Power

Context

Electricity is a major challenge.

Many issues are not solved.

Blackoutreport

Nigeria Power Grid Collapses For Second Time This

Year

outline

May 13, 2021 & Chris Owens 🖓 0 Comment IIII Power News

State of the state

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











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Access to Power

Context

Electricity is a major challenge.



High winds cut power to thousands of Skye and Uist homes

⊙ 10 March



outline



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

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Department of Science & Technology, Government of India

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It happens everywhere!

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Mini grid

Context

outline

A mini grid is essentially :

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- Means for generating power
- Means to save power (to manage intermittency)
- Means to use power

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Sized for a household/village

There is a global need for :

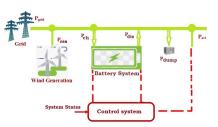
- Producing more (clean) energy
 - Grids more efficient
 - 2. Grids more economically attractive

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Power Balance

(Context)

outline

A mini grid is :



- \blacktriangleright Receiving power from the renewable sources : P_{re}
- Providing enough power to meet the consumer needs : Pload

Conclusion

• Buying/selling power to the grid : P_{grid} .

Deep Reinforcement Learning

Charging/discharging the battery : P_{batt}

and the power balance is :

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

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

So more users will desire one



outline (Context) MPC Deep Reinforcement Learning Conclusion

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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

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- less heating/risks with second hand battery
- delivery to the consumer (loads, grid and REs are all intermittent)

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Image: Second second

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

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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.

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outline (Context) MPC Deep Reinforcement Learning Conclusion

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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!

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

Situations can evolve during usage!

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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

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

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

(MPC) Deep Reinforcement Learning

Conclusion

Methodology Results

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outline

Model Predictive Control (MPC)

It is similar to how the grandmaster plays chess.







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Conclusion

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(MPC)

outline

Model Predictive Control (MPC)

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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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(MPC)

outline

Model Predictive Control (MPC)



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- 3. The opponent plays and updates the board state.

No 120 million line and the Contact which which

- 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.

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outline

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Conclusion

Limits of MPC

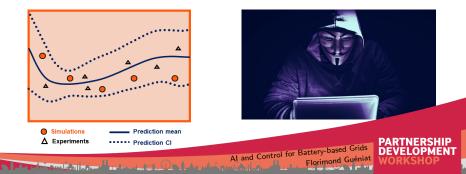
Context

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





Context

(MPC)

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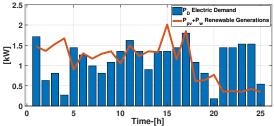
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Numerical Results [ECC2021,CDC2021]



Considered control objectives are :

- user electric power demand satisfaction
- revenue maximization

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 minimizing battery operating costs Constrains :

- exceeding/missing power variations
- unreliable main grid

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Context

(MPC)

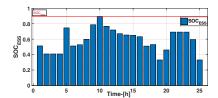
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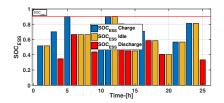
Battery SOC Results [ECC2021,CDC2021]

Deep Reinforcement Learning

Conclusion







The second second

- 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.

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Methodology Results

Context

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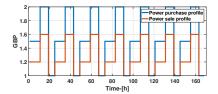
outline

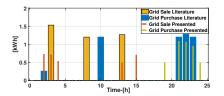


Energy Market Participation [ECC2021,CDC2024]

Deep Reinforcement Learning







The second second second second second second second

- 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

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Context

(MPC)

outline

Saving batteries [ECC2021,CDC2021] The battery life is extended up to 27%.

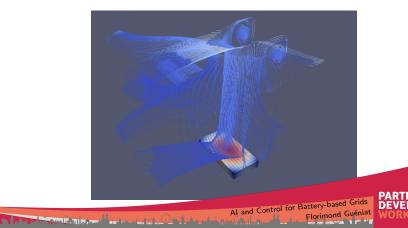
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It also means reducing the heat and fire hazard for second hand batteries.

Conclusion



Context MPC (Deep Reinforcement Learning) Conclusion

Methodology Results

outline

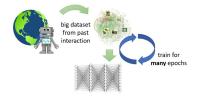
Deep Reinforcement Learning (DRL)







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Deep Reinforcement Learning (DRL)





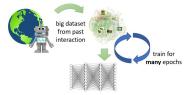
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It is similar to how the grandmaster learns how to play chess.

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- 1. The grandmaster tries a move, based on the board state and his previous notes. He takes note if the move is actually possible.
- 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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Deep Reinforcement Learning (DRL)



DEVELOPMEN

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Contraction and the second s

- 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.

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AI and Control for Battery-based Grids

(Deep Reinforcement Learning)

Conclusion

Methodology Results

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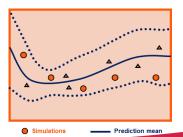
outline

Strengths and Limits of DRL

DRL can be an uncertain approach

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- Optimality is not guaranteed
- Learning phase is long



Solution and the second s

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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

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outline

(Deep Reinforcement Learning)

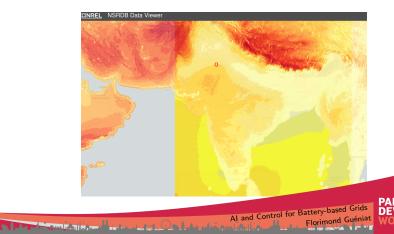
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Source of data

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

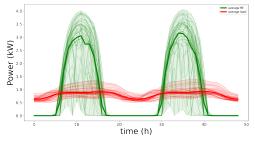


outline Context MPC Methodology Results

(Deep Reinforcement Learning)

Conclusion

Numerical Results



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Considered control objectives

are :

- user electric power demand satisfaction
- revenue maximization

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soon : minimizing battery operating costs

Constrains

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

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Conclusion

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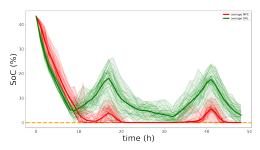
Context

outline

States of Charge

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MPC



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.

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PARTNERSHIP DEVELOPMENT

Conclusion

Methodology Results

Context

outline



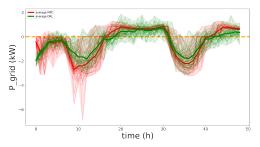


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Energy Market Participation

MPC



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By its predictive nature, the DRL tends to

(Deep Reinforcement Learning)

- sell 38% less
- buy 16% less

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

		time (sec)	Value (\$)	
	MPC	$\textbf{34.9} \pm \textbf{3.8}$	$\textbf{27.9} \pm \textbf{9.8}$	
	DRL	0.05 ± 0.003	28.5 ± 9.4	
	diff	6955%	3.8%	
diff 6955% 3.8% The speed up is around 7000%, and the overall performance are				
slightly increased.				

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AI and Control for Battery-based Grids

outline Context

MPC Deep

Deep Reinforcement Learning

Conclusion



Conclusions and openings

Al-powered control can

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

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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?

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