Modeling Capabilities to Quantify the Benefits of DERMS

Cooperative Research and Development Final Report

CRADA Number: CRD-17-00713

NREL Technical Contact: Fei Ding

Co-Author: Rishabh Jain

NREL is a national laboratory of the U.S. Department of Energy
Office of Energy Efficiency & Renewable Energy
Operated by the Alliance for Sustainable Energy, LLC

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Contract No. DE-AC36-08GO28308

Technical Report
NREL/TP-5D00-82239
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Suggested Citation

Ding, Fei, and Rishabh Jain. 2022. *Modeling Capabilities to Quantify the Benefits of DERMS: Cooperative Research and Development Final Report, CRADA Number CRD-17-00713.* Golden, CO: National Renewable Energy Laboratory. NREL/TP-5D00-82239. https://www.nrel.gov/docs/fy22osti/82239.pdf.

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Cooperative Research and Development Final Report

Report Date: February 21, 2022

In accordance with requirements set forth in the terms of the CRADA agreement, this document is the final CRADA report, including a list of subject inventions, to be forwarded to the DOE Office of Scientific and Technical Information as part of the commitment to the public to demonstrate results of federally funded research.

Parties to the Agreement: FedIMPACT, LLC

CRADA Number: CRD-17-00713 (Project 2)

CRADA Title: Modeling Capabilities to Quantify the Benefits of DERMS

Responsible Technical Contact at Alliance/ National Renewable Energy Laboratory (NREL):

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Sponsoring DOE Program Office(s): Advanced Research Projects Agency - Energy (ARPA-E)

Joint Work Statement Funding Table showing DOE commitment:

No NREL Shared Resources

Estimated Costs	NREL Shared Resources a/k/a Government In-Kind
TOTALS	$.00

Executive Summary of CRADA Work:

The funds-in under the CRADA will fund a team of National Renewable Energy Laboratory (NREL) researchers to participate in Energy I-Corps (formerly known as Lab-Corps). Energy I-Corps pairs teams of researchers with industry mentors for an intensive two-month training where the researchers define technology value propositions, conduct customer discovery interviews, and develop viable market pathways for their technologies. FedIMPACT, LLC and its affiliate IP Group, Inc., will evaluate the work completed at Energy I-Corps to determine whether it would like to pursue further commercialization and development of related technologies and background intellectual property.

Summary of Research Results:

Tasks 1-4 were completed with the work and outcomes summarized below. Wherein, tasks 1-3 were conducted by the partner IP Group, Inc., and task 4 was conducted by NREL.

Task 1. Project Management

Subtask 1.1: Project Management

Task Description: This subtask will ensure that all project deliverables are provided on time and within budget.

Accomplishment Explanation: All project deliverables were accomplished on time.

Task 2. Commercial/ Business Development

Subtask 2.1. North America Market Analysis

Task Description: Participant will contract a third-party consultant to provide guidance on target markets, sequence, and timing to leverage the product's strengths and ability to successfully demonstrate capabilities in multiple settings (NREL test bed, Behind-the-Meter microgrid, multi-jurisdictional electric cooperative, recommendation of other potential pilots). Assessment will include market potential, competitive landscape within each market, barriers to entry, access routes to key decision-makers, level of demonstration maturity required to interest target markets, and alignment of key distinguishing OptGrid characteristics with market needs. Initial emphasis will be on the North American market, but other potential markets will be investigated at a high-level and in greater detail if warranted (as decided in conjunction with Participant). For the international assessment, additional consultants may be brought in if necessary. This work will culminate in a workshop to review the market assessment results and finalize a list of priority market/markets.

Accomplishment Explanation: IP Group, Inc. investigated similar technologies that are available on the North America market. A summary of the market analysis is provided together with the deliverable of next subtask.

Subtask 2.2. International Market Analysis

Task Description: Execute similar activities to task 2.1 but focused on the international ecosystem leveraging the appropriate methodology.

Accomplishment Explanation: IP Group, Inc. investigated similar technologies that are available on the international market. A summary of the market analysis is provided below.

Type	Company	Amount Raised ($MM)	Notes	Drawbacks
Integrated	Enbala	$42	Started by aggregating load at sewage treatment plants to participate in frequency regulation markets Partnering with ABB to build out its DERMS capabilities Has partnership with National Grid Installs some hardware Historically, most of the system designed to respond to grid signals	Centralized solution
Integrated	Spirae		DERMS to manage DER for VPP, microgrid, distribution grid operations Partnering with Survalent (ADMS) to provide DERMS integration Software and hardware solution	Centralized solution, using server racks Custom design for each system Devices cannot opt-in or out in real time
Integrated	Smarter Grid Solutions	$6	Hardware based system that manages DER autonomously for grid stability Demonstrated at scale in Orkneys Manages 120MW of DER in UK Reduces interconnection costs Had a pilot in ESIF at NREL	Finite state machine is rule based System wide properties are not known or optimized Fault planner functionality is centralized
Integrated	Autogrid	$40	Data analytics from lots of DER devices Integrate with ADMS systems to reach behind the meter Also does VPP For customers provide demand charge management, volt/var control, etc. Customers include HECO, FPL, Palo Alto, Sacramento	Centralized, cloud based solution
Grid Focused	Opus One		Monitors, analyzes and manages DER down to feeder level Front of the meter management SDTC funded pilot with AMS. AMS and SGS manage behind the meter	
Grid Focused	Power Analytics		Specializes in power flow and microgrid modeling software Microgrid management system monitors microgrid operations and performs top-down control Centralized approach Non-rule based	

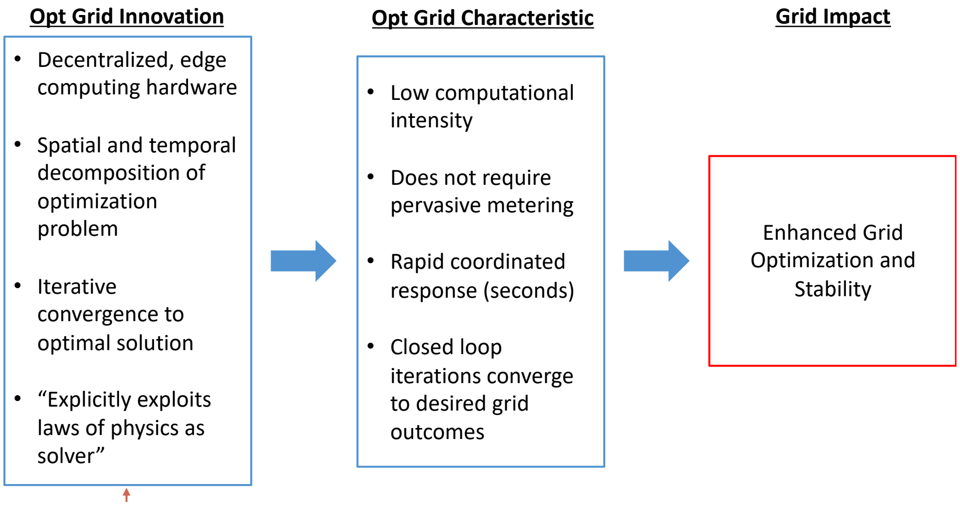
Type	Company	Amount Raised ($MM)	Notes	Drawbacks
			Claims seconds timescale	
Behind the meter	Blue Pillar	$34	Partnered with NRG energy retailer to provide software and NRG provides customers Control behind the meter assets for buildings, with emphasis on backup generators Responds to grid signals 600 customers and 400% growth over 5 years Cloud based	Behind the meter
Behind the meter	OhmConnect		Aggregator of customers Texts customers to change demand behavior during peak demand events Cloud based control of thermostats also available	Behind the meter
Behind the meter	EcoFactor	$24	Residential energy management service Utilizes external data, such as weather as well Aggregates to participate in CA DRAM market	Behind the meter
Behind the meter	Viridity	$40+	Software to allow users to use DER to reduce energy bills or generate more income Cloud hosted Not automated, more like monitoring and dashboards Cofounded by Audrey Zibelman Sold to Ormat for $35MM	Behind the meter
Behind the meter	Tendril	$190	Helps utilities manage behind the meter smart thermostats. Not coordinated	Behind the meter
Behind the meter	Advanced Microgrid Solutions	$58	Aggregating TESLA batteries on customer sites to reduce demand charges and provide capacity to utilities. Aggregation allows them to get scale, get utility interest and lower costs	Behind the meter

Type	Company	Amount Raised ($MM)	Notes	Drawbacks
			Macquarie putting $200MM into AMS products	
Behind the meter	Tesla		Limited to PowerWall management Centrally dispatched	Behind the meter

Subtask 2.3. Business Plan Development

Task Description: Participant will contract a third-party consultant to develop specific deployment strategies for identified priority market/markets. This will include additional details on engaging key market entities within each priority market, determining timing and audience to market ongoing demonstrations, identify additional pilots and partners, and identify path from demonstration/pilot to commercial product offering based on the priority markets. Specific requirements on necessary partners, hardware product and software package considerations, and revenue options (e.g. licensing, embedded system, microgrid-in-a-box solution, utility use-case-specific solutions) will be recommended with the understanding that these will evolve with the multiple demonstrations and any additional pilot efforts.

Accomplishment Explanation: IP Group, Inc. identified the differentiations of OptGrid compared to other existing technologies, and summarized the potential market plan. Figure 1 below shows the features of OptGrid.



Coordinated, localized, optimal estimates are computationally simpler and result in long-term global optimum

Figure 1. The features of OptGrid.

Markets and Markets estimates the global DERMS market size to be $600MM by 2022, consistent with GTM estimate. Deploying DERMS for bulk grid applications is challenging for a number of reasons, including value of DER are not fully monetized, regulations are not in place or evolving, and multitude of stakeholders. However, as DER penetration increases, DERMS value is demonstrated, regulations and monetization schemes are put in place it is expected that the bulk grid DERMS market will grow rapidly in the 2020s.

Meantime, the microgrid market is expected to be large. For example, Grandview Research estimates $18B by 2025; GlobalData estimates $23B by 2021; and Markets & Markets estimates $39B by 2022. The growth is expected to be rapid:

- 17% CAGR until 2025, Grandview Research
- 32% CAGR until 2021, Navigant

So, assuming 3% of microgrid cost is DERMS and $25B marketsize, microgrid DERMS could be $750MM annually in 2021. And, mixture of diesel and solar generation is ideal for maximizing value of OptGrid.

To sum up, the potential market strategy for applying OptGrid can be summarized as:

- Proof of concept demonstrations at NREL, winery microgrid and bulk-grid utility (ARPA-E funded)
- IPG funds commercial activity and commercial product development
- Initially target islanded microgrid market where OptGrid value is greatest
- Pursue bulk-grid market when conditions are appropriate (regulations and monetization in place)
- Revenue derived from a combination of hardware sales and ongoing service fees

Task 3. Talent

Subtask 3.1. Commercial Consultant

Task Description: Participant will commission a commercial consultant to develop an initial business model for OptGrid and provide a report analysis of the findings. The goal of this scope is to identify a first market for the OptGrid technology accounting for the technoeconomic analysis findings, the competitive landscape, deployment, and ability to monetize the technology.

Task Explanation: The consultant identified islanded microgrids as a potential market in the near-term, while waiting for the bulk-grid market to develop. The microgrid market identified was estimated to be $18B by 2025, but was identified to be very distributed and difficult to acquire multiple customers in a scalable manner.

Subtask 3.2. Commercial Lead

Task Description: The purpose of the subtask would be to explore, evaluate, identify, and down select potential commercial leads for the NewCo (short for New Company planned to be spun out of NREL). Participant will engage its internal talent services to execute this scope.

Task Explanation: IP Group, Inc. ultimately decided not to take a license to the intellectual property and form a NewCo. Accordingly, no commercial lead candidates were recruited.

Subtask 3.3. Technical Team

Task Description: Engage potential technical team candidates, finalize the hiring plan for technical team, and acquire commitments from technical team for NewCo.

Task Explanation: IP Group, Inc. ultimately decided not to take a license to the intellectual property and form a NewCo. Accordingly, no technical team candidates were recruited.

Task 4. Technical:

In this project, the team worked on developing a distribution system model with high penetration of distributed PVs, modeling the OptGrid and applying it to the distribution system model, and evaluating the performance of OptGrid considering both technical and economic impacts. The results have been summarized into a report, which was delivered to FedIMPACT. Also, the team had regular meetings with the point of contact from FedIMPACT to present the result and get feedback. Details of the tasks are provided below. All milestones were met for the following Task 4 subtasks.

Task 4 Subtask 4.1: Test System Selection

Task Description: In this task, NREL will select one distribution feeder or microgrid dataset to model. The dataset will be selected from a set of publicly available realistic distribution feeder models, models provided by utility partners, or synthetic feeders created from NREL's SMART-DS Project. The test system(s) will be modeled using OpenDSS to perform three-phase unbalanced power flow. Test systems will feature data with a granularity of one second or a few seconds.

Accomplishment Explanation: A distribution system with reasonable share of both residential and commercial loads was selected from the SMART-DS model for Greensboro, NC. A test setup with distributed implementation of OptGrid based controls was developed using Python and OpenDSS. For the high (67%) PV penetration case, a fleet of measurement nodes were assumed to have meters for voltage measurement. These measurements were communicated to the distribution system operator (DSO). Details of the test system were provided below.

Fig. 1 shows the one-line topology of the test system. This represents one of the feeders from the SMART-DS system models for Greensboro, NC. The system has 823 nodes in total. The system peak load is 6.5 MW and total PV generation is modeled to be 4.2 MW. The corresponding voltage profile based on the distance from the substation is presented in Fig. 3.

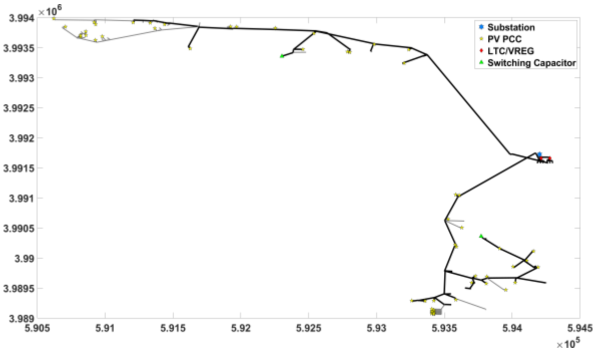


Figure 2. One-line topology of the test system.

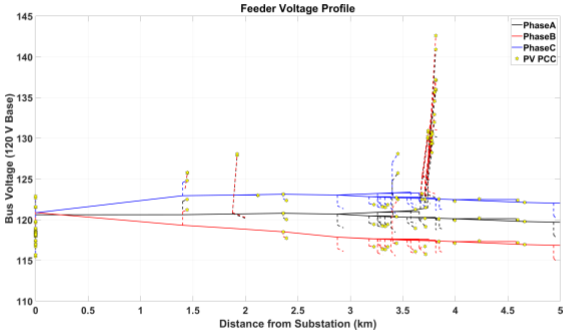


Figure 3. Voltage Profile vs. Distance from the Substation.

Task 4 Subtask 4.2: Simulation Platform Development

Task Description: In this task, NREL will develop a simulation platform using Python to model and perform techno-economic cost-benefit analysis for the real-time optimization (RTO) technology. This task will be accomplished by leveraging one of NREL's existing software (software record number will be listed later). The simulation platform will integrate the RTO algorithm and OpenDSS power flow solver, and it will be able to conduct quasi-static time-series (QSTS) simulations on the test systems identified in Task 1 and analyze and visualize the impact of the real-time algorithm on distribution feeders.

Accomplishment Explanation: NREL team developed the simulation platform based on the existing Python software tool that has been developed previously. The final simulation platform was used to integrate the distribution system model developed in Task 1 and model the OptGrid optimization algorithm, and then conduct QSTS simulations. Fig. 3 shows the overview of OptGrid based control for voltage and power management in distribution systems. Based on the available measurements collected across the system and net substation power demand objectives, the DSO dispatches reference signals for each of the participating assets. Based on these signals and local measurements, the respective OptGrid controller located at each asset regulates the respective dispatch to help the DSO meet their control objectives. Fig. 5 presents the flow of information between the participating agents.

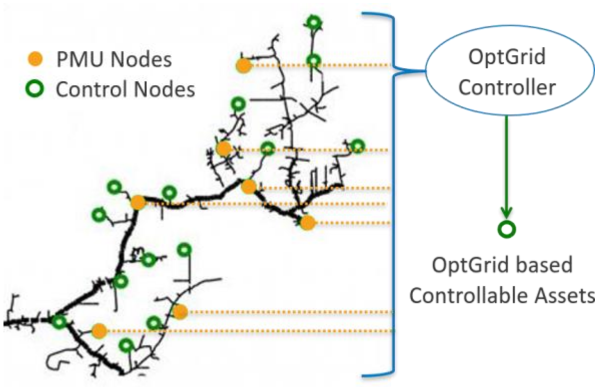


Figure 4. OptGrid based control for distribution systems.

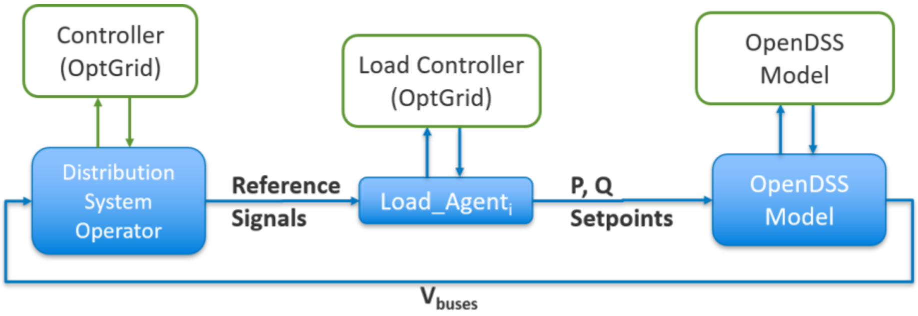


Figure 5. Evaluation platform that uses OptGrid for voltage/power management

The study assumes that distribution systems may have a combination of controllable PV and loads. For all participating PV systems, OptGrid is allowed to use the inverters for controlled reactive power compensation as needed, without curtailing the real power output. For all participating loads, OptGrid based controller can curtail the demand based on the user preferences. These preferences may or may not change over time, depending on the use-case.

Generally, two control settings were modeled in the project. The first control allows the substation operator to dispatch localized voltage regulation objectives subject to the measurements from all the respective sites. For PV plants, unless operating under limited power output, the reactive power contribution will be regulated for improving the system voltage. Loads may be shed (reducing both the real/reactive power consumption) for improvements in the system voltage. The second control allows the substation operator to combine the dispatch of the assets for voltage management with substation power demand goals. The aggregate control signal is a weighted sum of the voltage regulation and virtual power plant (VPP) signals. For this study, both parameters have been given equal importance. But this may vary based on the DSO preferences.

Task 4 Subtask 4.3: Use Case Studies

Task Description: In this task, the baseline simulation study will be first conducted and all DERs are operated under legacy control setpoints. Then, the RTO algorithm under test will be enabled and QSTS simulations will be performed. The stability and economic impact (capex and opex) will be compared between the baseline, RTO and competitor timeframes.

Accomplishment Explanation: In this task, the baseline simulation study was first conducted and all DERs were operated under legacy control setpoints. Then, the OptGrid technology was enabled and QSTS simulations were performed. Multiple scenarios were defined and reviewed by the IP Group customer. With the agreed scenarios, NREL team conducted multi-scenario simulation studies. The stability and economic impact were compared between the baseline and OptGrid scenario. A final report was developed and delivered to the customer.

To evaluate the performance of OptGrid against state-of-the-art solutions, each voltage management strategy was individually evaluated. Four major scenarios were considered, including: (1) Regulators Only – The regulators in the system are installed with the respective controls monitoring one of the buses from the lower 10% of the system voltage. Any capacitors or other voltage regulation assets modeled in the original system have been disabled. Each regulator step is 0.00625 p.u.. (2) Capacitors Only – Two 3-phase capacitor banks of size 400kVAR, 350kVAR respectively have been installed in the system downstream. Any regulators or other voltage control assets modeled in the original system have been disabled. The capacitor banks have a simple on-off control, as is traditional with the state-of-the-art installations. (3) Regulators and Capacitors – Both the regulators and capacitors considered for the "regulators only" and "capacitors only" are enabled. This case represents a traditional state-of-the-art model for managing the distribution system voltage. (4) OptGrid – These cases consider any other voltage regulation assets (including regulators and capacitors) besides OptGrid are disabled. The objective is to allow for better comparison between the improvements.

Additionally, we defined the voltage violation magnitude index (VVMI) that quantifies the average voltage violation exceeding a predefined limit V_{limit}, (Upper/Lower Limit). If at time t, $\delta V_{j,t} = V_{j,t} - V_{limit}$ is defined as the overvoltage on the j^{th} node voltage, $V_{j,t}$ in per unit exceeding the limit. Then $VVMI$ is given as:

$$VVMI = \frac{\sum_{t=0}^{M-1} \sum_{j=1}^{N} \delta V_{j,t}}{\mathrm{n}\left(OV_{j,t} > 0\right)}$$

VVMI represents the average deviation from the limit voltage. (+) $\Longrightarrow$ Overvoltage, (-) $\Longrightarrow$ Undervoltage, (0) $\Longrightarrow$ No Violations.

Results

Figure 6 represents the overall voltage magnitude distribution (in p.u.) at the buses where voltage was measured across the system. It presents the magnitude region where most of the bus voltages are, as well as the maximum and minimum voltage seen. Fig. 6 represents the box plot for the same voltages, showing the band of voltages for most of the buses. These figures demonstrate that compared to the baseline, smart inverters show the most drastic increase in the number of buses where the voltage is closest to the ideal value (1 p.u.). OptGrid based strategies using PV only (with/without load and VPP) comes second by improving the voltage across the system. However, the maximum overvoltage in the system increases when using smart inverters, while OptGrid based strategies consistently reduced the maximum overvoltage in the system as well.

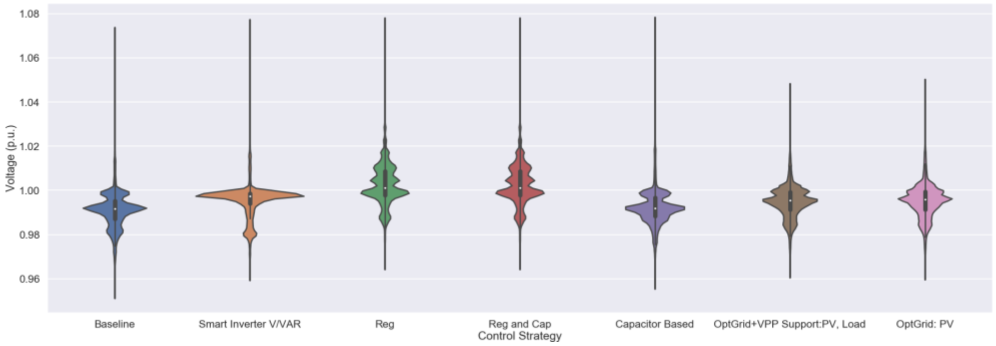


Figure 6. Voltage distribution for different control strategies.

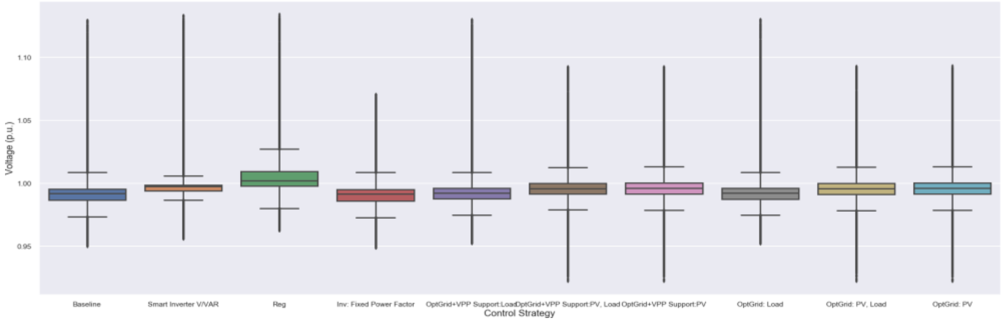


Figure 7. Mean voltage distribution for different control strategies.

Figures 8, 9 compare the real and reactive power output for the different OptGrid based strategies with respect to the baseline. Note that, while the real power output of the PV in both cases is practically the same (no curtailing - as per the assumptions), the reactive power support increases significantly resulting in the respective voltage improvements. As noted previously, the reactive power support depends on the input from the DSO, and the available inverter capacity. In other words, the reactive power support is minimal when a DER is generating power close to its maximum inverter rating.

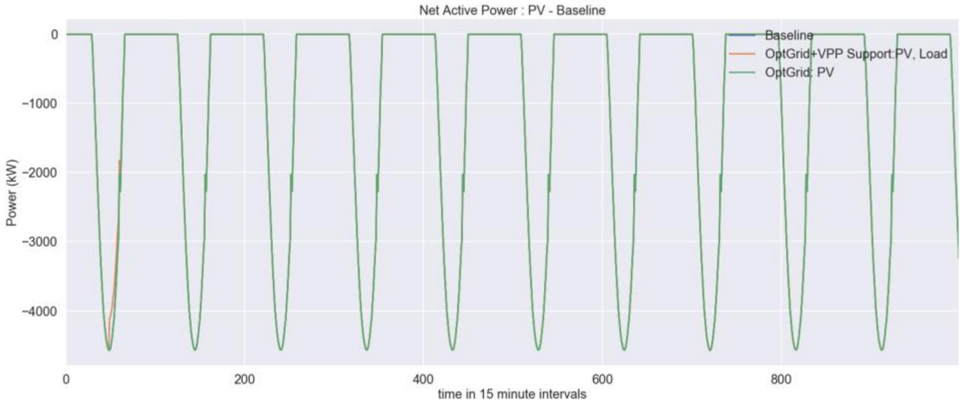


Figure 8. Real Power Output from PV for the different OptGrid control strategies.

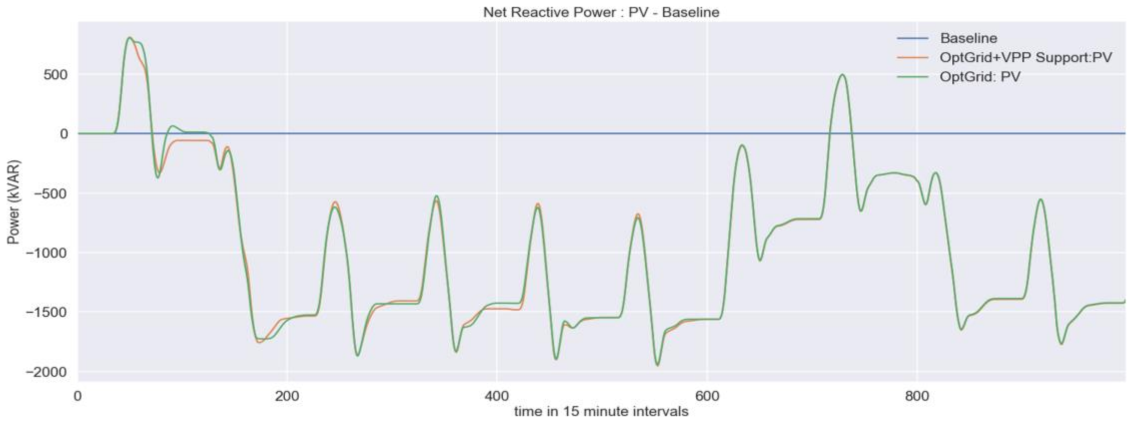


Figure 9. Reactive Power Output from PV for the different OptGrid control strategies.

Fig. 10 demonstrates that the controllable loads did shed their load by up to 10% (350kW) as needed. Consecutive change in the net power exchanged at the substation can also be seen in Fig. 10. However, since the net load shed is only 5% of the overall substation load, "load only" based OptGrid controls were seen to have more improvements for the local voltage, but didn't affect the overall system voltage as well as when using PV based reactive power compensation. This demonstrates that the OptGrid controllable loads are valuable for helping the DSO participate in managing the substation power, and also help the local voltage to some extent.

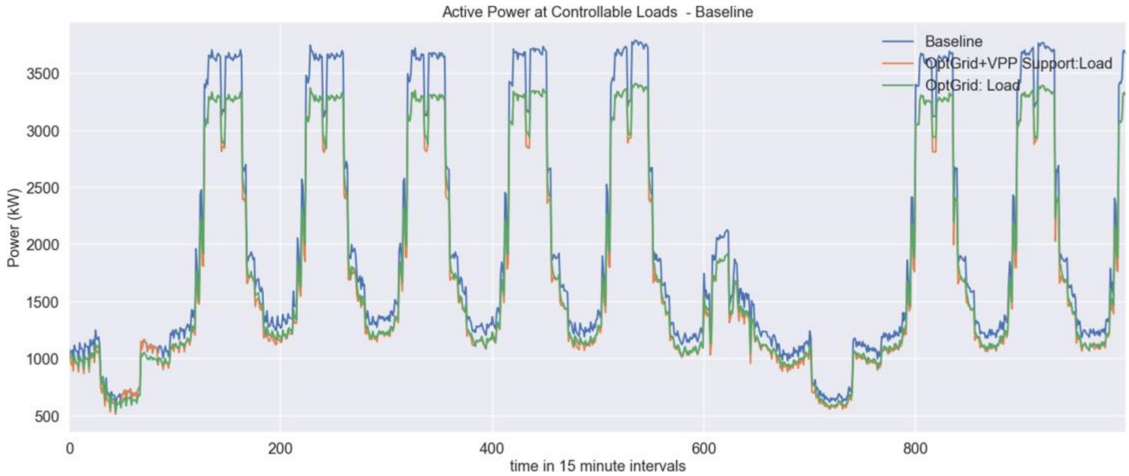


Figure 10. Net real power demand from the controllable loads in the system.

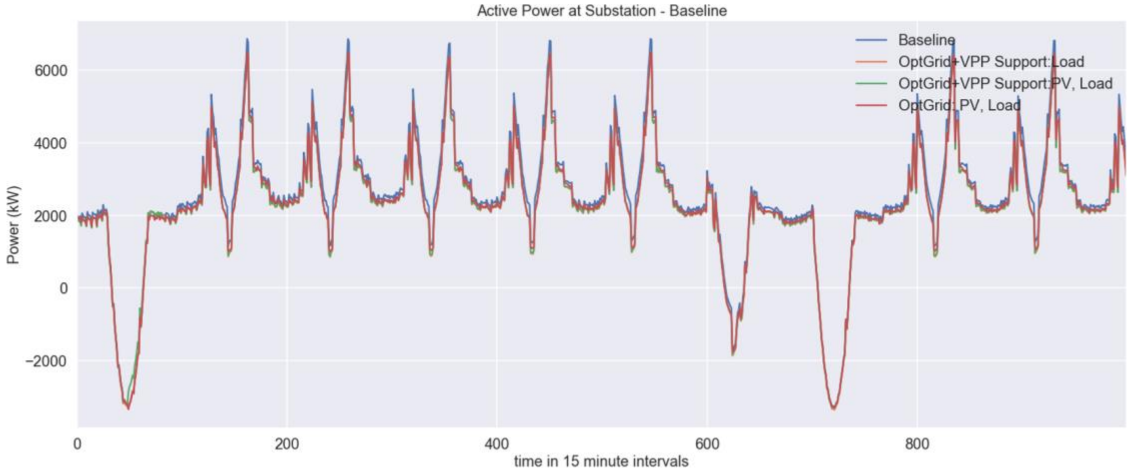


Figure 11. Net real power demand at the Substation when using controllable loads.

Figure 12 presents the average magnitude of voltage violation across the buses measured. It can be noted that, among all the control strategies, OptGrid based control strategies involving PV (with/without load) have the most reduction in the magnitude of voltage violation. Table 2 shows the comparison of costs for different scenarios.

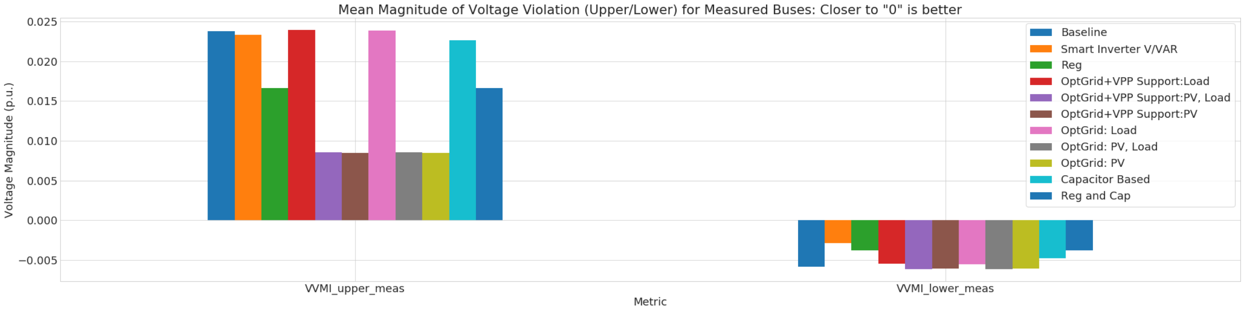


Figure 12. Comparison of the Voltage Violation Magnitude Index for different control strategies.

Table 2. Comparison of costs obtained for different scenarios.

Cost	Smart Inverters	Regulators	Capacitors	OptGrid
Capital	-	$150,000	$40,000	$200
Installation	-	Included	Included	$100
Moving	-	$50,000	$3,900	$0
Customer Acquisition	-	$00	$00	$100
Maintenance	-	Included	Included	$200
Net Cost per unit	-	$150,000	$40,000	$600
Number of Units	-	1	1	58
Net Cost	$0	$150,000	$40,000	$34,800

<u>Subject Inventions Listing</u>: None

<u>ROI #</u>: None