Contact: Steven Zhang
steven@trex-ai.ca

Enhancing Grid Resiliency with ALEX: A Real-Time Distributed Energy Resource Coordination System

Summary

Electrification and distributed energy resources are a challenge for utilities, especially with regards to electricity grid resilience and stability. This article addresses the challenges of grid resiliency with the rise of distributed energy resources (DERs) and introduces ALEX, a real-time DER coordination system.

ALEX, developed by TREX-Ai Inc., is an AI-based, real-time DER coordination system that enables efficient and scalable coordination of DER usage. ALEX's ability to coordinate resources across buildings not only is the key to its performance, it also results in a much more resilient and adaptive DERMS setup. This performance is achieved at significantly lower scaling and deployment costs and bottlenecks than a performance-equivalent, fully centralized DERMS.

The article presents a comparative analysis using a virtual community with 17 solar-equipped buildings and compares ALEX against a baseline and a state-of-the-art decentralized DER management system (DERMS). The evaluation metrics include netload, energy import/export, daily peak, ramping rate, and peak-to-average ratio. The results show that ALEX outperforms the baseline and individual DERMS in reducing imports, exports, daily peak, ramping rate, and peak-to-average ratio, thereby improving overall system efficiency and stability.

In conclusion, ALEX represents a significant advancement in intelligent and adaptive grid management systems. Its real-time DER coordination capabilities address challenges in grid stability and resiliency while remaining scalable and easily deployable. ALEX's demonstrated ability to enhance grid efficiency, boost resilience, and adapt to the growing deployment of DERs paves the way for a sustainable and resilient energy landscape in the future.

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1. Introduction

The ongoing electrification and increasing deployment of distributed energy resources (DERs) presents opportunities and challenges for grid resiliency. This is true for both population-dense areas and weakly grid-tied or islanded microgrids (such as ones used by remote communities). In the absence of a strong grid connection, microgrids are generally more fragile and susceptible to disruption. Excess solar generation often has to be aggressively curtailed, and fossil fuel generators have to be relied upon to make up for shortfalls. However, advancements in DER technologies and the implementation of intelligent control methods offer promising solutions to enhance the efficiency and resiliency of such systems.

2. Opportunities

Currently, small-scale DERs primarily operate behind the meter, with minimal coordination among neighbors. This lack of coordination often results in localized imbalances and inefficiencies (the "duck curve", for example). However, the right control system can leverage the closely packed, heterogeneous mix of DERs to eliminate the “ducklings”. As we show later, decentralized coordination of DERs can significantly improve grid efficiency, resiliency, and resource utilization.

3. ALEX (Automated Local Energy Exchange)

ALEX is the core offering of TREX-Ai Inc. that has been under research and development over the last 7 years. With ALEX, it is simple and economical to achieve real-time DER coordination at any location and scale.

In contrast to schedule-based demand response methods, such as pricing-based one-day-ahead optimal power flow (OPF) optimization, ALEX uses artificial intelligence (AI) agents to coordinate DER usage in real-time, using only smart meter[1] readings. This decentralized, self-learning approach is naturally resilient against unexpected system dynamics, such as DER installations/dropouts[2], changes in behavior, etc., making systems using ALEX far more robust in comparison. Additionally, the cost of scaling a centralized system is exponential with respect to the number of devices controlled, whereas the cost for a decentralized system is linear.

[1] Smart meter reading is preferred, as it is legally the “ground truth”. However, data from any energy meter that can measure bi-directional flow can be used.
[2] This is especially important for electric vehicle to grid (V2G) applications

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4. Demonstration

This demonstration uses a virtual community formed by 17 solar-equipped buildings, using smart meter data provided by the CityLearn 2022 dataset[3]. We benchmark ALEX against a baseline and a state-of-the-art decentralized DER management system (DERMS) using the same set of inputs, resulting in the following scenarios:

1. No DERMS: A baseline, established using metering data, with no controllable loads or energy storage in place.
2. Individual DERMS: A battery storage equivalent to Tesla Power 1 is added to each building to grant energy-shifting capabilities. Each building uses a strategy to maximize self-sufficiency while shaving peak load using their batteries.
3. ALEX: Using the same system as in case (2), ALEX is deployed instead of individual DERMS. Since ALEX has built-in economic incentives to use locally generated/stored energy, the AI agents that are deployed to each building aim to minimize their individual bills as their sole objective.

Net load-dependent metrics are used for evaluation, following the logic that improvements in these metrics would reduce or eliminate problems related to line congestion and system stability for any circuit layout. The metrics we look at are aggregate netload, average and maximum energy import, average and maximum energy export, average daily peak, daily ramping rate, and daily peak-to-average ratio (PAR).

The average netload, energy import, and export act as good indicators of the overall efficiency of DERMS utilization. The maximum energy import, maximum energy export, and average daily peak indicate the risk of feeder congestion[4]. The daily ramping rate[5] and daily peak-to-average ratio (PAR)[6] act as indicators for overall power system stability. In general, it is desirable to minimize the delta between import/export, as it reduces the required line capacity[7]. Likewise, it is desirable to minimize the ramping rate and PAR[8], as it makes it easier to balance the local system.

[3] https://dataverse.tdl.org/dataset.xhtml?persistentId=doi:10.18738/T8/0YLJ6Q

[4] Energy import is defined as all energy supplied to the community from outside. energy import(t)=max(net load(t), 0) Energy export is defined as the opposite, as energy export(t)=max(-net load(t), 0)

[5] Ramping rate can be defined as the absolute difference between two consecutive building net load readings: ramping rate(t) := absolute(net load(t-1) - net load(t))

[6] PAR is calculated as the ratio of the max net load to the average net load within a timing window, as PAR(t) :=max(net $load_{t-w}$, ...,net $load_t$)/mean(net $load_{t-w}$, ...,net $load_t$)

[7] The average daily import and export can be used as a measure of the system's overall self-sufficiency, and the peak import/export can be used as a measure of the system's ability to coordinate load demand.

[8] Both metrics measure volatility and transient properties of the net load signal, where the ramping rate reflects moment-to-moment volatility and the PAR reflects the variability of the signal during the day.

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6. Results

We begin the analysis by looking at the average daily net load for the entire year, shown in Figure 1.

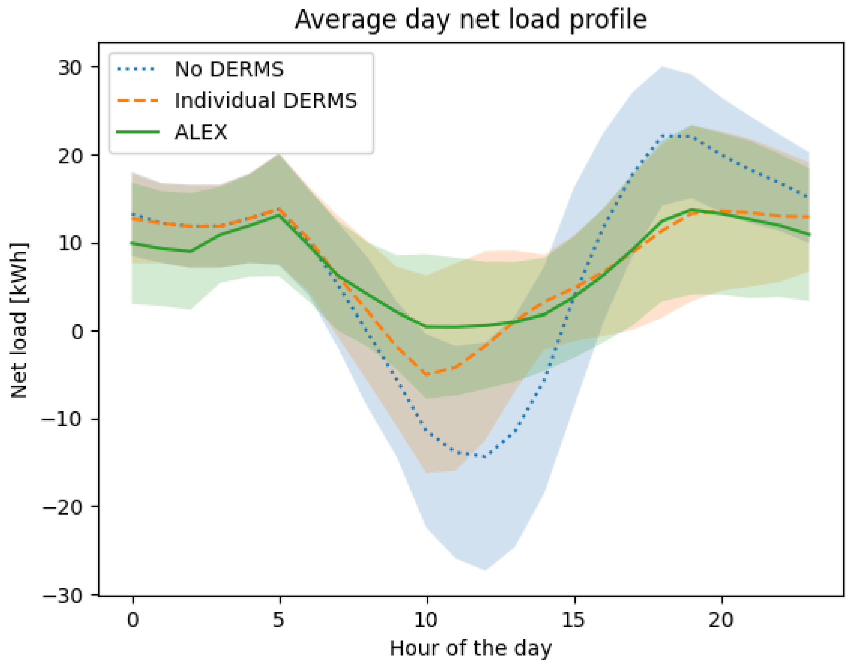

Figure 1: Average day net load profile for the managed community. Plotted are the average net load profile as well as standard deviation bands for No DERMS, Individual DERMS and ALEX scenarios.

A clear “duck curve” can be seen for the baseline case (blue line). The addition of battery storage, paired with individual DERMS (orange), reduces the duck curve. By enabling DER coordination, ALEX (green) reduces the duck curve even further beyond. The complete set of data for comparisons is in Table 1.

Compared to the baseline, individual DERMs manage a 16.9% decrease in daily average imports and a 65.8% decrease in daily average exports. **ALEX managed a 21.6% decrease in imports, and a 83.9% reduction in exports, significantly outperforming individual DERMS.** While the individual DERMS and ALEX achieve the same performance with regards to maximum peak, ALEX actually achieves a notable reduction of minimum valley at 22.5% compared to the individual DERMS at only 2.7%. **ALEX further outperforms the individual DERMS in the reduction of average daily peak (24.1% vs 22.1%), and far exceeds in terms of average daily valley reduction (89.9% vs 63.6%)**. The ramping rates tell a similar story. Individual DERMS manage reductions of 32.9%. **ALEX manages further reductions, achieving 33.6%. ALEX also outperforms with regard to the daily load factor complement (12.3% vs 10.9%) and the monthly load factor complement (4.9% vs 2.4%).**

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Table 1

	No DERMS	**Individual DERMS**	**ALEX**
Avg Daily Import [kWh]	258.54	214.81	**202.68**
Avg Daily Export [kWh]	-77.48	-26.49	**-12.46**
Avg Daily Peak [kW]	25.61	19.95	**19.44**
Avg Daily Valley [kW]	-16.55	-6.35	**-1.67**
Max Peak [kW]	49.06	42.37	**42.37**
Min Valley [kW]	-37.86	-36.8	**-29.34**
Avg Daily Ramping Rate	4.28	2.87	**2.84**
1 - Avg Daily Load Factor	0.73	0.65	**0.64**
1 - Avg Monthly Load Factor	0.82	0.8	**0.78**

Table 1: Metric based comparison of No DERMS, Individual DERMS and ALEX scenarios based on average or cumulative metrics for the whole simulated year. Metrics include cumulative energy import, cumulative energy export, average hourly ramping rate and avg daily PAR.

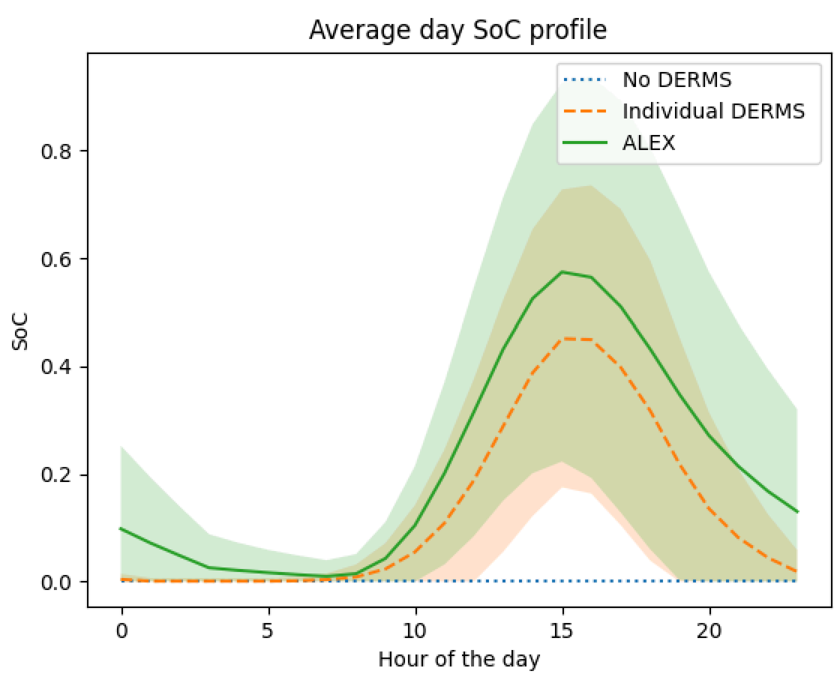

Figure 2: Average day state of charge (SoC) levels of the battery energy storage systems (BESS) of the managed community. Plotted are the average SoC as well as standard deviation bands for No DERMS, Individual DERMS and ALEX scenarios

One interesting metric to look at is the daily state of charge (SoC) for the batteries added. The SoC delta is a good indicator of the efficiency of local resource utilization. The average SoC for all the batteries on the system is shown in Figure 2. It is clear that ALEX better utilizes the storage capacity available (compared to individual DERMS). This results in ALEX being able to use stored energy until after sunrise, serving periods where no solar generation is available. Both of these observations, combined with the previous metrics, confirm that ALEX drastically improves system efficiency and resiliency.

7. Conclusion

The rise of distributed energy resources (DERs) and electrification highlights the importance of intelligent and adaptive grid management systems. ALEX, developed by TREX-Ai, represents a significant advancement in this realm, with its AI-enabled, real-time DER coordination addressing challenges in grid stability and resiliency while highly scalable and easily deployable.

Through a demonstration using a virtual community, ALEX is shown to far surpass traditional DERMS through a robust catalog of metrics, such as community daily energy import/export, daily peak demand, ramping rate, and peak to average ratio. Improvements in these metrics lead to improvements in grid efficiency and will decrease or eliminate line congestion-related phenomena, such as the "duck curve".

This demonstration convincingly showcases ALEX’s capability to optimize grid efficiency, boost resilience, and scale economically with the growth in DERs. With more exciting products in the pipeline, TREX-Ai is paving the path for a future of sustainable and resilient energy landscapes.