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Sent: Friday, April 12, 2024 11:53
To: Comentarios <comentarios@jrsp.pr.gov>
Subject: Fwd: Negociado de Energía

INCREASING HOSTING CAPACITY OF DISTRIBUTION FEEDERS THROUGH ENERGY STORAGE AND SMART INVERTER FUNCTIONS

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EXPO CONVENCIÓN CIAPR

Introduction

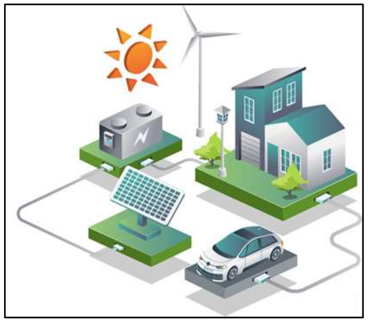
Climate change

- Need to curb greenhouse gas emissions to avoid the adverse, or negative effects of climate change.
- Many countries have promoted policies to contribute to safeguarding the environment with environmentally friendly means of electricity generation.
  - In Puerto Rico, public policy 82-2010 establishes that by 2050, electricity generation must be 100% renewable energy [1]

Distributed energy resources (DERs)

DERs are small or medium sized renewable power sources connected directly to the low voltage (LV) distribution network or near the point of power consumption [2].

- Advantages
  - Environmental conservation
  - Resilient households
  - Decongestion of transmission lines
- Disadvantages
  - High penetration levels can produce negative impacts on power quality



Introduction

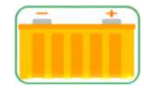
Hosting capacity analysis overview

Hosting capacity (HC) analysis evaluates the number of DER that can be added to a specific feeder without causing technical problems or requiring major changes to the grid infrastructure [3].

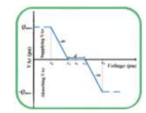
Limiting Factors of HC[4]			
Category	Criterial	Basic	Flag
Voltage	Overvoltage ✓	Feeder voltage	1.05 Vpu
	Voltage deviation	Deviation in voltage from no PV to full PV	3% at primary 5% at secondary ½ band at regulators
	Unbalance	Phase voltaje deviation from average	3% of phase voltage
Loading	Thermal ✓	Element loading	100% normal rating
Protection	Element Fault Current	Deviation in fault current at each sectionalizing device	10% increase
	Sympathetic Breaker Tripping	Breaker zero sequence current due to an upstream fault	150A
	Breaker Reduction of Reach	Deviation in breaker fault current for feeder faults	10% decrease
	Breaker/Fuse Coordination	Fault current increase at fuse relative to change in breaker fault current	100A increase
Harmonics	Individual Harmonics	Harmonic magnitude	3%
	THDv	Total harmonic voltaje distortion	5%

Method to increase HC

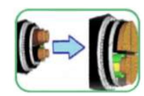
- Energy storage



- Smart inverters
  - Reactive power (Volt-VAR)
  - Active power (Volt-Watt)



- Reconfiguration / Reinforcement



HC Analysis Methodologies[5]

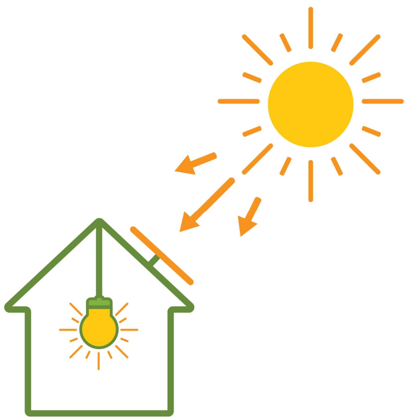
1. Streamlined method
2. Iterative method ✓
3. Stochastic method

Research Objectives

To analyze the HC of distributed PV systems in a typical urban feeder

To increase this HC using RESS and the Volt-VAR function of smart inverters

To propose solutions that maximize feeder HC



Research Methodology

Literature Review

Feeder modeling
OpenDSS

Case 1
Feeder + PV only

Case 2
Case 1 + Battery(Algorithm 1)

Case 3
Case 1 + Smart inverter(Vol -VAR)

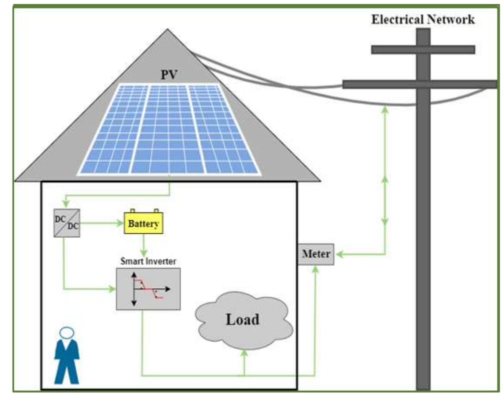
Case 4
Case 1 + Battery +
Smart inverter (Vol -VAR)

Algorithm 1
Designed to reduce the power consumption from the grid.

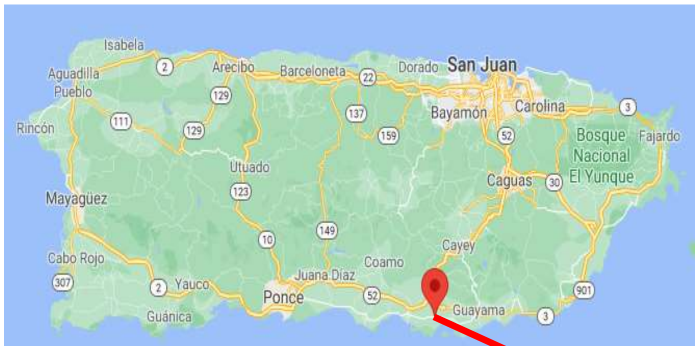
Algorithm 2
Designed to reduce reverse power flow

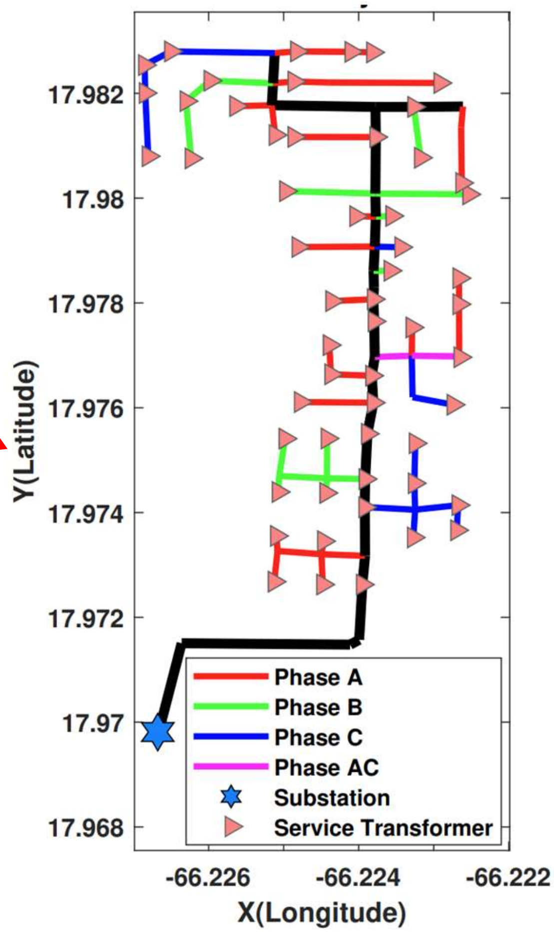
Data Collection and Analysis

Conclusions



Distribution System



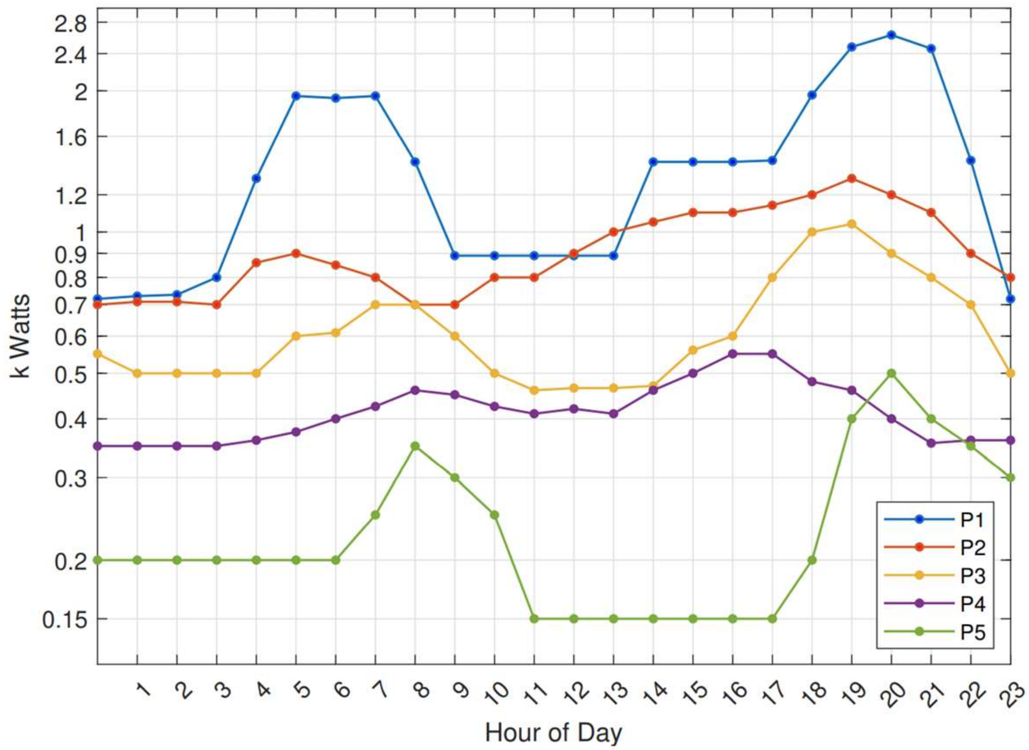


- Open database gis.pr.gov.
- Capstone course reports feeder [14, 15].
- Solar resource and Temperature NASA'S POWER database
- Peak sunshine hours 5 kWh/m2

Characteristics of the distribution network		
Substation	Voltage	38kV - 4.16kV
	Capacity	2MVA
Service Transformer	Voltage	4.16kV - 120/240kV
	Capacity	25kVA - 1 unit
		50kVA - 30 units
		75kVA - 25 units
Feeder	Peak current	152.7A
	Peak load	769kVA
	Length of feeder	3.7km

Demand Profiles

Demand Profile	Family Members	Daily Energy Demand(kWh)	Household Distributed Percent(%)	Number of Households
1	6	33	8.6%	61
2	5	22	29.5%	209
3	4	15	28.3%	200
4	2	10	9.8%	70
5	1	5.75	23.7%	168
			100%	708

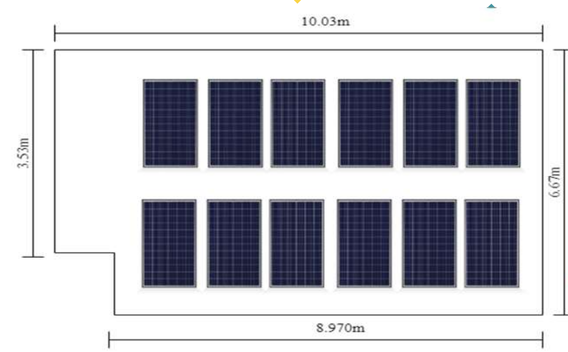


PV scenarios

Classification of households by type of demand profile at each distribution transformer										
Node	Trans.	Rating (kVA)	P1	P2	P3	P4	P5	Number of HH	Demand	
			33kW	22kW	15kW	10kW	5.75kW		Total(kWh)	Total(kVA)
749	T_1	50	1	4	5	1	3	14	223.3	9.30
750	T_2	50	1	6	5	3	1	16	275.8	11.49
765	T_10	50	1	2	2	0	0	5	107.0	4.46

Trans.	Households with PV systems														
	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%	110%	120%	130%	140%	150%
T_1	2	3	4	6	7	8	9	11	12	13	14	13	14	14	13
T_2	2	4	5	7	8	10	11	13	14	16	15	16	16	15	16
T_10	1	2	2	3	4	4	5	5	5	5	5	5	5	5	5

Types of photovoltaic arrays		
Color	Number of Panels	PV System Power(kW)
	12	3.96
	14	4.62
	16	5.28
	18	5.94
	20	6.6
	22	7.26



Therefore, for a photovoltaic array we have:

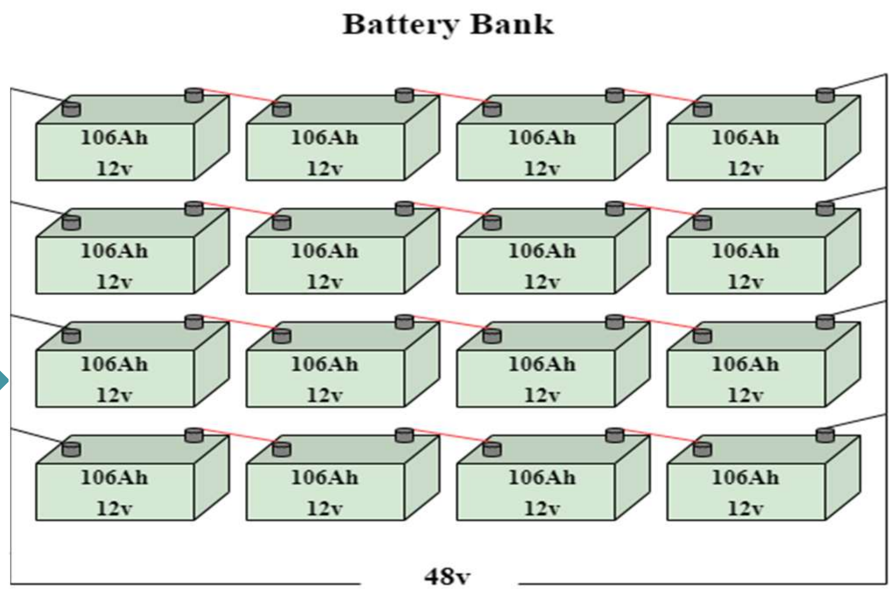
$$Sun\ Peak\ Hours = 5h$$
$$PV_{Power} = 12 \times 330W = 3960W$$
$$PV_{energy} = 3960W \times 5h = 19.8kWh$$

Battery Banks

Battery	Capacity (Ah)	Nominal Voltage	Life Cycles 50% DoD	Price	$/kWh
A - Lead acid	106	12	2750	286	0.164
B - Lithium Ion	100	12	1000	295	0.492

Battery bank power capacity 20.35 kWh

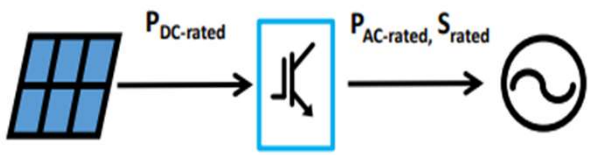
- 2 days back up
- Depth of discharge(DoD) 50%
- Load to be supplied 5 kWh/Day



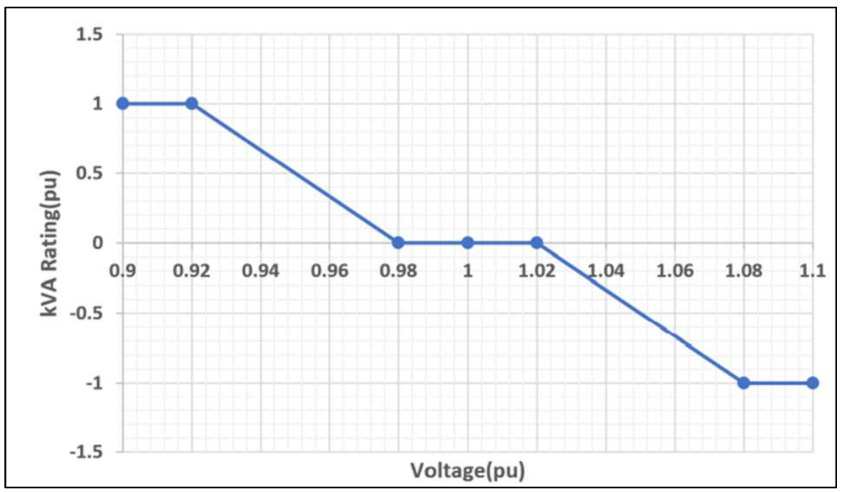
Critical Load				
Loads	Unit	Power (W)	Hours of Use (hrs)	Consumo Total (kWh/D)
Refrigerator	1	140	24	3360
Pedestal Fan	2	100	6	600
Ceiling Fan	1	75	4	300
LCD TV	1	105	4	420
Radio	1	7	12	84
Smart Phones	2	6	4	24
Light Bulbs	4	20	8	160
			Total	5

Inverter (Volt – VAR)

Inverter output power, for different PV array sizes			
PV Array Paneles	PV Array Power(kW)	Inverter Output Power(kW)	DC-to-AC Ratio
12	3.96	3.8	1.04
14	4.62	4.4	1.04
16	5.28	5.1	1.04
18	5.94	5.7	1.04
20	6.6	6.3	1.04
22	7.26	7.0	1.04



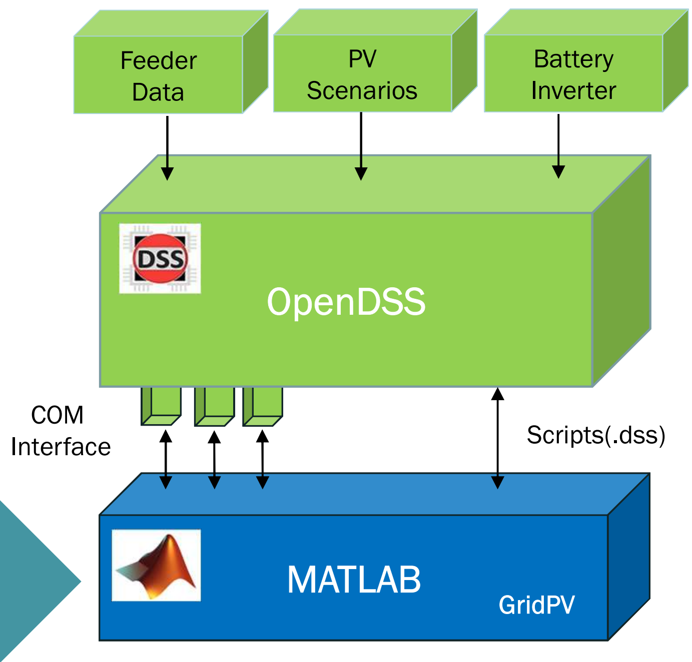
$$DC - to - AC = \frac{P_{DC-rated}}{P_{AC-rated}} = \frac{3.96\ kW}{3.8\ kW} = 1.04$$



IEEE Voltage Regulation Subgroup Proposed Volt-VAR Settings. (Source [16])

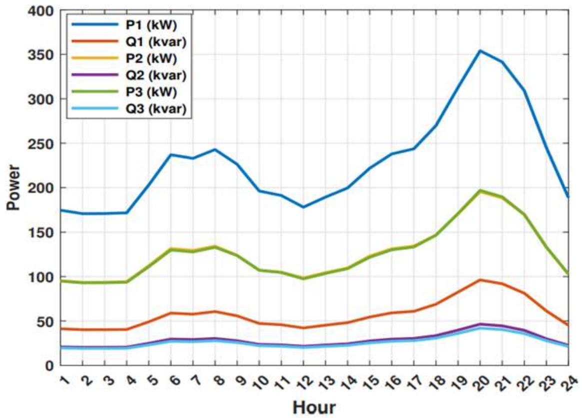
- The maximum reactive power delivery from either injection or absorption is limited to 44% of rated capacity per Hawaii Rule 14H and IEEE 1547 default settings category B

Simulation in OpenDSS and MATLAB

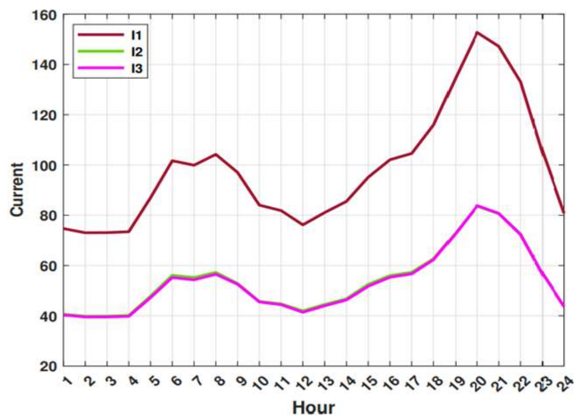


- Open-Source Distribution System Simulator (OpenDSS) is a useful tool for distributed system simulation.
- The solution is presented in long .txt format, difficult to interpret.
- Solution? connect via COM interface to MATLAB.
- MATLAB is a programming software with great capabilities and many built-in functions such as the GRIDPV toolbox that allows graphing the results obtained from OpenDSS.
- Taking control of OpenDSS from MATLAB enhances its functionality and makes it easier to process the results.
- Additionally, MATLAB can be used to control and modify the simulations performed by OpenDSS.

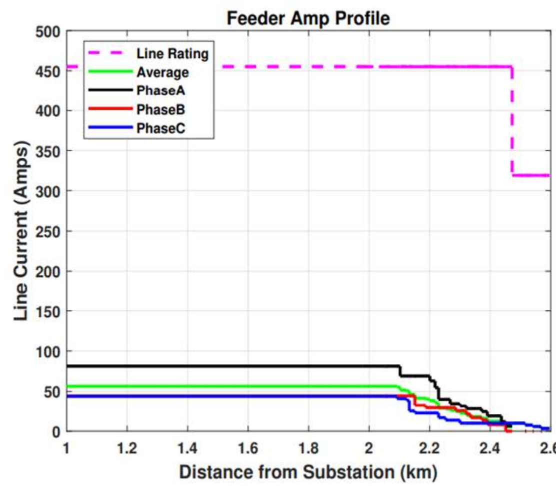
Feeder Power Flow – No PV



(a) Power demanded in the substation

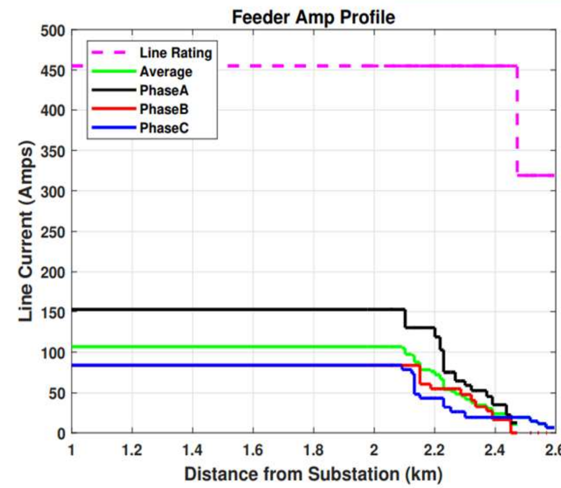


(b) Current demanded in the substation



(a) Current profile for 13:00

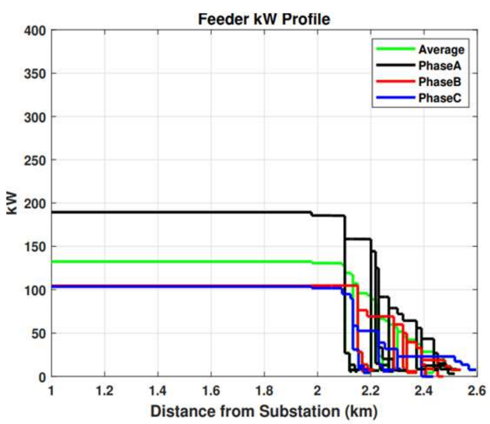
- ➢ The **average current** demand at the substation is **56.52A**



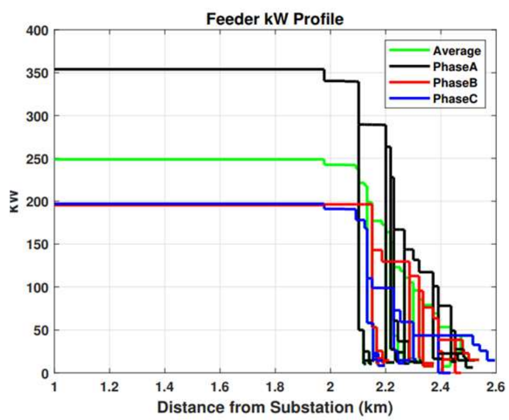
(b) Current profile for 20:00

- ➢ The **average current** demand at the substation is **106.74A**

Feeder Power Flow – No PV



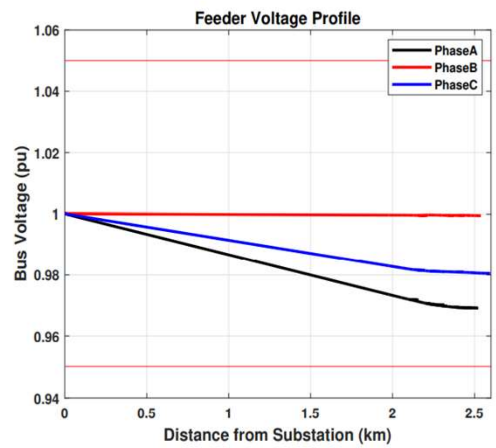
(a) active power profile for 13:00



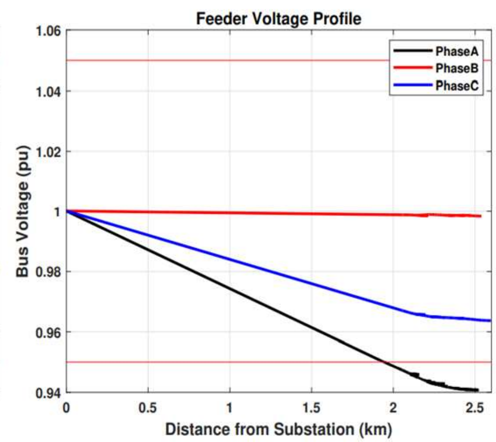
(b) active power profile for 20:00

- The **average active power** demanded at 13:00 hours is **132.4kW**
- the **average peak power** demanded is **248.82kW**

- For 13:00 hours, all **phases are within the allowed voltage range**
- For 20:00 hours, **phase A violates the voltage limits**

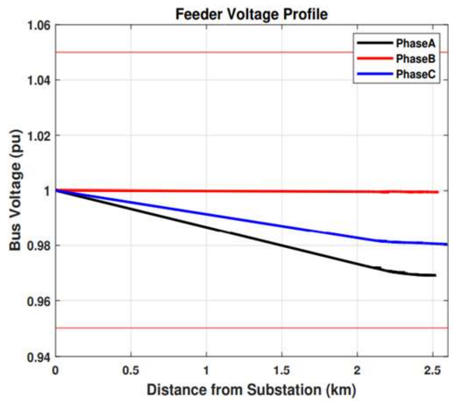


(a) Voltage profile for 13:00

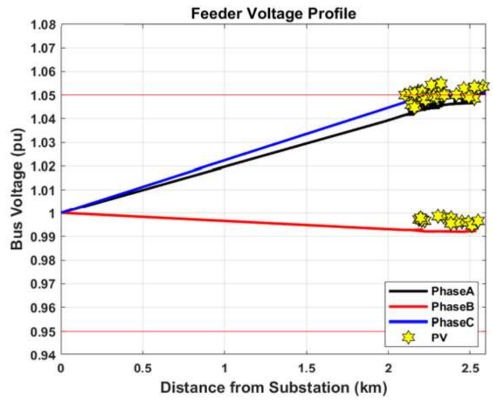


(b) Voltage profile for 20:00

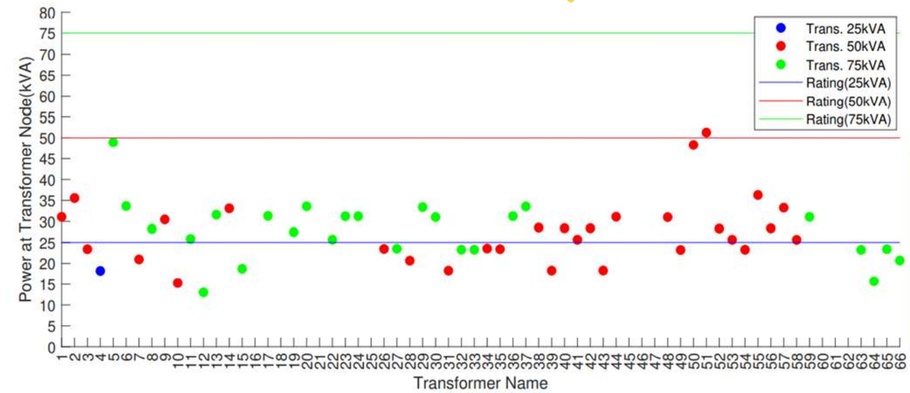
Case 1: PV Only



Without PV



70% PV



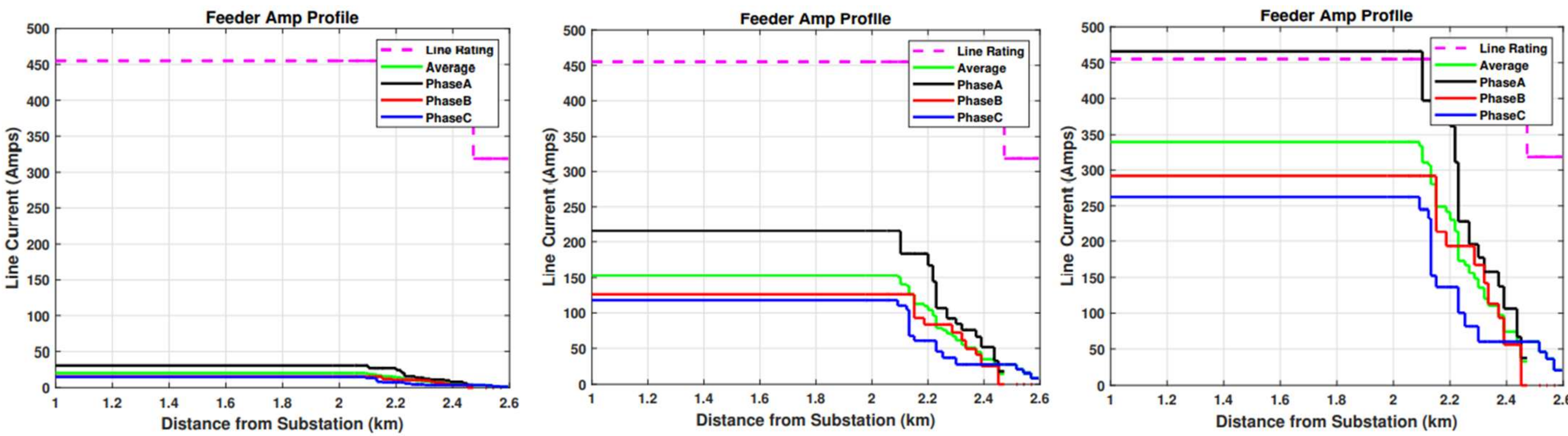
90% PV

PV Level	Hora											
	<6:00	7:00	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	>17:00
10% PV	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
20% PV	1.000	1.000	1.000	1.000	1.002	1.004	1.006	1.005	1.001	1.000	1.000	1.000
30% PV	1.000	1.000	1.000	1.000	1.010	1.014	1.015	1.014	1.009	1.000	1.000	1.000
40% PV	1.000	1.000	1.000	1.006	1.020	1.024	1.026	1.025	1.019	1.007	1.000	1.000
50% PV	1.000	1.000	1.000	1.013	1.028	1.034	1.035	1.034	1.028	1.013	1.000	1.000
60% PV	1.000	1.000	1.003	1.020	1.038	1.045	1.046	1.045	1.038	1.020	1.003	1.000
70% PV	1.000	1.000	1.007	1.026	1.046	1.054	1.055	1.054	1.046	1.027	1.007	1.000
80% PV	1.000	1.000	1.012	1.034	1.056	1.064	1.065	1.063	1.055	1.034	1.012	1.000
90% PV	1.000	1.000	1.016	1.040	1.063	1.072	1.073	1.071	1.062	1.040	1.016	1.000
100% PV	1.000	1.000	1.020	1.046	1.071	1.081	1.082	1.081	1.071	1.046	1.020	1.000
110% PV	1.000	1.000	1.023	1.051	1.077	1.087	1.089	1.087	1.077	1.052	1.023	1.000
120% PV	1.000	1.001	1.029	1.060	1.088	1.100	1.101	1.099	1.088	1.060	1.029	1.000
130% PV	1.000	1.003	1.033	1.066	1.096	1.109	1.110	1.108	1.095	1.066	1.033	1.000
140% PV	1.000	1.006	1.039	1.074	1.107	1.122	1.124	1.122	1.106	1.074	1.039	1.000
150% PV	1.000	1.008	1.043	1.079	1.115	1.132	1.133	1.131	1.114	1.079	1.043	1.000

Percentage of transformer capacity violations, Case 1

PV Level	Transformer	Hour				
		10	11	12	13	14
90%	T_51	0.00%	1.26%	2.60%	1.14%	0.00%
100%	T_50	0.00%	7.74%	8.88%	7.39%	0.00%
	T_51	0.16%	13.53%	14.86%	13.37%	0.00%
110%	T_50	0.00%	12.73%	13.88%	12.39%	0.00%
	T_51	11.33%	25.86%	27.16%	25.67%	10.53%
120%	T_2	0.00%	0.35%	0.62%	0.00%	0.00%
	T_50	21.08%	36.50%	37.57%	36.07%	19.95%
	T_51	20.48%	35.99%	37.27%	35.78%	19.66%
	T_55	0.00%	1.26%	2.09%	1.03%	0.00%

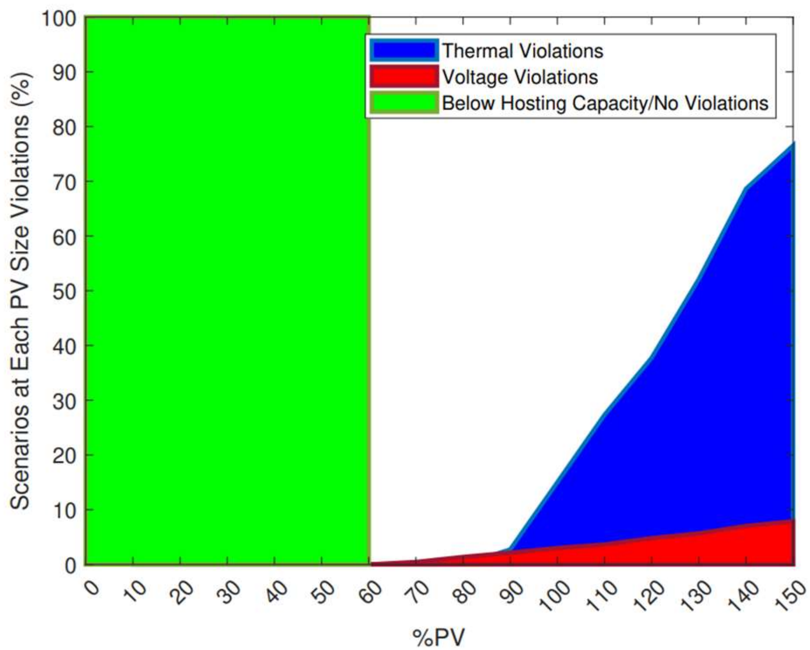
Case 1: PV Only

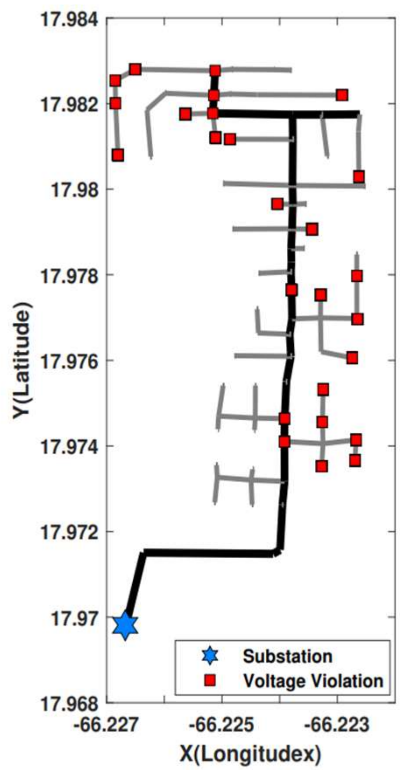


(a) 20% PV (c) 70% PV (d) 140% PV

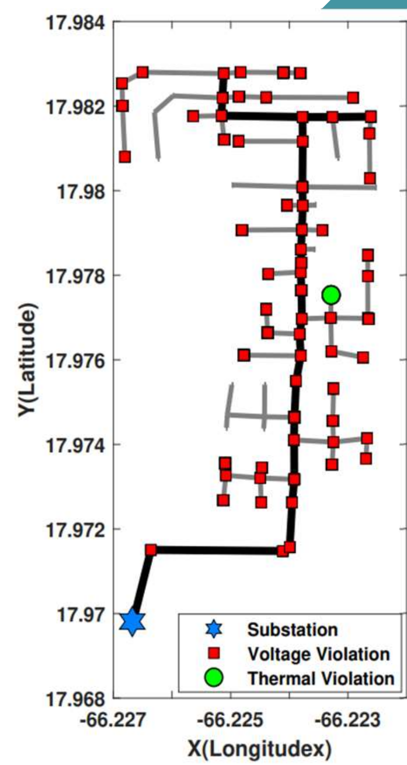
- The mid-day feeder current profile for different PV penetration levels
- Current flowing through the lines does not violate the conductor rating up to 130% PV penetration
- For a penetration level of 140%, the amount of current flowing through the phase A conductor manages to violate the conductor capacity very close to the substation

Case 1: PV Only



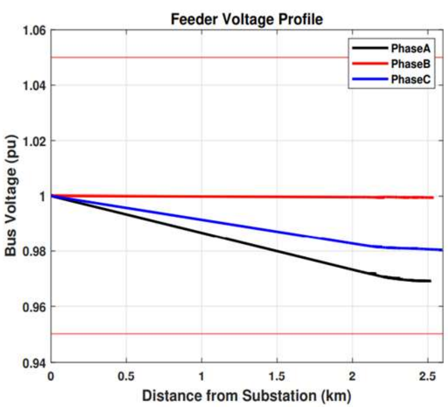


(a) 70% PV

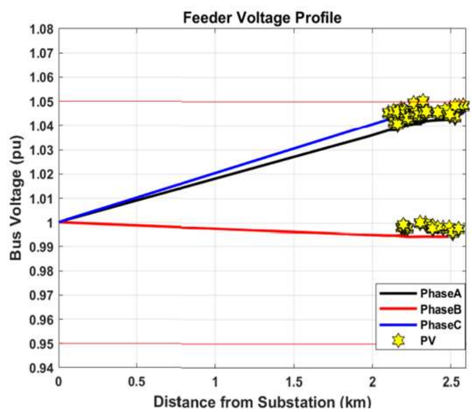


(b) 90% PV

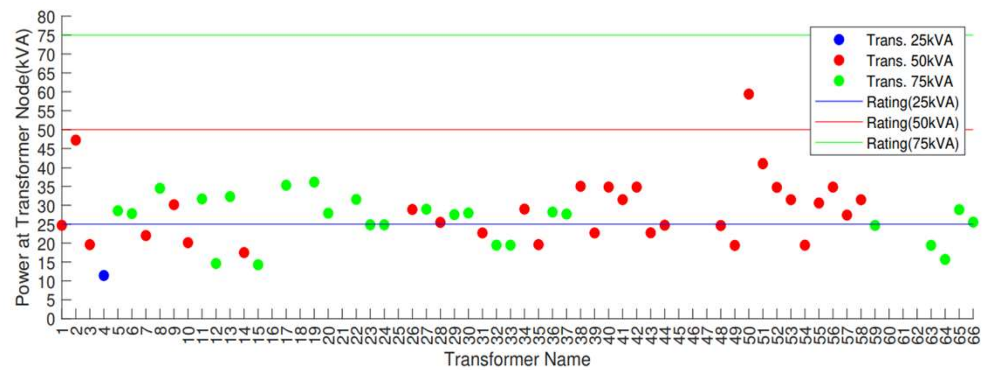
Case 2: PV and Batteries



Without PV



120% PV



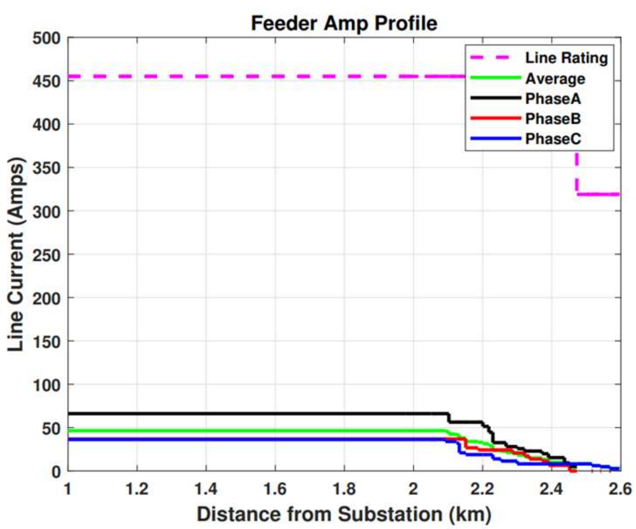
130% PV

PV Level	Hora											
	<6:00	7:00	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	>17:00
10% PV	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
20% PV	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
30% PV	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
40% PV	1.000	1.000	1.000	1.001	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
50% PV	1.000	1.000	1.004	1.005	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
60% PV	1.000	1.002	1.008	1.010	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
70% PV	1.000	1.006	1.012	1.014	1.002	1.000	1.000	1.000	1.002	1.004	1.000	1.000
80% PV	1.000	1.009	1.017	1.018	1.005	1.000	1.000	1.000	1.008	1.009	1.000	1.000
90% PV	1.000	1.012	1.019	1.021	1.006	1.000	1.000	1.000	1.014	1.012	1.000	1.000
100% PV	1.000	1.015	1.022	1.024	1.008	1.000	1.000	1.004	1.020	1.017	1.000	1.000
110% PV	1.000	1.017	1.025	1.027	1.009	1.000	1.000	1.004	1.032	1.020	1.000	1.000
120% PV	1.002	1.021	1.028	1.029	1.010	1.000	1.003	1.023	1.051	1.028	1.000	1.000
130% PV	1.004	1.024	1.031	1.032	1.011	1.000	1.011	1.061	1.060	1.032	1.000	1.000
140% PV	1.007	1.028	1.035	1.035	1.012	1.002	1.031	1.092	1.072	1.037	1.000	1.000
150% PV	1.008	1.030	1.037	1.036	1.015	1.011	1.043	1.108	1.078	1.041	1.000	1.000

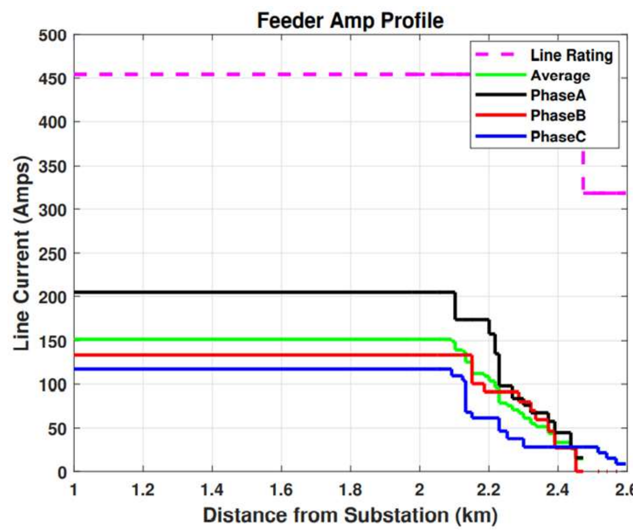
Percentage of transformer capacity violations, Case 2

PV Level	Transformer	Hour	
		13:00	14:00
130%	T_50	19.30%	0.00%
140%	T_2	7.75%	0.00%
	T_50	33.26%	0.51%
	T_51	32.97%	0.22%
150%	T_2	16.19%	0.00%
	T_5	1.59%	0.00%
	T_50	50.64%	4.02%
	T_51	39.98%	5.61%
	T_55	3.83%	0.00%

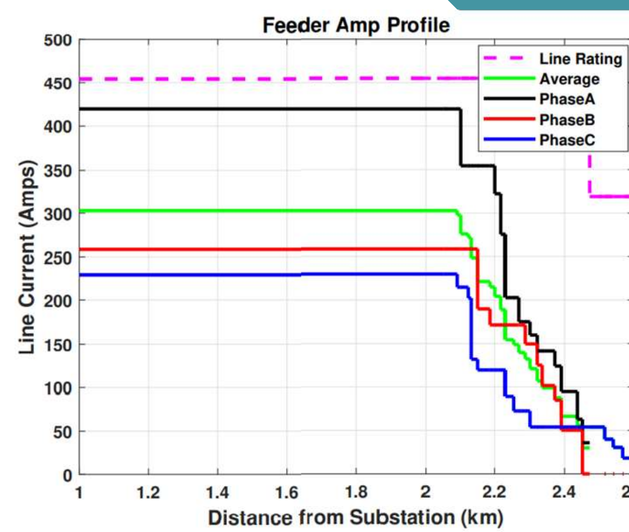
Case 2: PV and Batteries



(a) 20% PV



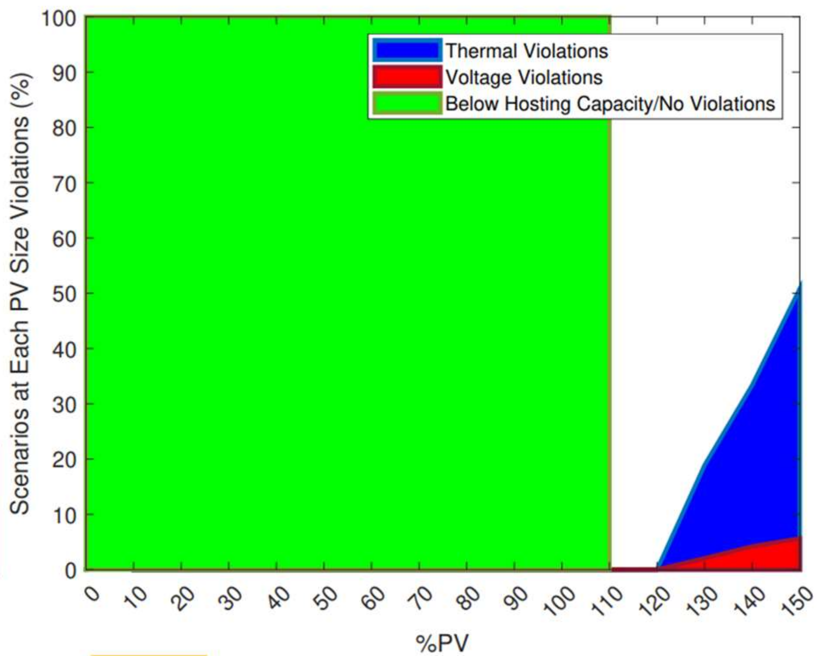
(c) 120% PV

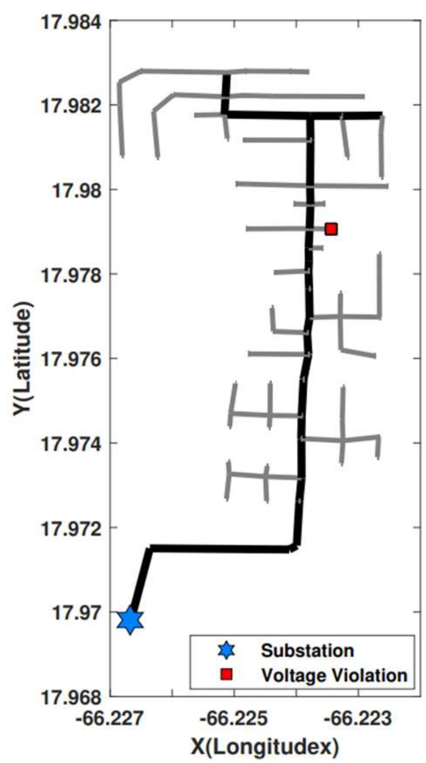


(d) 150% PV

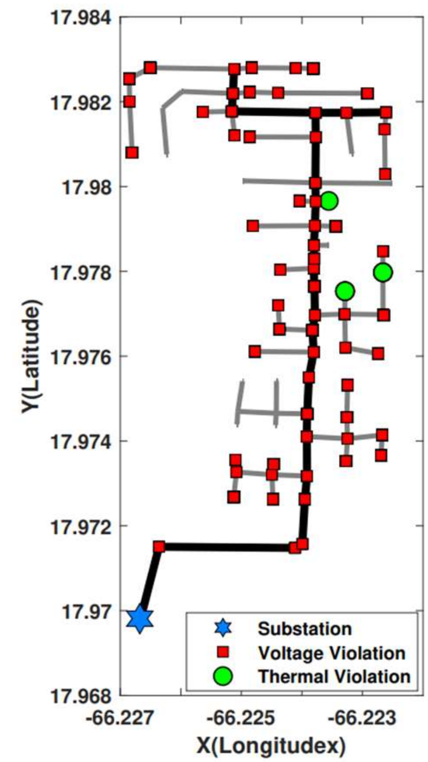
- Shows the feeder current profile at 13:00 hrs for different PV penetration levels.
- The current flowing through the lines does not violate the conductor’s capacity.

Case 2: PV and Batteries





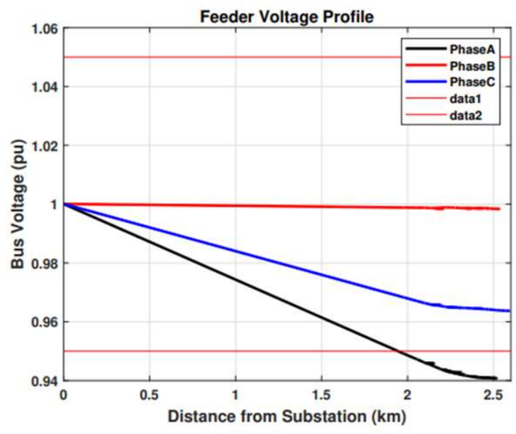
(a) 120% PV



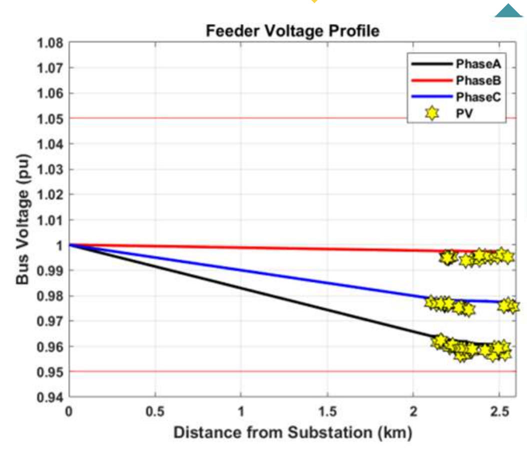
(b) 140% PV

Case 2: PV and Batteries

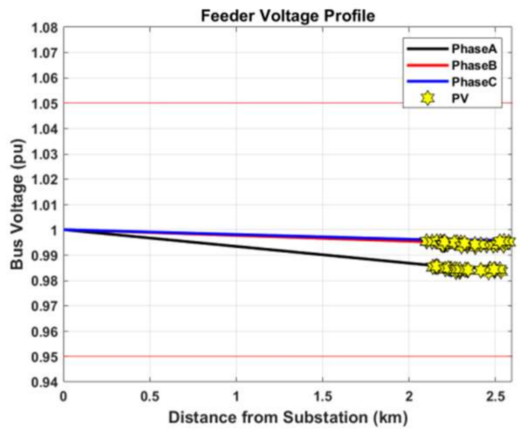
- An important aspect to consider with RESS is that during the hours of peak PV generation the batteries will be charged so that at night, they can supply the household load.



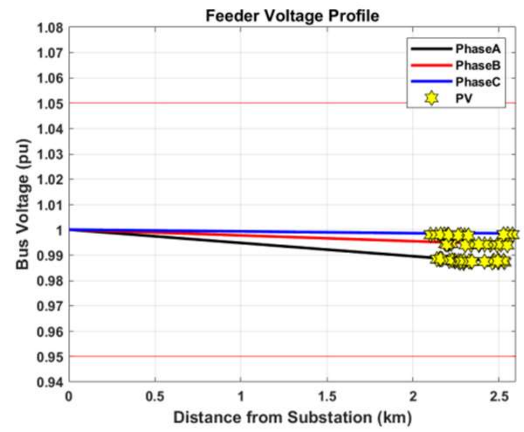
(a) No PV



(b) 20% PV

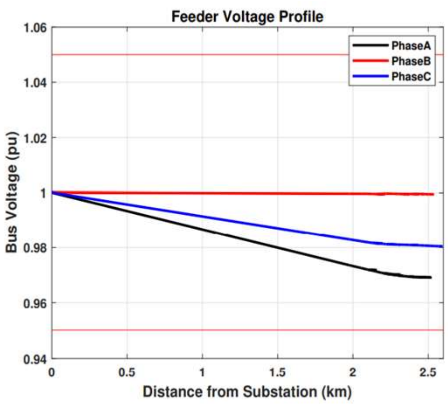


(c) 80% PV

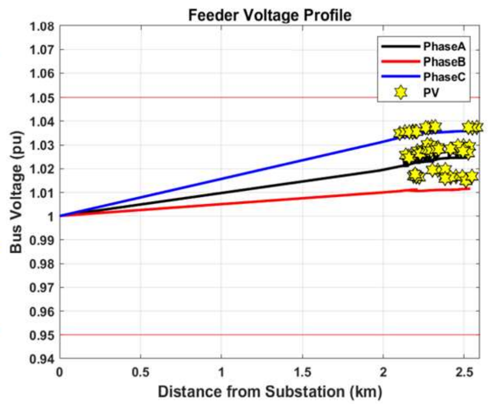


(d) 150% PV

Case 3: PV and Smart Inverter

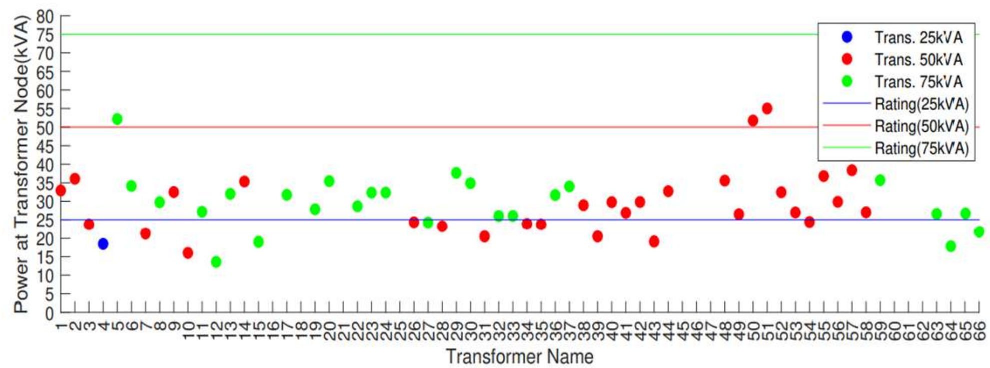


Without PV



90% PV

PV Level	Hora											
	<6:00	7:00	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	>17:00
10% PV	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
20% PV	1.000	1.000	1.000	1.000	1.001	1.004	1.006	1.005	1.001	1.000	1.000	1.000
30% PV	1.000	1.000	1.000	1.000	1.010	1.014	1.015	1.014	1.009	1.000	1.000	1.000
40% PV	1.000	1.000	1.000	1.006	1.020	1.023	1.024	1.023	1.019	1.006	1.000	1.000
50% PV	1.000	1.000	1.001	1.013	1.024	1.027	1.028	1.027	1.024	1.013	1.000	1.000
60% PV	1.000	1.000	1.002	1.020	1.028	1.031	1.031	1.030	1.027	1.020	1.002	1.000
70% PV	1.000	1.000	1.006	1.023	1.030	1.033	1.034	1.033	1.030	1.022	1.006	1.000
80% PV	1.000	1.000	1.011	1.025	1.033	1.036	1.036	1.035	1.032	1.025	1.011	1.000
90% PV	1.000	1.000	1.015	1.027	1.034	1.037	1.038	1.037	1.034	1.026	1.015	1.000
100% PV	1.000	1.000	1.019	1.028	1.036	1.039	1.040	1.039	1.036	1.028	1.019	1.000
110% PV	1.000	1.000	1.021	1.029	1.037	1.040	1.040	1.040	1.036	1.029	1.021	1.000
120% PV	1.000	1.000	1.022	1.031	1.039	1.042	1.042	1.041	1.038	1.031	1.022	1.000
130% PV	1.000	1.000	1.023	1.031	1.039	1.042	1.043	1.042	1.039	1.031	1.023	1.000
140% PV	1.000	1.000	1.024	1.033	1.041	1.044	1.044	1.043	1.040	1.032	1.024	1.000
150% PV	1.000	1.000	1.024	1.033	1.041	1.045	1.045	1.044	1.041	1.033	1.025	1.000

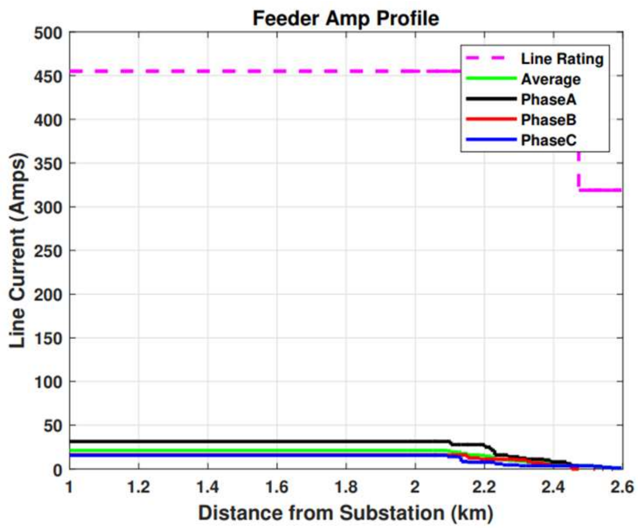


90% PV

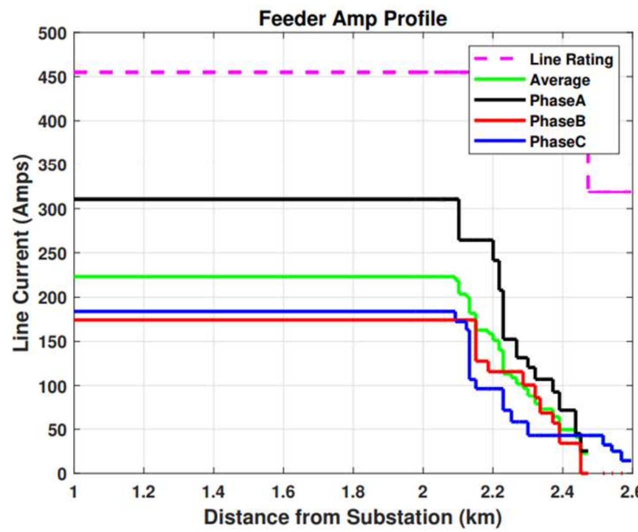
Percentage of transformer capacity violations, Case 3

PV Level	Transformer	Hour				
		10:00	11:00	12:00	13:00	14:00
90%	T_50	0.00%	2.24%	3.51%	2.06%	0.00%
	T_51	0.00%	8.55%	10.00%	8.55%	0.00%
100%	T_50	1.55%	15.93%	17.18%	15.77%	0.68%
	T_51	7.13%	22.26%	23.68%	22.27%	6.53%
110%	T_50	6.76%	21.83%	23.07%	21.67%	5.99%
	T_51	19.59%	36.18%	37.60%	36.20%	19.11%
	T_57	0.00%	0.00%	0.23%	0.00%	0.00%
120%	T_50	30.66%	48.06%	49.29%	47.91%	29.77%
	T_51	30.01%	47.49%	48.91%	47.53%	29.40%
	T_55	0.00%	4.00%	4.81%	3.66%	0.00%
	T_57	0.00%	11.88%	12.81%	11.73%	0.00%

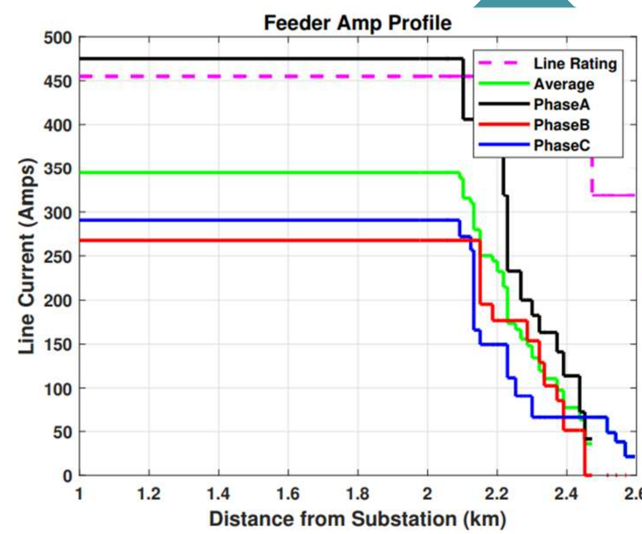
Case 3: PV and Smart Inverter



(a) 20% PV



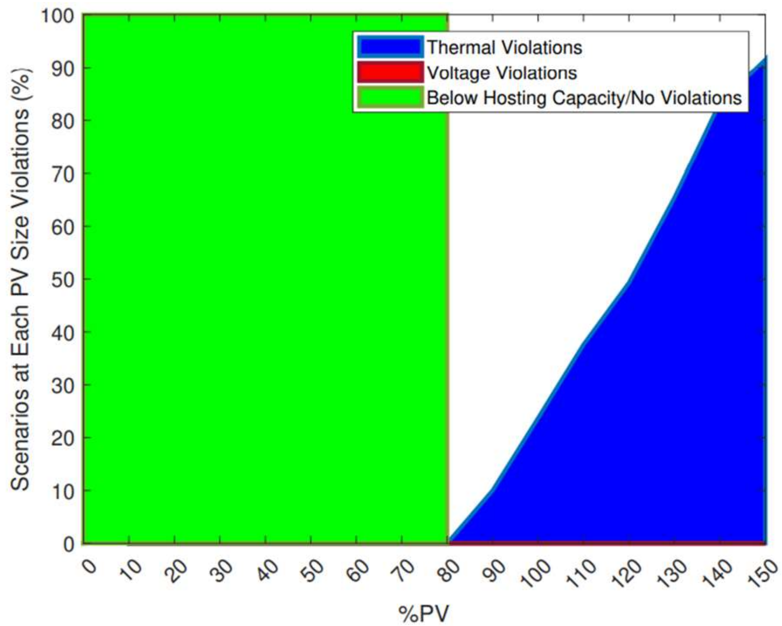
(c) 90% PV

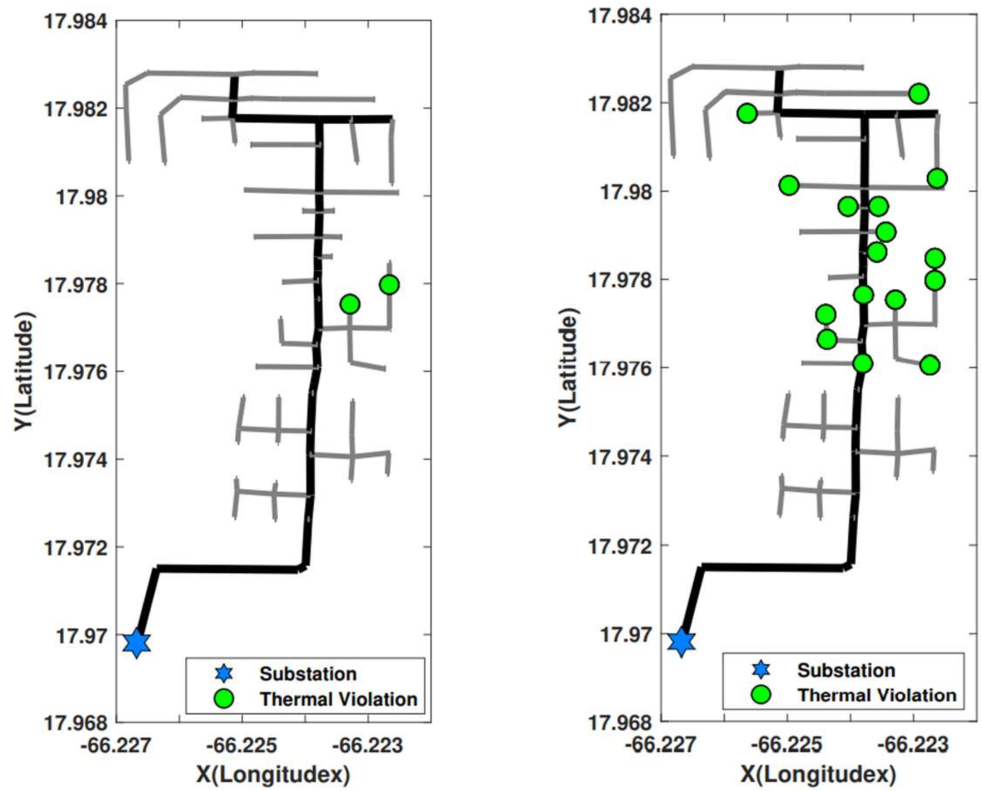


(d) 130% PV

- Shows the feeder current profile at 12:00 hrs for different PV penetration levels.
- For a PV penetration of 130%, the reverse current flowing through the phase A conductor violates the conductor rating near the substation.

Case 3: PV and Smart Inverter



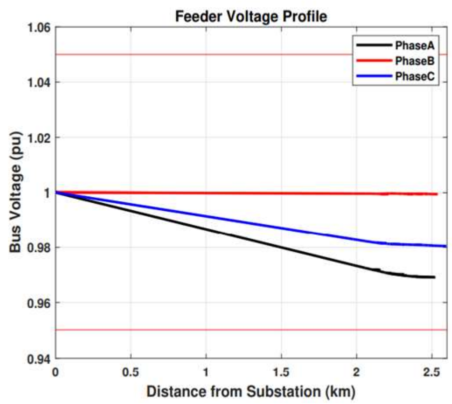


(a) 120% PV

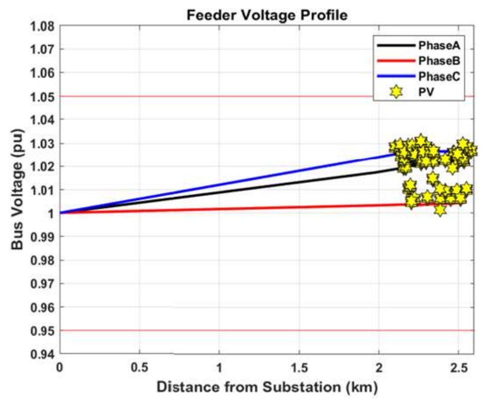
(b) 140% PV

Case 4.1: PV, Batteries and Smart Inverter – Algorithm 1

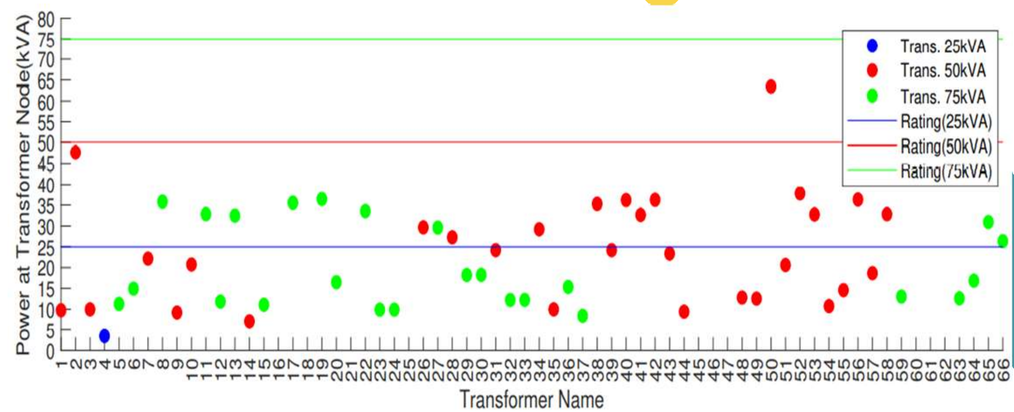
- Algorithm 1: Designed to reduce the power consumption from the grid



Without PV



130% PV

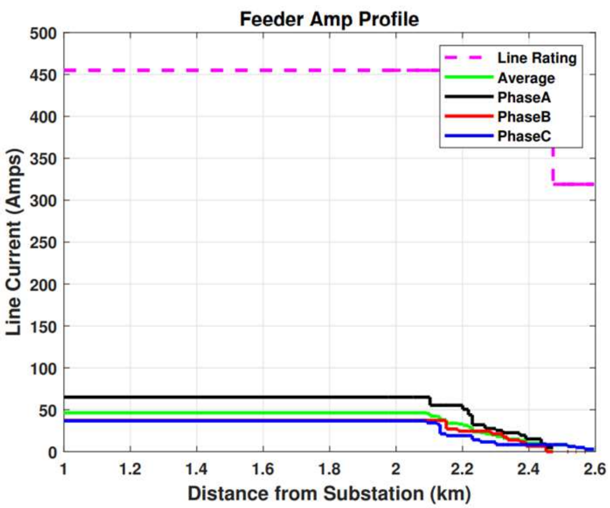


130% PV

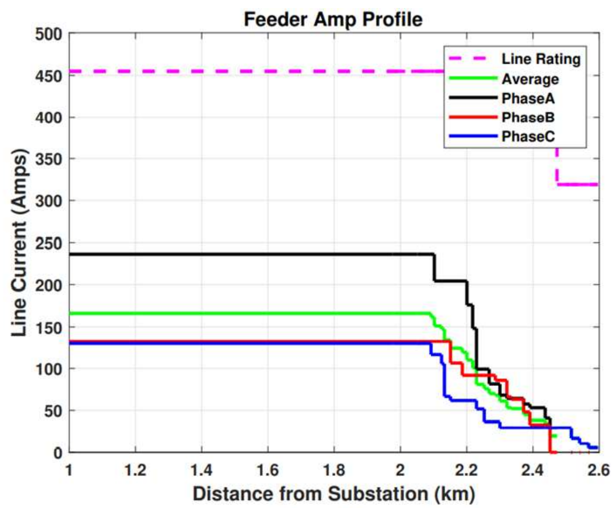
PV Level	Hora										
	<6:00	7:00	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	>17:00
10% PV	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
20% PV	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
30% PV	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
40% PV	1.000	1.000	1.000	1.001	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
50% PV	1.000	1.001	1.003	1.005	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
60% PV	1.000	1.001	1.008	1.010	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
70% PV	1.000	1.005	1.012	1.014	1.002	1.000	1.000	1.000	1.000	1.003	1.000	1.000
80% PV	1.000	1.010	1.016	1.018	1.005	1.000	1.000	1.000	1.007	1.008	1.000	1.000
90% PV	1.000	1.014	1.019	1.021	1.006	1.000	1.000	1.000	1.012	1.011	1.000	1.000
100% PV	1.000	1.020	1.021	1.022	1.008	1.000	1.000	1.005	1.019	1.016	1.000	1.000
110% PV	1.000	1.022	1.022	1.023	1.009	1.000	1.000	1.004	1.023	1.019	1.000	1.000
120% PV	1.000	1.023	1.022	1.022	1.010	1.000	1.000	1.024	1.029	1.022	1.000	1.000
130% PV	1.000	1.023	1.023	1.024	1.011	1.000	1.000	1.031	1.030	1.023	1.000	1.000
140% PV	1.000	1.024	1.023	1.024	1.012	1.001	1.007	1.037	1.032	1.024	1.000	1.000
150% PV	1.000	1.025	1.024	1.024	1.014	1.012	1.014	1.040	1.033	1.025	1.000	1.000

Percentage of transformer capacity violations, Case 4.1			
PV Level	Transformer	Hour	
		13:00	14:00
130%	T_50	26.91%	0.00%
140%	T_2	10.45%	0.00%
	T_50	43.82%	7.51%
	T_51	43.43%	7.14%
	T_57	3.91%	0.00%

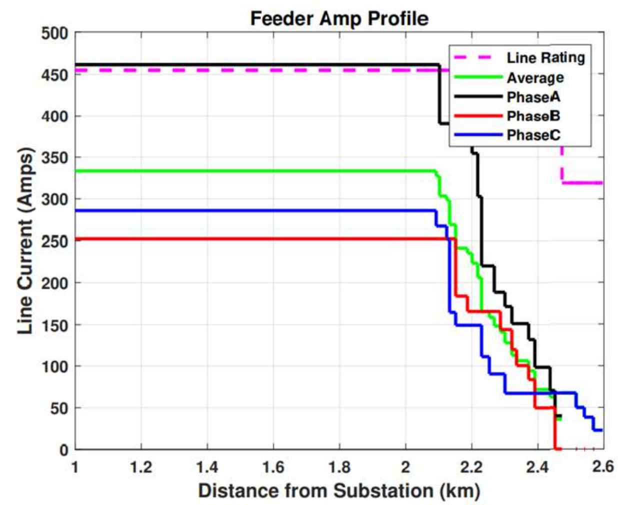
Case 4.1: PV, Batteries and Smart Inverter – Algorithm 1



(a) 20% PV



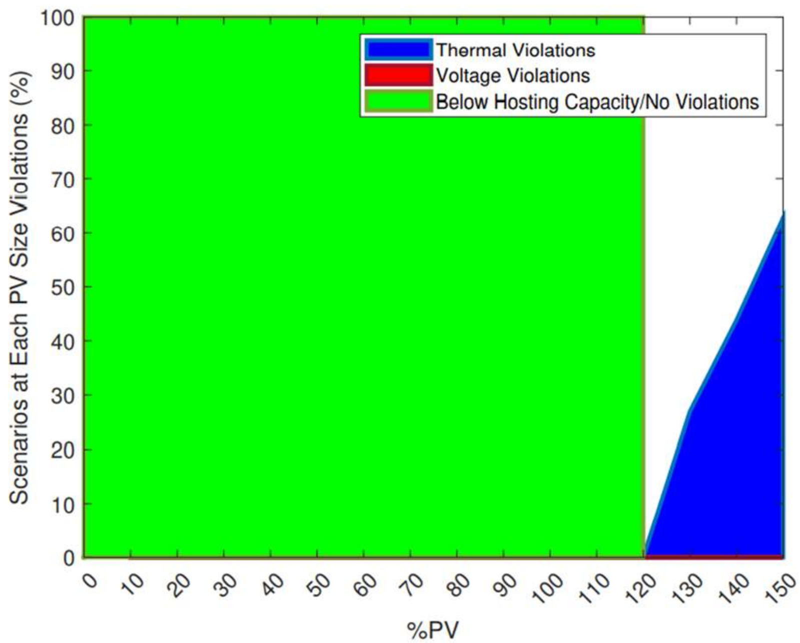
(c) 130% PV

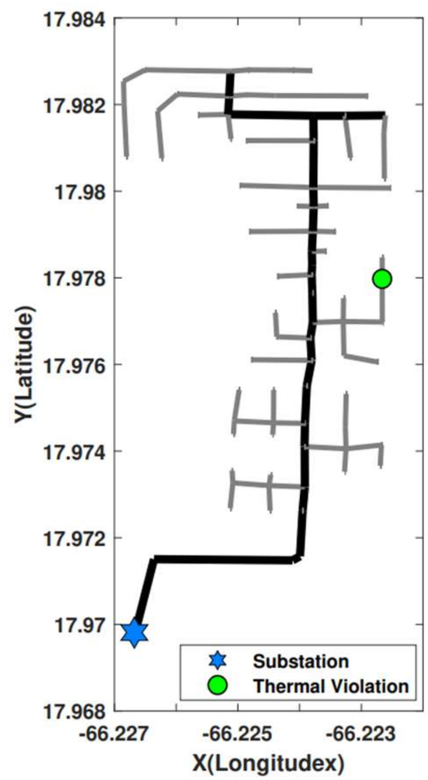


(d) 150% PV

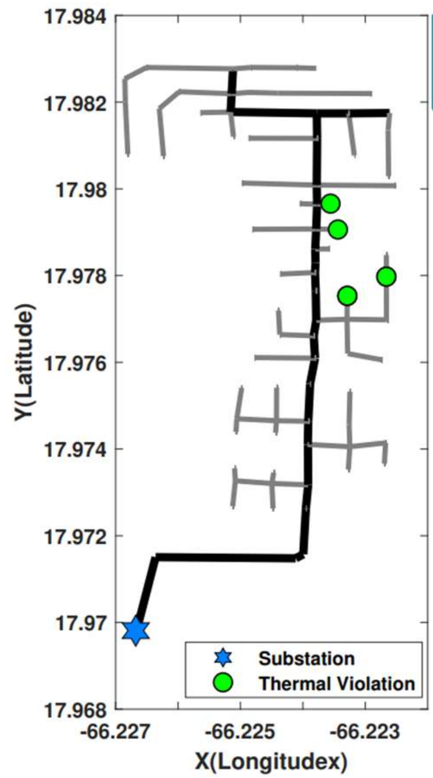
- Shows the feeder current profile at 13:00 hrs for different PV penetration levels.
- For a PV penetration of 150%, the reverse current flowing through the phase A conductor violates the conductor rating near the substation.

Case 4.1: PV, Batteries and Smart Inverter – Algorithm 1





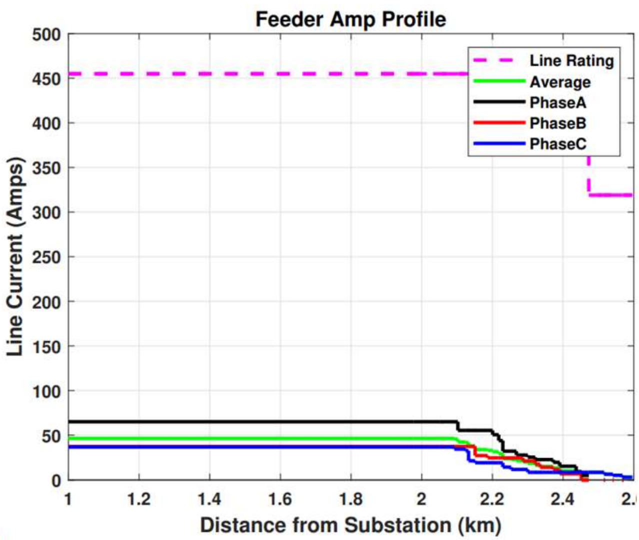
(a) 130% PV



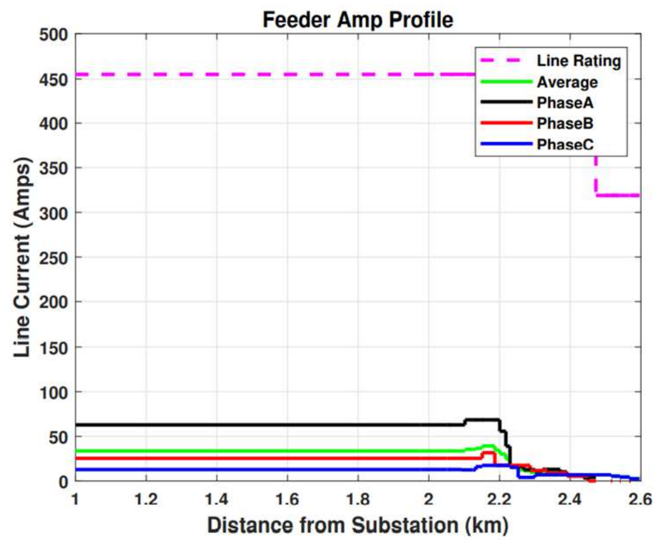
(b) 140% PV

Case 4.2: PV, Batteries and Smart Inverter – Algorithm 2

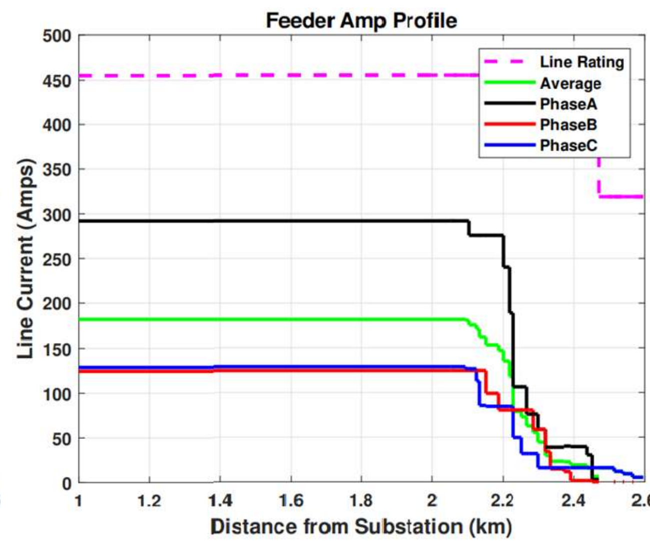
- Algorithm 2: Designed to reduce reverse power flow



(a) 20% PV



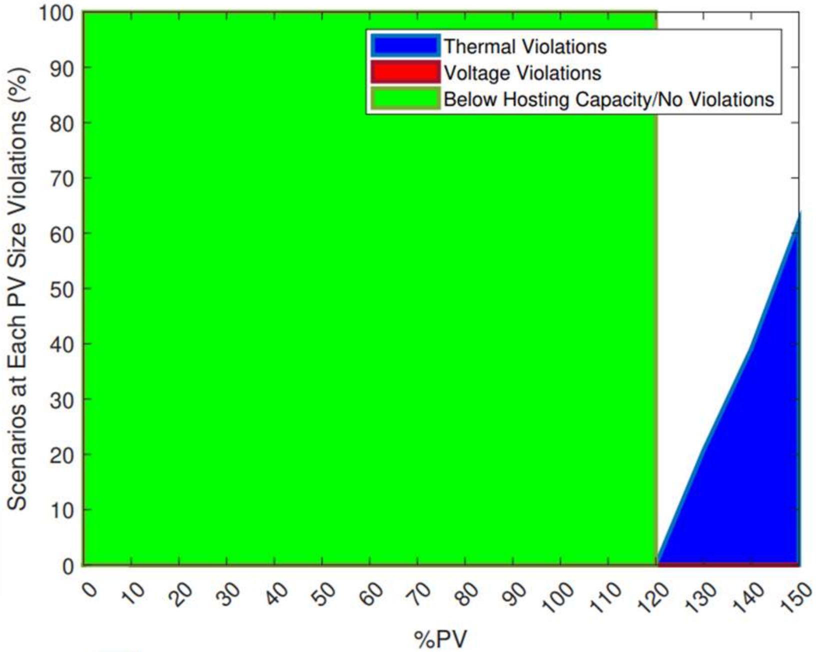
(c) 130% PV

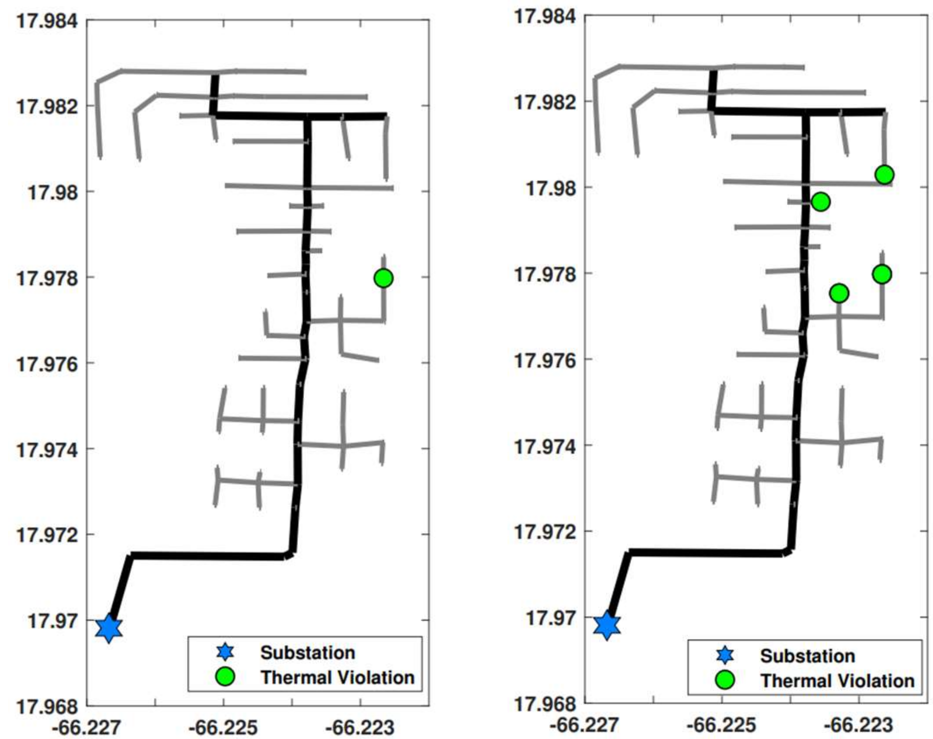


(d) 150% PV

- Shows the feeder current profile at 13:00 hrs for different PV penetration levels.
- The current flowing through the lines does not violate the conductor's capacity.

Case 4.2: PV, Batteries and Smart Inverter – Algorithm 2





(a) 130% PV

(b) 140% PV

Case study results comparison

PV% level	Case 1		Case 2		Case 3		Case 4.1		Case 4.2	
	Violations		Violations		Violations		Violations		Violations	
	Voltage(%)	Thermal(%)	Voltage(%)	Thermal(%)	Voltage(%)	Thermal(%)	Voltage(%)	Thermal(%)	Voltage(%)	Thermal(%)
<60	0.0	0.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
70	0.5	0.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
80	1.4	0.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
90	2.2	2.6	0.00	0.00	0.00	10.00	0.00	0.00	0.00	0.00
100	3.0	14.9	0.00	0.00	0.00	23.68	0.00	0.00	0.00	0.00
110	3.7	27.2	0.00	0.00	0.00	37.60	0.00	0.00	0.00	0.00
120	4.8	37.6	0.05	0.00	0.00	49.29	0.00	0.00	0.00	0.00
130	5.7	51.9	1.07	19.30	0.00	65.39	0.00	26.91	0.00	20.68
140	7.0	69.5	3.98	33.26	0.00	83.30	0.00	43.82	0.00	39.05
150	7.9	78.6	5.54	50.64	0.00	91.54	0.00	62.80	0.00	62.11

Conclusion

- In this research
  - Analysis period for 24 hours a day with one-hour steps. Hence, the simulation is of a quasi-static type.
  - PV penetration levels range from 10% to 150% (in 10% steps).
  - Power flow analysis of the feeder, phase A accounted for much of the feeder load, followed by phase B, and phase C.
  - During peak demand hours, phase A experienced low voltage problems

- When comparing all cases, case four proved to be the best method to increase the HC of the distributed PV system feeder under study.
  - Smart inverters prevented voltage violations from occurring during maximum PV generation through reactive compensation.
  - Battery charging during maximum PV generation reduced reverse flows, and therefore, reduced thermal violations.
  - The same maximum HC was obtained in cases 4.1 and 4.2.
  - RESSs reduced the load on the feeder during peak hours, improving grid stability by reducing voltage sags.

- During the simulations, thermal violations occurred at the same transformers on all four cases.
  - Transformers number 50 and 51, where thermal violations always occurred, had the highest feeder loads, predisposing them to suffer thermal violations.
  - The identification of the transformers where thermal violations occur frequently is important because as a solution to increase the HC, the capacity of these transformers could be increased.

Additional Information

Residential Electric Energy Storage System to Reduce Voltage and Thermal Violations in Distribution Lines and Increase PV Integration

Anny Huaman-Rivera[1], and Agustin Irizarry-Rivera[1]
[1]University of Puerto Rico-Mayagüez, Mayagüez, Puerto Rico 00682, USA

***Abstract*—The electrical system is in constant transformation, and this has been more noticeable in the distribution systems since in recent years the penetration of distributed energy resources (DERs) has increased. This may lead to increased reverse power flows and overvoltages in low voltage (LV) networks causing deterioration of power quality and limiting the increase of DERs in distribution systems. Energy storage systems (ESSs) are useful to decrease reverse flows that cause thermal violations in distribution transformers and conductors. This study employs residential energy storage systems (RESS) to mitigate voltage and thermal violations, thereby enhancing the integration potential of rooftop photovoltaic (PV) systems on an urban distribution feeder in Puerto Rico.**

***Index Terms*—Distribution system, Energy storage systems, Thermal violations, Voltage violations.**

I. Introduction

The need to reduce greenhouse gas emissions and address the impacts of climate change has become increasingly urgent in recent years. As a result, many countries, including Puerto Rico, have implemented policies aimed at promoting more environmentally friendly means of electricity generation. In line with this objective, there has been a significant rise in the deployment of distributed PV systems on rooftops in Puerto Rico in recent years. In Puerto Rico, cost and increased electric service reliability are additional to use DERs. Finally, DERs also help meet the targets outlined in public policy 82-2010 Second Amendment, which aims for 100% renewable energy generation on the island by 2050 [1].

As residential PV systems on the island increase, it may impact power quality and reliability in the distribution system. This impact can be affected by three fundamental parameters: penetration level, generation distribution, and distribution circuit conditions. To mitigate the negative impacts of excess PV power production, the use of storage systems has been proposed [2]–[4]. These storage systems can be centralized, distributed in the grid, or at the residential level, and can help reduce the inflow of reverse flows into the power system. Additionally, these types of storage systems can offer benefits such as reduced energy prices for consumers, improved grid stability and power quality, and increased security for users in the event of power system failure.

The study focused on evaluating the impact of increasing PV penetration and the effectiveness of RESS in mitigating associated challenges related to voltage and thermal violations. Our study analyzed two case studies: Case 1, PV deployment without distributed RESS, and Case 2, PV deployment with distributed RESS. We developed these case studies using the Open-Source Distribution System Simulator (OpenDSS) interfaced with MATLAB and the GridPV toolbox.

II. Methodology

This section describes the methods used to evaluate the impact of increased photovoltaic penetration in distribution feeders.

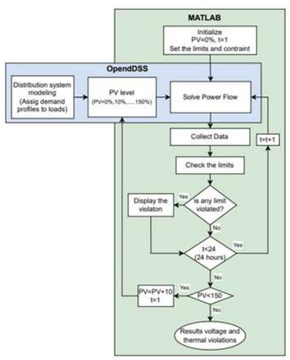


Fig. 1. Algorithm to evaluate the impact of increased photovoltaic penetration

A. Algorithm Description

The methodology used to determine the impact of increased photovoltaic penetration is shown in Figure 1. The impact of increased photovoltaic penetration analysis is performed for 24 hours with one-hour steps. The simulation is quasi-static, since for each hour, a static power flow analysis is

Integration and Assessment of Photovoltaic Systems in Puerto Rican Communities

Oscar D. Garzon, Anny Huaman, Matias Patino, Jan Diaz, Yuly V. Garcia, Fabio Andrade, Adriana C. Luna and Agustin Irizarry

Evaluation Of Hosting Capacity Increase Using Smart Inverter Volt-VAr And Volt-Watt Functions

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***Abstract*—As the number of residential photovoltaic (PV) systems increase on distribution grids, utilities must evaluate the impacts of distributed energy resources (DER). The main impacts reported in the literature due to high penetration of residential PV systems are overvoltages and thermal violations of transformers and conductors. To overcome these impacts, smart inverters provide control functions such as Volt-VAr and Volt-Watt that allow residential PV generation to act in coordination with the distribution grid, managing voltage at the point of common connection (PCC). This article discusses how these smart inverter control functions can help increase the hosting capacity (HC) of a typical urban feeder, mitigating the problems caused by the high penetration of residential PV systems.**

***Index Terms*—Hosting capacity, Thermal violations, Voltage violations, Volt-VAr, Volt-Watt.**

I. Introduction

In recent years, there has been a considerable increase in the installation of residential PV systems. These systems provide customers with greater energy security in the face of potential grid outages. This is especially important in tropical regions, such as Puerto Rico, since the island's residents, experiment frequent power outages due to damage caused by tropical storms or hurricanes.

This increase in distributed PV generation is transforming the electric grid into a decentralized system and poses new challenges for utilities. One of these challenges is addressing power quality (PQ) issues, namely voltage and thermal violations, due to PV system penetration, without limiting PV generation during peak production hours [1]. According to ANSI C84.1, the acceptable voltage ranges from 0.95 to 1.05pu, if this exceeds the maximum threshold it is called an overvoltage violation [2]. Thermal violations, on the other hand, occur when current in conductors exceeds their rated capacity or when transformers exceed their kVA rating [3]. Effectively addressing these challenges is crucial to ensure an adequate electrical system and compliance with established standards.

In the search for solutions to minimize these challenges, hosting capacity studies are conducted to allow electric utilities to determine the PV penetration capacity that a feeder can support, without having to modify the feeder's infrastructure. Hence, utilities can make better decisions when evaluating solutions to ensure reliability in the distribution network.

To increase the hosting capacity, researchers have proposed the use of smart inverter control functions in PV systems. Researchers in [4] describe how smart inverter Volt-Watt and Volt-VAr control functions alleviate the overvoltage problem in distribution networks. Similarly, in [5] researchers study the ability of the smart inverter to contribute to voltage regulation, and discuss the pros and cons of each inverter control function. In [6], smart inverter functions are used to mitigate voltage surge in a realistic distribution network with a large number of PV systems, while, [7] evaluates the impact of the Volt-VAr function on reducing voltage volatility and consequently increasing the PV hosting capacity of distribution systems.

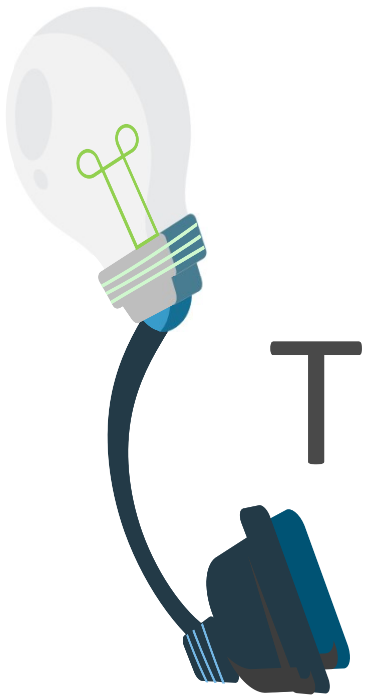
This paper aims to investigate how the use of the smart inverter Volt-Watt and Volt-VAr control functions can help increase the hosting capacity of a typical feeder with high levels of PV penetration. To achieve this, a practical model was developed using the Open-Source Distribution System Simulator (OpenDSS) interfaced with MATLAB.

II. Voltage regulation

Utilities are responsible for managing the voltage on distribution circuits through a variety of devices and methods. Voltage regulation in low voltage distribution networks has been managed by different methods, such as load tap changers, line regulators and capacitors to maintain voltages within ranges in accordance with the ANSI C84.1 standard [5]. However, these devices are not designed to react fast enough to mitigate the rapid fluctuation of voltage levels caused by PV systems. For these reasons the main problem of high PV penetration is overvoltage, which is caused by the injection of active and reactive power. Equation 1 defines the voltage variation where P and Q are the active and reactive power injected by the PV system, V_{nom} is the nominal voltage of the feeder and R and X are the resistance and reactance of the line [4].

$$\Delta V = \frac{(P \times R + Q \times X)}{V_{nom}} \tag{1}$$

Smart inverters based on the IEEE 1547 standard offer new ways to help manage the impact on distribution circuits caused by PV systems [8]. These inverters have different modes of operation, including the Volt-VAr mode, which is based on reactive power management, and the Volt-Watt, which is based on active power management.



Thank You

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