17 February 2023

California Energy
Commission
715 P Street, Sacramento,
CA 9581
Via Electronic Filing

CEC Docket 22-RENEW-01: Clean Coalition Comments on January 27, 2023 DEBA Workshop

Dear Chair, California Energy Commission Members, and Staff,

The Clean Coalition is a nonprofit organization whose mission is to accelerate the transition to renewable energy and a modern grid through technical, policy, and project development expertise. The Clean Coalition drives policy innovation to remove barriers to procurement and interconnection of distributed energy resources ("DER") — such as local renewables, demand response, and energy storage — and we establish market mechanisms that realize the full potential of integrating these solutions for optimized economic, environmental, and resilience benefits. The Clean Coalition also collaborates with utilities, municipalities, property owners, and other stakeholders to create near-term deployment opportunities that prove the unparalleled benefits of local renewables and other DER.

We appreciate the opportunity to submit these comments on the January 27 DEBA workshop and are generally pleased with the breakdown of funding as well as the proposed timelines. While our main assertion remains that DEBA will be most successful if it includes implementing an efficient procurement program (e.g., a Feed-In-Tariff) that will allow any new capacity—ideally, paired with energy storage—to be interconnected in a timely manner, the answers to the questions posed below will also address resource potential that DEBA should take advantage of.

1. How best can DEBA invest in assets for emergency load reduction without interfering in the Resource Adequacy Program or creating clean stranded assets? How can it best do both?

As past comments by the Clean Coalition and other parties have stated, funds should be focused on <u>effectively procuring additional distributed capacity, investing in emerging technologies, and capitalizing on opportunities to deploy microgrids</u>.

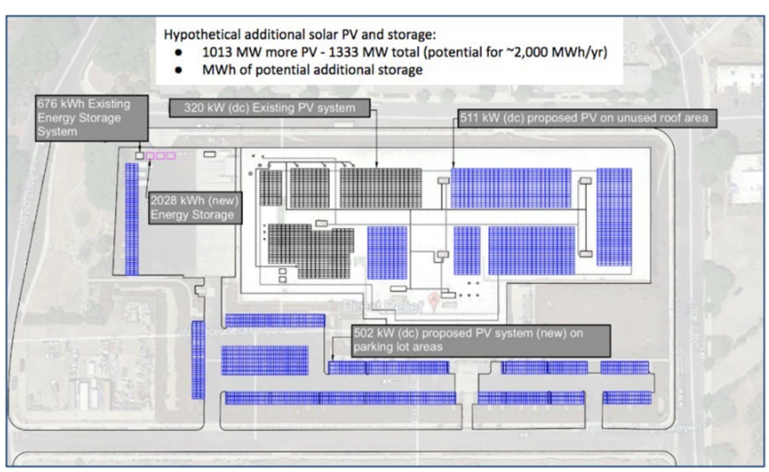
Effectively procuring additional distributed capacity: DEBA should target deployments of solar+storage on built environments (e.g., rooftops, parking lots, and parking structures). Based on Clean Coalition's experience conducting Solar Siting Surveys for the City of San Diego, East Bay Community Energy, and Peninsula Advanced Energy Community (PAEC), over 50% of the siting potential on built environments is on parking lots.[1] The opportunity is clear, but so is the reason that there has not been further development thus far: program limits and the interconnection process. Behind-the-meter (BTM) deployments are constrained by Net Energy Metering (NEM) requirements that limit project sizing to the

[1] https://clean-coalition.org/solar-siting-surveys/

existing site load, which caps the amount of solar that can be deployed and removes the possibility of deployments at locations without a corresponding existing electrical load. Consider the photo below, which shows non-profit Direct Relief's building in Santa Barbara, with a solar PV deployment sized according to existing NEM requirements.

Photo of Direct Relief's new headquarters, located near the Santa Barbara Airport.

Notice that only a small portion of the total roof space has solar deployed and none of the parking lot is being utilized. **Current BTM interconnection programs do not allow properties to fully utilize all available space, even when doing so would improve reliability and resilience, benefitting the local community and the broader electrical grid.** The schematic below shows the Direct Relief site, if solar+storage could be deployed on the entire built environment, which a Feed-In-Tarff (FIT) would enable.[2]



Direct Relief solar+storage deployment under a FIT scenario

For the other portion of parking lots that cannot utilize the Rule 21 interconnection process, developers who choose a front-of-meter interconnection (FOM) via existing Community Solar programs rather than

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[2] https://clean-coalition.org/community-microgrids/direct-relief-case-study/

delving into CAISO markets will quickly come up against a headache of requirements including, but not limited to—an RFO process filled with uncertainty, finding a site in a DAC, partnering with a local CBO, the ineligibility of co-located storage, and the tenuous reputation of past Public Utilities Commission (PUC)-administered WDG programs. Clean Coalition has submitted a FIT proposal to the PUC and believes that alignment between that program and DEBA could result in a significant amount of Community Solar+Storage being sited and deployed within a short time frame.

Investing in emerging technologies: The Commission should consider investing DEBA funds in emerging technologies that optimize grid performance and maximize the benefits from aggregated distributed energy resources (DER). For example, distributed energy resources management systems (DERMS) are a combination of hardware and software solutions that effectively manage aggregated DER, creating value through increased hosting capacity, resilience, and system visibility & control.[3] As additional distributed capacity is deployed and managed through an integrated operating system, the state will realize the opportunities to enable microgrids and reap the full benefits of DER.

Another relevant emerging technology that should be considered is the distribution STATCOM (d-STATCOM), a proven technology originally used for optimization of the transmission system adapted for use on the distribution grid. Unlike other traditional infrastructure solutions, as more DER are interconnected to a feeder, d-STATCOMS will function more effectively, leading to increasing benefits over time. Appendix A, below, is an analysis of the J1 distribution feeder that demonstrates the potential value d-STATCOMS can add when optimally sited for reactive power management. The J1 feeder has a peak load of 6 MW and 2 MW of existing solar deployed. With d-STATCOMS installed, the amount of solar able to be deployed on the feeder increases by 10 times— to 20 MW of solar. The d-STATCOMS are able to maintain the feeder integrity even as the deployed solar rose to 125% of the zone substation transformer rating.[4] By improving the efficiency of the distribution grid, emerging technologies such as the two described above, reduce line losses and the need for transmission-interconnection energy, improving reliability.

Capitalizing on opportunities to deploy microgrids: Though past iterations of the Commission's Integrated Energy Policy Report (IEPR) have underscored the benefits of microgrids, and the PUC has spent three years attempting to meet the SB 1339 mandate to commercialize microgrids, the technology remains grossly underutilized in California. Deployments of BTM microgrids have not increased at the expected rate and the number of installed Community Microgrids remains in the single digits. However, given the monumental amount of new capacity needed in the state, the fact that microgrids create an unparalleled trifecta of economic, environmental, and resilience benefits—while providing extremely reliable service—makes them an ideal solution for DEBA. Microgrids can function as traditional generating resources or island an operate as a demand response resource. Evolved power control systems now allow for microgrids comprised solely of inverter-based resources (IBRs) to swiftly identify and react to faults and to seamlessly transition from an islanded mode to a grid following mode, or vice versa.

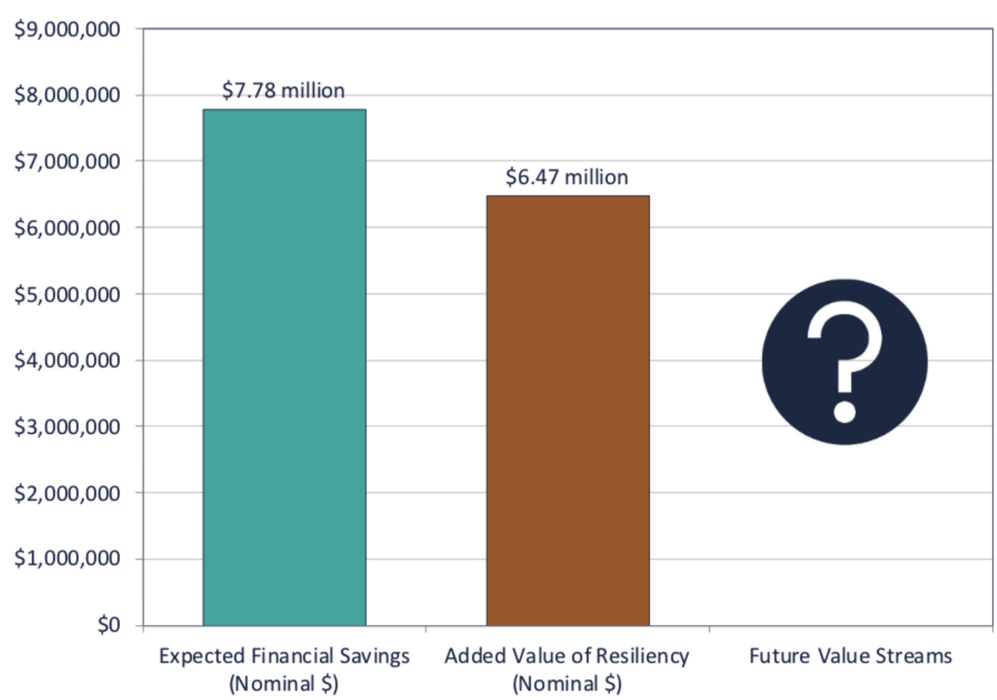
[3] https://clean-coalition.org/news/derms-webinar-june-2020/ (webinar by Smarter Grid Solutions)
[4] See Appendix A, figures 6-8, for a graphical representation of these results.

Past state action on microgrids has not included taking the foundational step of adopting a standard value of resilience, which remains a major roadblock to the widespread deployment of microgrids. DEBA funding, along with streamlined procurement are important steps toward resolving the ambiguity surrounding the value of resilience and will lead to swift deployments in three key areas: solar microgrids at schools, Community Microgrids in load pockets, and single parcel microgrids that span multiple meters.

1. *Solar Microgrids at schools*

One of the low hanging fruits for DER deployment, especially in disadvantaged communities (DACs), should be the deployment of solar, Solar+Storage, or Solar Microgrids across schools, district buildings and government facilities. Because school district revenues come, in part, from the collection of property taxes, lower-income communities are at a disadvantage as compared to wealthier communities. DEBA investments to deploy Solar Microgrids would help meet reliability goals, while also checking boxes for environmental justice goals, resilience goals, and quality-of-life benefits for students (increased shading, reliable cooling/heating during extreme weather events, opportunities to learn about renewable energy, and better funded schools, and a safe community center).

Clean Coalition worked to facilitate the deployment of Solar Microgrids for Santa Barbara Unified School District (SBUSD), resulting in deployments of solar at fourteen sites and full Solar Microgrids at six sites. In total over the lifetime of the 28-year power purchase agreements, SBUSD will see guaranteed bill savings of $7.8 million and an additional $6.5 million in value-of-resilience (VOR) for free.[5]



Financial savings from SBUSD

[5] https://www.edhat.com/news/santa-barbara-school-board-approves-solar-microgrids

This same model can be replicated effectively at school districts throughout the state to improve reliability and resilience, while also helping public facilities electrify. The Commission should consider using Peninsula Clean Energy's streamlined procurement for local governments, where developers bid for the rights to deploy solar, solar+storage, or Solar Microgrids for a bundle of projects at public facilities throughout a municipality.[6] This program condenses the normally complex, and time-consuming process, of hiring a consultant to conduct a feasibility study and an RFO, while maximizing the savings for the local government.

2. *Community Microgrids in load pockets*

Community Microgrids solve for questions of reliability and resilience in load pockets, which are defined as geographic areas of load that, because of transmission limitations, must have resources internal to the area available to operate so as to ensure reliable service to the area's load.[7] For example, the Goleta Load Pocket (GLP) spans 70 miles of coastline, from Point Conception to Lake Casitas, encompassing the cities of Goleta, Santa Barbara, and Carpinteria.

Important to know is that the GLP's only connection to the transmission system is routed through the heart of fire, landslide, and earthquake zones via the Goleta Substation. The highly vulnerable transmission route is shown as a purple line in the maps above and below, and as can be seen in the fire risk map below, the GLP's transmission connection is routed through a treacherous fire zone.

[6] https://www.peninsulacleanenergy.com/solicitation/publicfacilitiesrfp/
[7] https://www.lawinsider.com/dictionary/load-pocket

The Clean Coalition has worked to size a Community Microgrid capable of sustaining the most critical loads in the region for an extended period. Achieving indefinite renewables-driven backup power that provides 100% protection to the GLP against a complete transmission outage (known as an "N-2 event") will require 200 MW of solar and 400 MWh of energy storage to be sited within the GLP. Much of the energy storage has already been deployed; what the GLP needs most to advance the GLP Community Microgrid is more deployed local solar and the right set of circumstances (e.g., funding, an appropriate tariff, and a utility willing to work as a partner).

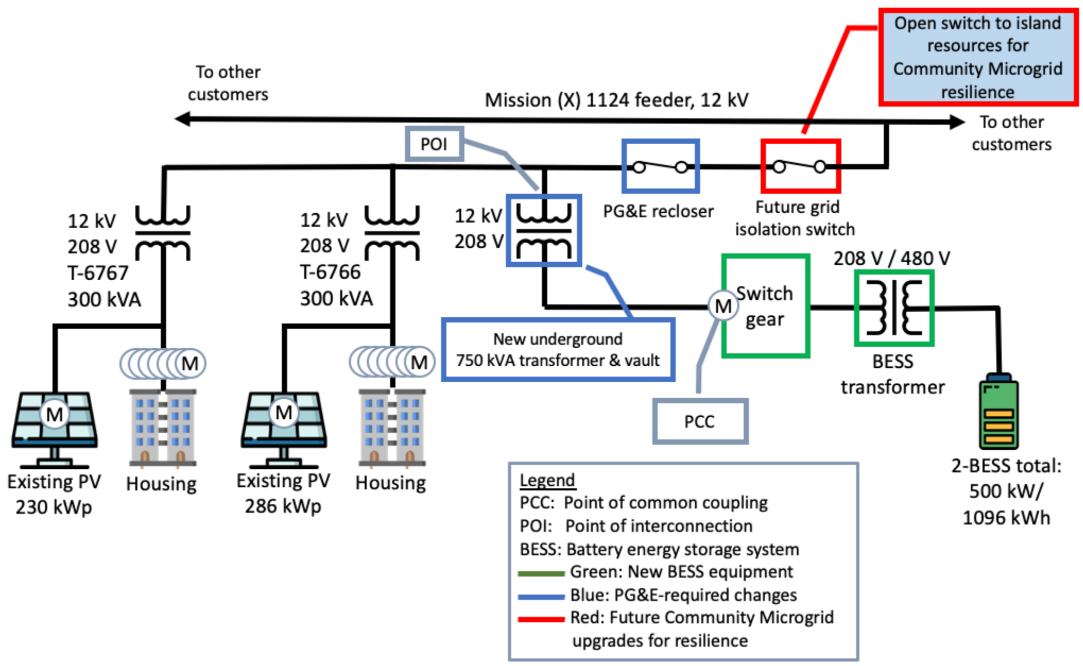
3. Single parcel microgrids that span multiple meters

Around 45% of Californians rent their housing, with the majority residing in apartments or other multi-unit single-property buildings.[8] Without owning the property, it is difficult for residents to have sufficient agency for energy planning and all but precludes the possibility of deploying a resilience solution. For other multi-meter buildings such as commercial buildings or mixed-use properties, complex rules related to metering are equally as limiting as the rules for residential buildings. For all three types of single-parcel properties with multiple meters, installing a single recloser would be enough to form the microgrid, while leaving the utility's visibility of the site relatively unchanged. Unfortunately, this market segment has been completely passed over by the PUC in the microgrids proceeding (R. 19-09-009), where it has been clear thus far that significant changes to Rule 18 are not up for discussion.[9]

Consider the Valencia Gardens Energy Storage (VGES) project, a FOM merchant energy storage project the Clean Coalition is working to deploy in PG&E's service territory as part of a CEC grant. The plan is to deploy the energy storage on the same 12 kV feeder as FOM-interconnected solar and the Valencia Gardens Apartments (low-income senior housing). This situation, and many other like it, are perfect candidates for Community Microgrids.

[8] https://calmatters.org/commentary/2022/03/every-city-in-california-needs-to-do-its-fair-share-to-create-more-housing/

[9] D. 21-01-018 approved an **extremely limited** exemption to Rule 18 that permits two adjacent publicly owned critical facilities (but they must be owned by two separate agencies) to share energy, only during grid outages. Such a small subset of critical facilities is eligible for this Rule 18 exemption that it really isn't useful at all. Clean Coalition is not aware of **any deployed projects** that have used this exemption.



VGES Single Line Diagram

As shown by the Single Line Diagram above, after the energy storage is situated, only a few upgrades will be needed—the installation of a recloser and a microgrid control system—before a Community Microgrid is deployed and operational. Current regulations do not permit the deployment a Community Microgrid because the microgrid would utilize a portion of PG&E's distribution grid and islanding necessitates a special agreement to guarantee utility-worker safety. Clean Coalition believes that DEBA instructions for microgrids should lay out allowances for Community Microgrid deployments and provide specific situations when islanding is acceptable/mandatory.

2. Are the proposed program frameworks reasonable? What modifications could unlock additional resources for emergency events?

The proposed frameworks are reasonable. The focus should be on investing in additional capacity, not just creating programs that are duplicative of existing utility programs, such as demand response or the Emergency Load Reduction Program (ELRP).

3. Are there additional criteria that the CEC should consider when evaluating projects? How should the CEC rank or weight the evaluation criteria?

Additional benefits, to the broader grid and local community, should be counted in favor of applicants. Projects that can be deployed faster should be receive a few extra points, as should projects with local community support (assuming a point scale out of 100). The "cost" evaluation criteria should also consider the percentage of the total project cost requested to be covered by DEBA funds. The Commission should also take this opportunity to study whether a targeted DER deployment (based on location) would be more cost-effective than traditional location-agnostic policies.

4. What are reasonable exceptions to non-performance in an emergency event?
The focus should be on renewable resources. We have no further comments at this time.

5. What level of funding is needed to spur the development of a project?
No comments at this time.

The Clean Coalition appreciates the opportunity to submit these comments on the January 27 DEBA workshop and looks forward to further engagement on this subject.

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Appendix A

Feeder PV Hosting, Voltage Profile and Power Quality Management using advanced distribution level STATCOMs

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Abstract— **Traditional distribution level STATCOMs can regulate a feeder voltage profile through reactive power control. Advanced STATCOMs can support very high levels of distributed generation to the point of significant power flow reversal. Additionally, they improve phase current and voltage balance by suppressing negative and zero sequence voltages. The phase current and voltage balancing process will frequently require the transfer of real power from heavily loaded to more lightly loaded phases. For a three-phase system, current balancing inherently improves voltage regulation by eliminating the neutral conductor voltage drop. This paper demonstrates the current balancing and voltage regulation capabilities of advanced STATCOMS. Current balance improvement is demonstrated with shunt connected devices using only voltage measurements at the point of coupling.**

Keywords—STATCOM, distribution system, phase balancing, voltage regulation.

I. INTRODUCTION

Over the past two decades distribution networks have seen profound operational changes as new technologies, such as photovoltaics, home battery systems and electric vehicles proliferated, [1-3]. Technological innovation has also benefited the distribution network designer. A range of power electronic based devices can be deployed to improve the capacity and utilization of networks, [4]. This paper focuses on the application of advanced distribution level static compensators, (dSTATCOMS), to North American distribution feeders.

North American distribution feeders utilize a three-phase four-wire medium voltage backbone with significant single phase lateral branches. Most residential customers are single phase connections via single phase transformers connected from a medium voltage phase to the neutral conductor. These transformers are typically below 50kVA and often supply fewer than five homes. The existing North American feeders have been designed to operate successfully with a level of current unbalance that is higher than would be found in European or British Commonwealth systems.

This paper demonstrates the improvements to voltage profiles, feeder loading and solar hosting capacity, that can be achieved with the improved current balance that dSTATCOMs can provide.

II. STATCOM OPERATIONAL CAPABILITIES

A STATCOM is commonly implemented with a current controlled voltage source inverter (VSI), [4], that is able to inject programmable currents at the point of common coupling (PCC). The VSI has a DC bus with limited energy storage provided by capacitors. Given the limited internal energy storage, the inverter phase currents must be controlled so that the average inverter real power is zero. The permissible averaging time depends on the size of the DC bus capacitor but will typically be from one to a few dozen mains cycles.

In distribution and transmission applications, STATCOMs have be used for voltage regulation by the injection of reactive power, [4]. In railway applications, where trains may present single phase loadings above 10MW, STATCOMs are widely applied for phase current balancing and the control of negative sequence voltages, [5-7]. Only recently STATCOMS for phase balancing have appeared in distribution network applications, [8].

Inverter based STATCOMS are inherently capable of a wider range of operations. The physical constraint is that the average inverter real power must be zero. Permissible operations include:

- The supply programmable positive sequence reactive currents
- A zero-sum real power transfer amongst phases
- For systems with reasonably balanced voltages, the supply of programmable negative or zero sequence currents, [8]
- The supply, or sinking, of programmable harmonic currents, with arbitrary harmonic order, sequence and balance.

These activities can occur simultaneously. For a current controlled VSI, the inverter currents are the superposition of the currents needed for each task. For a current limited VSI, apportioning the available inverter capacity between several tasks is an interesting exercise. In many situations, for example where some voltage unbalance exists, these activities might consume or generate a small amount of average power. Power balance at the DC bus can be retained by importing or exporting positive sequence real power.

For the voltage regulation of a distribution network, a STATCOM's inherent capability to improve power system current balance, provides multiple benefits. A capacity to transfer real power from lightly loaded to heavily loaded phases may circumvent thermal limits. Balance improvements assist the network designer to satisfy the negative and zero sequence voltage limits that apply in each jurisdiction. A current-balanced three phase system has the best voltage regulation as any neutral voltage drop, or rise, is eliminated. A STATCOM that can improve current balance simultaneously assists the designer is meeting voltage balance limits as well as improving the feeder voltage regulation.

III. J1 Feeder Genealogy

The J1 feeder, located in the North-East of the USA, is a test case available from the Electric Power Research Institute (EPRI), [9]. This is a 12.47kV feeder with a peak load of approximately 6MW that serves 1300 residential, commercial and light industrial customers via 58 miles of primary lines. The feeder has an on-line tap changer at the zone substation which maintains the 12.47kV bus bar at 1.033pu. There are a further three voltage regulators and five voltage switched capacitors, totaling 3.9MVAr within the feeder. The feeder layout is shown as Figure 1. The line thickness indicates power flow, with the highest flow being 6.38×10^3kW. The substation, at the feeder head, is located at the bottom right. EPRI has provided a detailed network model, including load models, in OpenDSS. OpenDSS is an open-source distribution network analysis tool provided freely by EPRI, [10]. The J1 feeder has been widely used for photovoltaic system integration studies, [11-12]. The J1 feeder model has 3,434 buses of which 348 are three phase buses located on the 12.47kV primary lines. While there are higher voltage STATCOM solutions, in many implementations the STATCOMs would generally need to connect via dedicated transformers to the medium voltage system.

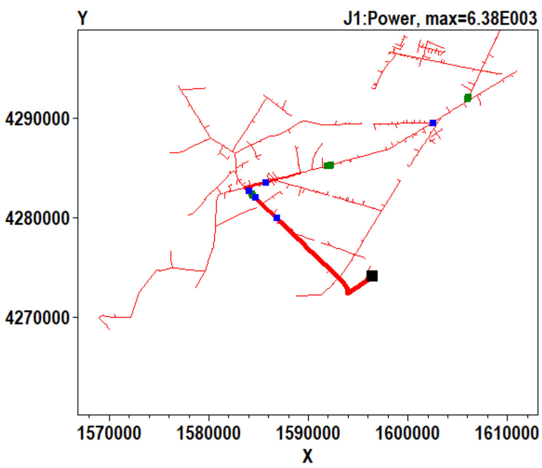

Fig. 1. J1 feeder substation black, regulators green, capacitors blue

IV. OpenDSS STATCOM Model

OpenDSS does not include a dedicated STATCOM model. There are two models that can be adapted. The existing generator model can operate in a constant power constant voltage (PV) mode. When the real power is set to zero, the generator will supply reactive power to regulate the positive sequence voltage. The existing photovoltaic inverter model can be set to exhibit a volt-VAr regulating characteristic. Both pre-existing models are available in singe and three phase forms.

This paper demonstrates the phase balancing benefits of distribution STATCOMs. For that purpose, a three phase STATCOM model is required that can operate in an unbalanced injection current mode. The STATCOM model uses a delta connection of three reactive power sources, V_{ab}, V_{bc} and V_{ca}, that are coupled by an ideal transformer to the four-wire system. The PCC is terminals 0 to 3. Figure 2 shows a schematic representation.

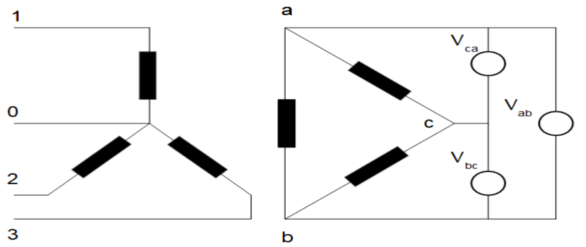

Fig. 2. OpenDSS STATCOM model

The three voltage sources are OpenDSS single phase generator models operated in the constant voltage (PV) mode. A delta connection of reactive sources, either passive inductor and capacitive elements, or active VAr sources such as STATCOMS or TCRs, is widely used for phase current balancing in the railway industry. The OpenDSS generators are constant power, constant voltage (PV) devices. The power setting is zero and the generators adjust their reactive power to maintain their terminal voltages. All generators are set to the nominal voltage set point. As the voltages are equal, the voltage phasors form an equilateral triangle. The primary and secondary voltages must take up a 120° phase displacement. This connection forces the negative and zero sequence voltages to zero at the PCC. The injected STATCOM currents will naturally adjust to produce this result. In some cases, the necessary currents cause real power to be transfers between the connected phases. As the OpenDSS generators are purely reactive elements, the constraint that the real powers sum to zero is maintained.

The inclusion of tightly coupled star-delta transformer in OpenDSS simulation supresses any zero sequence voltage without the need for any connected STATCOM elements. Kirchoff's voltage law taken around the delta winding forces the sum of the phase voltages, that is the zero sequence voltage, to be zero. The transformer will carry the necessary compensating currents, and have a resulting circulating delta winding current.

The coupling transformer parameters are initially selected to give near ideal behaviour. The leakage reactances and winding resistances are set near zero. This enforces the balanced three phase STATCOM voltages upon the four-wire power system. A natural consequence is a rebalancing of phase currents upstream of the STATCOM.

The OpenDSS constant PV generator model has an ideal voltage regulation characteristic. The resulting three-phase STATCOM model is voltage stiff and produces high compensation currents for small votlage errors. A drooping characteristic can be incorporated by adding leakage reactance to the coupling transformer.

V. Case Studies

In order to determine the effectiveness of STATCOMs as voltage regulation and balancing devices, the J1 feeder is assessed for the following cases:

A. Original circuit configuration, with peak load
B. Circuit with three STATCOMS at the regulator locations, with peak load
C. Circuit with three STATCOMS at the regulator locations, with load and 20MW distributed PV generation
D. Circuit with three STATCOMS at optimal placements, with peak load and capacitors
E. Circuit with three 1MVA STATCOMS, 1% droop, at the regulator locations, with peak load, capacitors retained
F. Circuit with three 1MVA STATCOMS, 1% droop, at the regulator locations, with load and 20MW distributed PV generation, capacitors retained.

Within any distribution network, STATCOMs will generate reactive powers if the network voltage deviates from their voltage setting. The STATCOM settings should be coordinated with the substation regulator setting to avoid unnecessary reactive power flows. In these simulations a flat voltage profile has been selected. The STATCOMS have the same voltage set point, 1.033pu, as the zone substation tap changer.

A. Original circuit configuration, with peak load

The original J1 feeder is evaluated with the supplied load distributed load case of 6MW. The standard case includes a further 5MW spot load at the zone substation. The system maintains the voltages within the range 0.967 to 1.040pu and the voltage profile is shown as Figure 3. The substation loading is 11.58MW + 0.033MVAr. The power factor is 1.00 and all capacitors are in service. At the furthest points, the highest boost provided by the regulators is 10%.

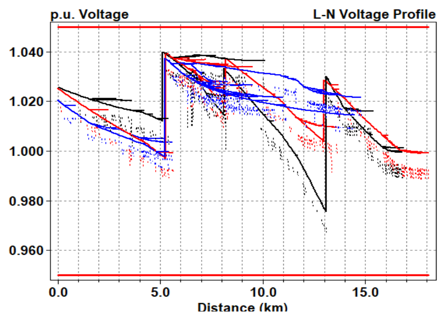

Fig. 3. Voltage profile, standard load.

B. Circuit with three STATCOMS at the regulator locations, with peak load

Three STATCOMS, each being three-phase and without current limits, are placed at the three pre-existing voltage regulator locations. This example illustrates the phase balancing capacity. The same voltage set points as used for the regulators are retained being 1.033pu. The voltage profile is shown in Figure 4. The voltage range is 0.988pu to 1.035pu which is better than the regulator-based solution. The substation loading is 11.72MW - 1.64MVAr. The power factor is 0.990 leading.

Table I shows the STATCOM real and reactive powers by phase. As well as purely reactive currents, there are significant real power transfers between the phases. Table II shows the real and reactive powers upstream and downstream of the STATCOMs. The STATCOMS clearly assist in current and power balance. For example, the STATCOM at bus B18967, the tail location, has upstream current magnitudes of 110.6A, 112.0A and 110.3A and downstream current magnitudes of 86.6A, 63.4A and 21.5A respectively. Table III shows the upstream and downstream powers. The upstream real powers by phase are 424kW, 347.7kW and 286.8kW. The real power ratio, heaviest to lightest, is 1.47. The downstream phase real powers are 524.7kW, 392.3kW and 133.8kW. The real power ratio, heaviest to lightest, is 3.92. The loading of the heaviest phase reduced by 100kW while the lightest phase load increased 153kW. These STATCOMs are larger than are practically required. It is possible to retain the switched capacitors and this significantly reduces the STATCOM reactive rating.

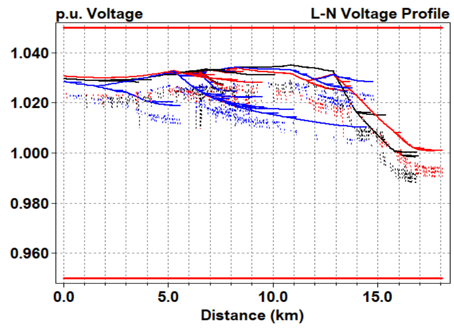

Fig. 4. Voltage profile with STATCOMs, standard load.

TABLE I. STATCOM Real and Reactive Powers

Bus Bar	Phase 1 (kW) (kVAr)	Phase 2 (kW) (kVAr)	Phase 3 (kW) (kVAr)	Total (kW) (kVAr)
B4870REG Head	180.7 -608.9j	96.4 -632.5j	-277.1 -896.0j	-0.0 -2137.5j
B18864REG Middle	58.0 -253.9j	-48.9 -299.8j	-9.1 -237.8j	0.0 -791.5j
B18967 Tail	-108.8 -1082.7j	-45.1 -1016.2j	152.6 -854.0j	-0.3 -2952.9j

TABLE II. STATCOM Upstream and Downstream Currents

Bus Bar	Upstream Current			Downstream Current		
	Phase 1 (A)	*Phase 2 (A)*	*Phase 3 (A)*	*Phase 1 (A)*	*Phase 2 (A)*	*Phase 3 (A)*
B4870REG Head	281.2 ∠12.1	279.2 ∠-108	276.2 ∠132.8	243.0 ∠5.2	249.1 ∠-116	291.4 ∠115.4
B18864REG Middle	141.8 ∠37.5	139.7 ∠-79.9	133.9 ∠158.0	111.2 ∠29.8	114.5 ∠-94.4	111.2 ∠147.4
B18967 Tail	110.6 ∠41.2	112.0 ∠-72.4	110.3 ∠171.8	86.6 ∠-53.1	63.4 ∠-172	21.5 ∠69.3

TABLE III. STATCOM Upstream and Downstream Powers

Bus Bar	Upstream Power			Downstream Power		
	Phase 1 (kW, kVAr)	*Phase 2 (kW, kVAr)*	*Phase 3 (kW, kVAr)*	*Phase 1 (kW, kVAr)*	*Phase 2 (kW, kVAr)*	*Phase 3 (kW, kVAr)*
B4870REG Head	1904.4 -858.1j	1892.0 -854.9j	1860.5 -868.8j	1723.3 -250.3j	1788.0 -228.6j	2137.2 +26.1j
B18864REG Middle	653.4 -829.5j	605.6 -845.7j	609.6 -788.4j	594.3 -576.5j	653.6 -546.9	617.8 -551.4j
B18967 Tail	424.4 -704.5j	347.7 -755.6j	286.8 -766.8j	524.7 +372.6j	392.3 +260.3j	133.8 +86.9j

C. Circuit with three STATCOMS at the regulator locations, with peak load and 20MW distributed PV generation

The original J1 feeder is supplied with a distributed solar generation case of 2MW. This is increased by a factor of ten to give a total of 20MW of generation. This ensures that power flow is significantly reversed in both the feeder and the zone substation. Solar generation of 10.868MW is added as distributed generation spread proportionally across the customer connection points. A further 9.132MW is added at the zone substation. The original J1 feeder load distributed load of 6MW is retained. The standard case includes a further 5MW load at the zone substation. The total loading is 11MW. The solar generation exceeds the load requirement. The 20MW of total solar generation is 125% of the zone substation transformer rating of 16MVA. The net distributed generation, 10.868MW exceeds the distributed load of 6MW. Likewise, the lumped generation at zone substation, 9.132MW exceeds the 5MW spot load.

The STATCOMs are well able to control the voltage profile which is shown as Figure 5. The voltage range is 1.021pu to 1.043pu. The substation loading is -8.48MW and 0.62MVAr. The power flow is significantly reversed while power factor is 0.9973 lagging. The net reactive power from the STATCOMs is 2,877.4kVAr. This is a reduction of 3,004kVAr from the previous load case without distributed generation.

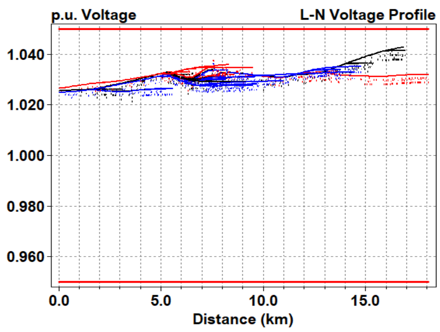

Fig. 5. Voltage profile, standard load with PV generation.

D. Circuit with three STATCOMS at optimal placements, with peak load and capacitors

STATCOMs have a zone of influence that extends upstream and downstream from the point of connection. A reasonable question is whether the regulator positions are reasonable STATCOM locations. In this example, three unrestricted STATCOMS are optimally placed using a genetic algorithm running in a combined MATLAB/OpenDSS environment. The cost function is the sum of squares of voltage deviations from the setpoint, 1.033pu. A weighting of 0.001 is applied to the system real power losses, in kilowatts. The resulting voltage profile is shown as Figure 6. The selected buses are: B19183; B18949; B18967. The cost function value is 1.3788. Figure 7 shows the bus locations. These locations are relatively close to the existing regulator positions and the STATCOM loadings are comparable in both cases. Two STATCOMs are placed close to the tail location. The very tight control of voltages at the tail forces the nearby 1200kVAr capacitor to switch off. The STATCOM at the middle position exchanges significant real power between phases. The voltage range is 0.986 to 1.038. The substation loadings are 11.73MW and -1.88MVAr.

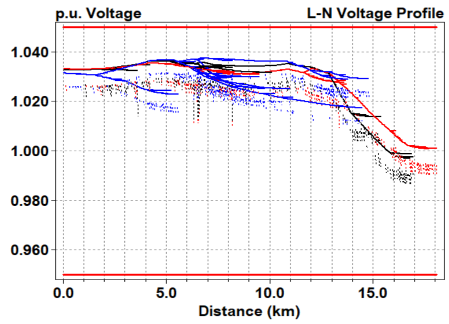

Fig. 6. Voltage profile, optimal placement with standard load.

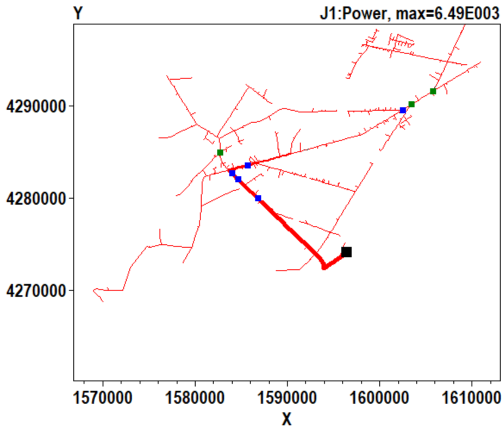

Fig. 7. Optimal placement locations with standard load, substation black, STATCOMS green, capacitors blue.

E. Circuit with three 1MVA STATCOMS, 1% droop, at the regulator locations, with peak load, capacitors retained

Three 1MVA rated STATCOMS with a 1% droop characteristic are placed at the regulator locations. Figure 8 shows the voltage profile. The voltage range is 0.982 to 1.036pu. All capacitors are in service. The STATCOM real and reactive powers are shown on Table IV. The tail STATCOM is current limited in two of three phases. The substation loading is 11.61MW and -1.71MVAr.

TABLE IV. STATCOM REAL AND REACTIVE POWERS

Bus Bar	Phase 1 (kW) (kVAr)	Phase 2 (kW) (kVAr)	Phase 3 (kW) (kVAr)	Total (kW) (kVAr)
B4870REG Head	64.7 +38.0j	75.4 -52.5j	-140.1 -146.6j	0.0 -161.0j
B18864REG Middle	31.4 -169.7j	8.3 -203.3j	-39.8 -133.3j	0.0 -506.3j
B18967 Tail	2.5 -416.1j	-78.1 -289.8j	75.6 -283.8j	0.0 -989.6j

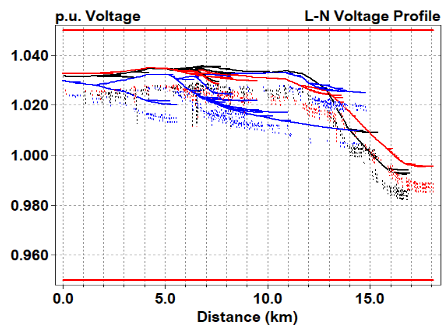

Fig. 8. Voltage profile with 1MVA STATCOMs, standard load.

F. Circuit with three 1MVA STATCOMS, 1% droop, at the regulator locations, 20MVA distributed generation, with peak load, capacitors retained

The 20MW of PV generation is added to the previous case. The voltage range is 1.014 to 1.041pu and the voltage profile is shown in Figure 9. To restrain the voltages the 1200kVAr capacitor at the tail location switches out of service. The tail STATCOM, which was nearly at its full capacitive rating in the previous load case, now provides inductive reactive power. The substation loading is -8.474MW and 0.478MVAr. Table V shows the head and tail STATCOMS transfer significant real power between phases.

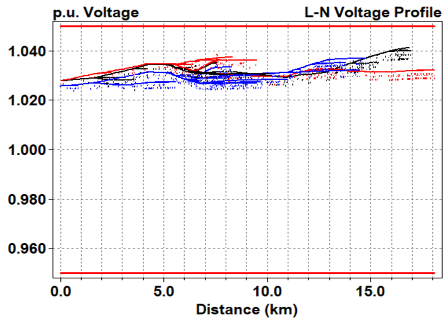

Fig. 9. Voltage profile with 1MVA STATCOMs, standard load and PV.

TABLE V. STATCOM REAL AND REACTIVE POWERS

Bus Bar	Phase 1 (kW) (kVAr)	Phase 2 (kW) (kVAr)	Phase 3 (kW) (kVAr)	Total (kW) (kVAr)
B4870REG Head	-114.4 +30.9j	-38.6 +42.4j	153.0 -75.6j	0.0 -161.0j
B18864REG Middle	-47.4 -59.6j	25.3 -97.9j	22.1 -91.3j	0.0 -506.3j
B18967 Tail	78.4 -25.3j	20.6 +18.3j	-99.1 +124.9j	0.0 -989.6j

CONCLUSIONS

STATCOMs have been shown to be a viable voltage regulation alternative for the J1 distribution system even in the case of very high levels of distributed generation. The case studies show that STATCOMs provide a strong phase current and voltage balancing capability. Notably, the current balancing feature does not require the measurements of downstream currents avoiding the need to retrospectively install current transformers. Voltage and current balancing increases the load and PV hosting capacity of any feeder through improvements to voltage regulation and alleviating thermal and power quality constraints. The current balancing feature is not offered by voltage regulators or switched capacitors. The current balancing ability is particularly useful at the tail of the J1 feeder. At this point the three phase feeder splits into two sections, one two-phase and one single-phase. Balancing the voltage at this junction transfers power from a lightly loaded phase to support more heavily loaded phases. This improves the voltages at the head of the single-phase sections.

For systems with a significant load reactive power, switched capacitors can be used to reduce the required STATCOM ratings. The STATCOM voltage set point must be carefully co-ordinated with other voltage regulation elements. Two reasonable starting points are to:

- Adopt a flat feeder voltage profile where the zone substation OLTC has the same set point as the STATCOMs
- Adopt a falling feeder voltage profile where the zone substation OLTC has the same set point as the set point for the first STATCOM. Set point voltages fall along the feeder length.

The first scenario is well suited to high PV penetration cases where power flow reversal is probable during some part of the day. Some voltage droop, for example 1%, is useful for limiting circulating currents between adjacent STATCOMs. Switched capacitors should have their turn off voltage points set at or very near the STATCOM voltage set points. This ensures capacitors turn off when the STATCOMS enter their inductive range.

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