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Benefits of Single-Phase Capacitor Switching in Conservation Voltage Reduction

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2021 Grid of the Future Symposium

Background & Motivation

- Voltage Optimization (VO)/Conservation Voltage Reduction (CVR)
  - Method of reducing demand, energy and losses on a distribution system by reducing the system voltage
  - CVR factors CVR_P & CVR_Q determine the levels of demand/energy/loss reduction

- Conventional VO works with gang-operated capacitor banks, LTCs and voltage regulators

- Why move to single phase VO?
  - Higher penetration of single-phase PV systems and adoption of electric vehicles can result in higher voltage imbalance
  - Motor loads are most affected by voltage imbalance
    - Motor loads with relay protection trip when the voltage imbalance is greater than 1.5 to 2%
    - 5% voltage imbalance on motors can reduce their output to 75% of their rated value (NEMA MG1)
  - Higher penetration of PVs that can also cause reverse power flow on a system, can potentially result in inverters tripping due to the high voltage conditions
  - Three Phase VO may over/under compensate system voltage depending on the phase being monitored
  - Single phase capacitor bank operation has benefits over single phase voltage regulators

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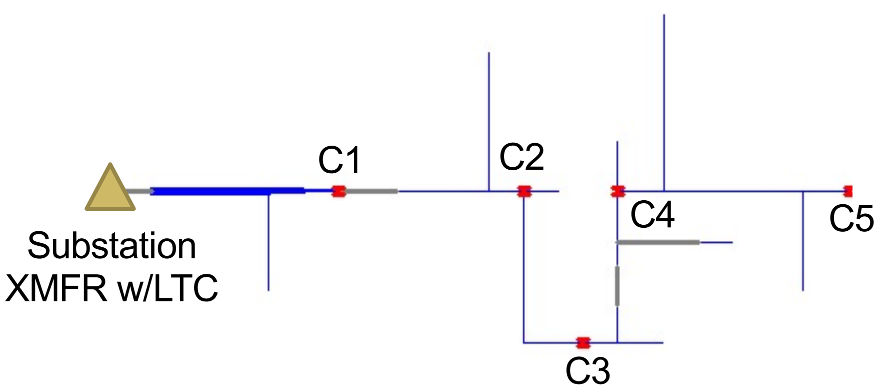
Outline of Work

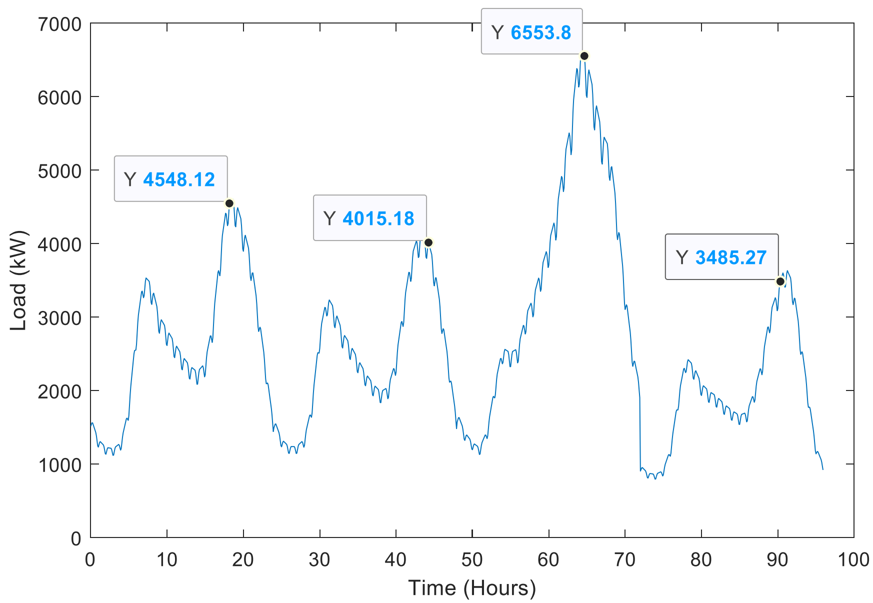
- Evaluate proposed VO approach with capacitor banks and LTC
- Compare the implementation of VO for single-phase vs three-phase capacitor bank operation
- Case Study:
  - Base Case – automatic settings
  - Three-phase capacitor switching
  - Single-phase capacitor switching

Test Feeder

- Modified IEEE 34 Node feeder
- 5 Capacitor Banks: 900, 600, 300, 300, and 600 kVAR
- Circuit Voltage: 12.47kV
- Peak Demand: 6.7MW
- 4 Days | the peak day in each season



Feeder Layout



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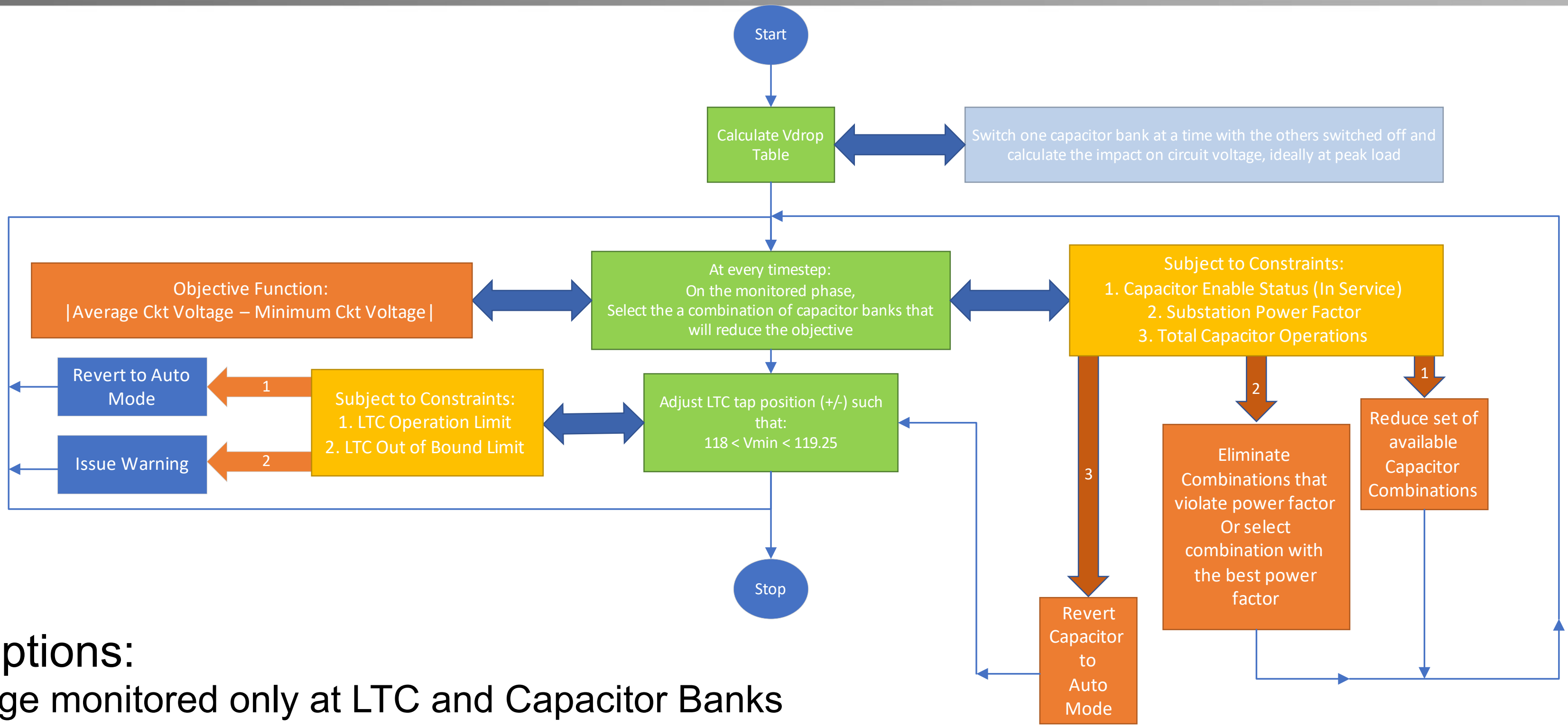
Base Case

- Distribution system with Load Tap Changer (LTC) and Capacitor Banks with local/auto-settings
  - LTC: 124.0V Band Center, 2.0V Bandwidth
  - Capacitor Banks: On: 118.0 V, Off: 124.0 V

- Issues:
  - Voltage monitoring being done only on one of three phases and used for VO algorithm
  - In some cases, voltage can be monitored on different phases on capacitor banks along the feeder
  - LTC voltage monitoring is also done on a single phase, which can be different from the phase that is being monitored on capacitor banks
  - Heavily loaded phases experience higher voltage drop resulting in lower voltage
  - Lightly loaded phases may have higher voltage

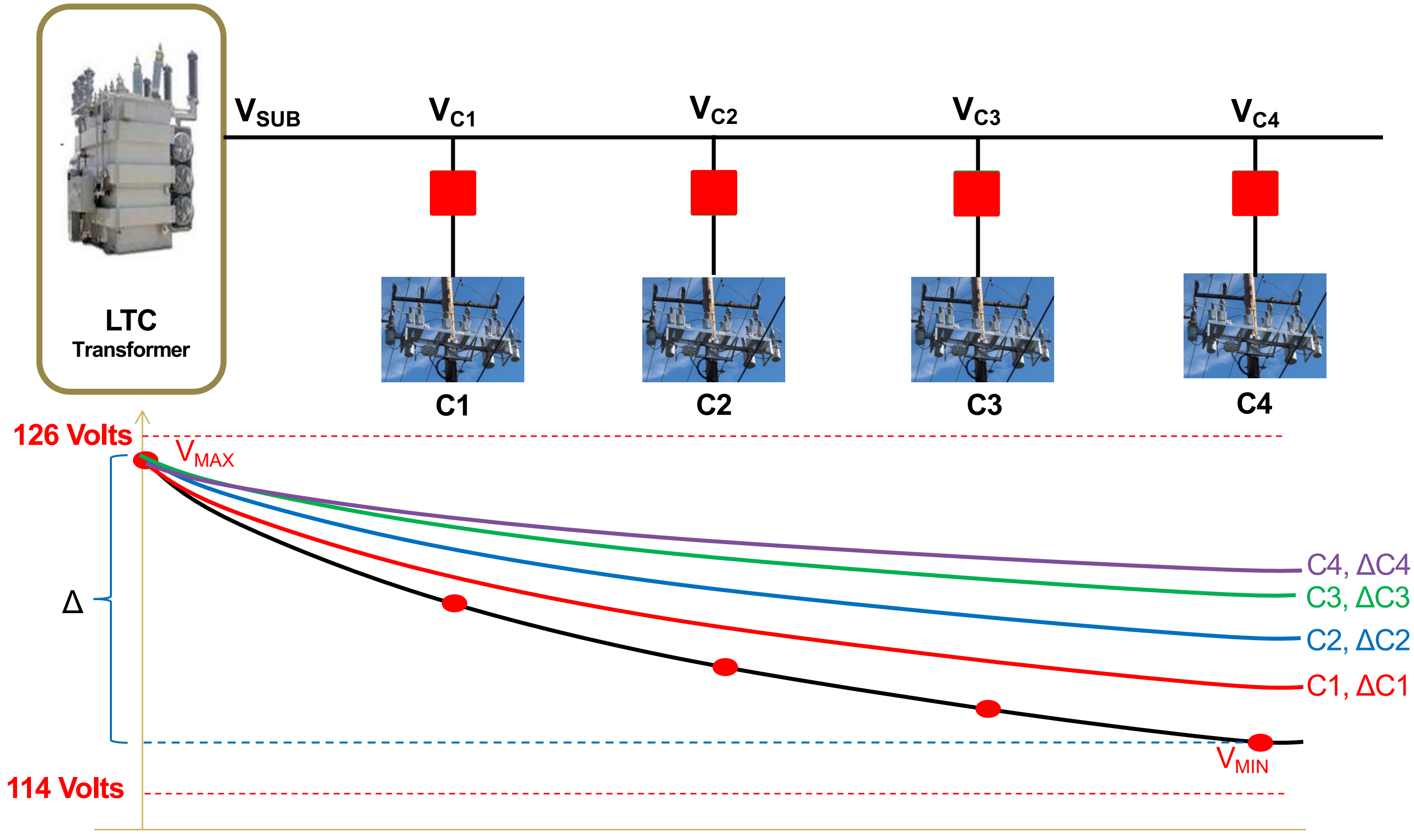
Algorithm – Three Phase/Gang-Operated



Assumptions:

- ❑ Voltage monitored only at LTC and Capacitor Banks
  - Only one phase is monitored at the each of these devices: (A) or (C)
  - Objective function calculated on monitored phase
- ❑ Capacitor status would be obtained from DMS/SCADA

Voltage Flattening



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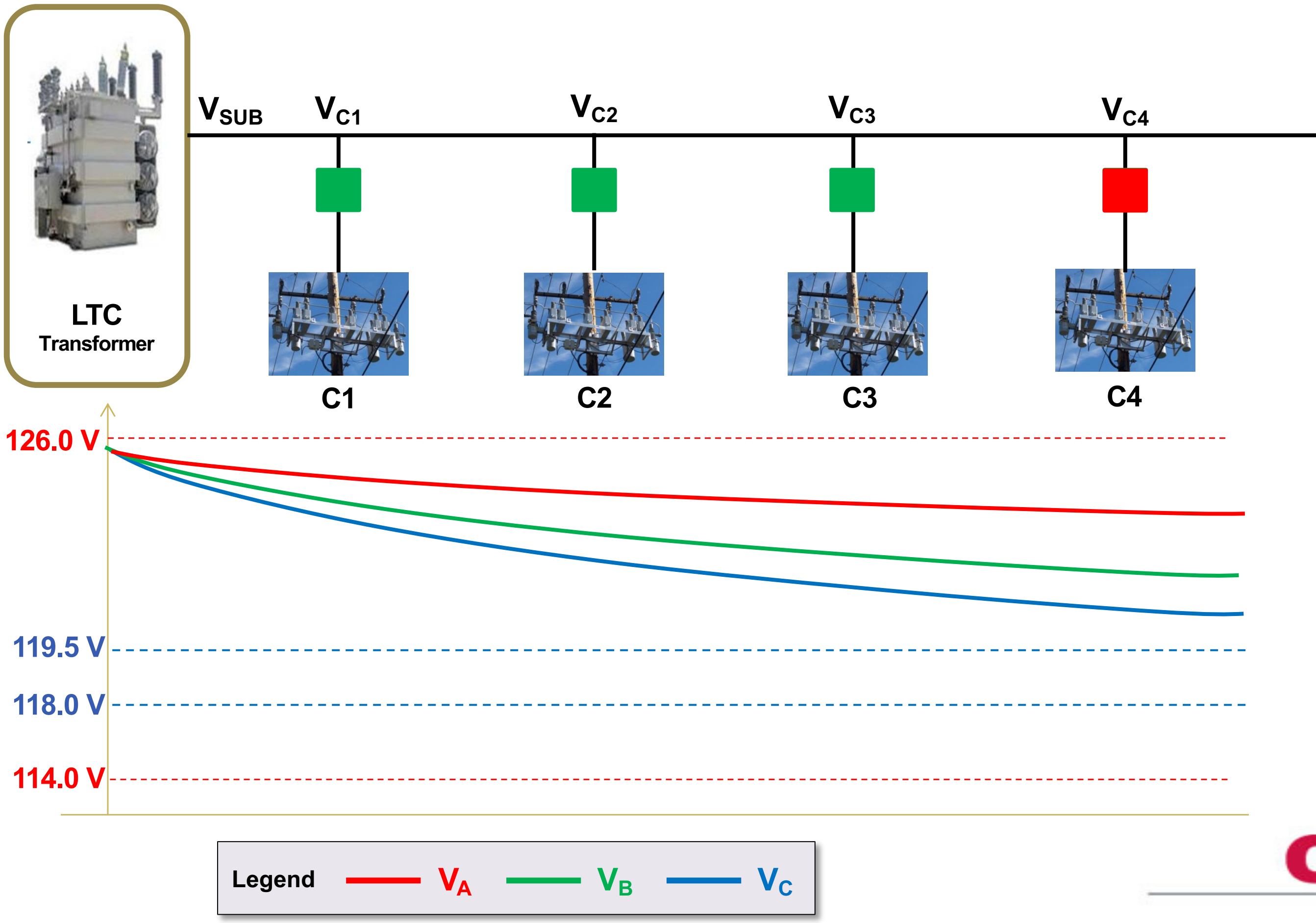
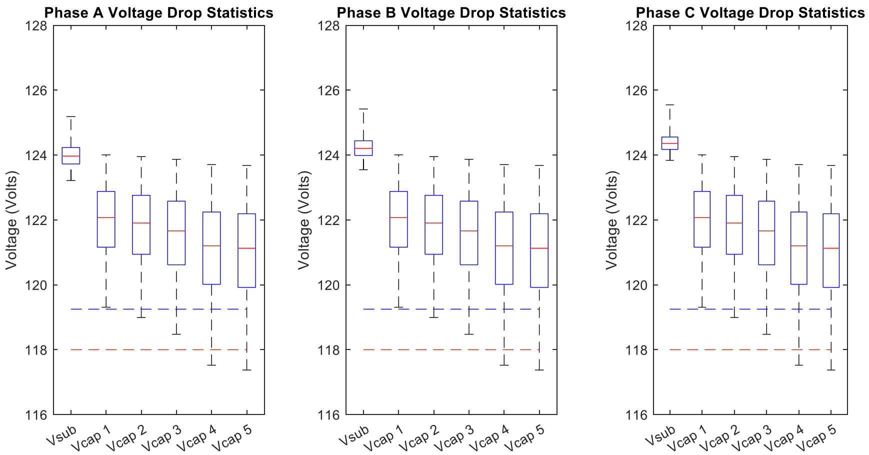
Voltage Reduction using LTC

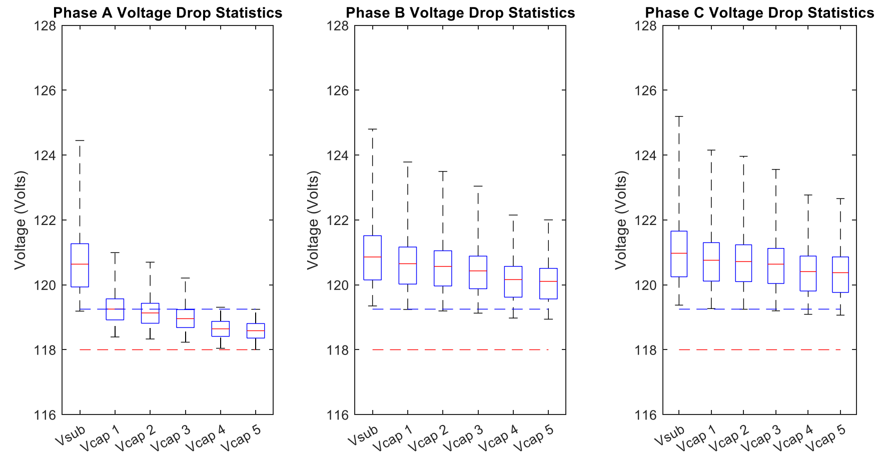


Results – Three Phase : Voltage profile statistics

Base Case



Three phase VO (A)



Comparison with Base Case shows expected lowering of system voltage

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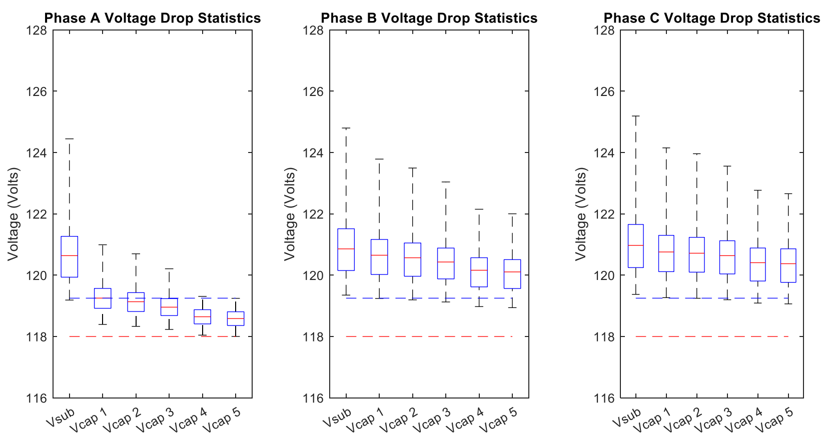
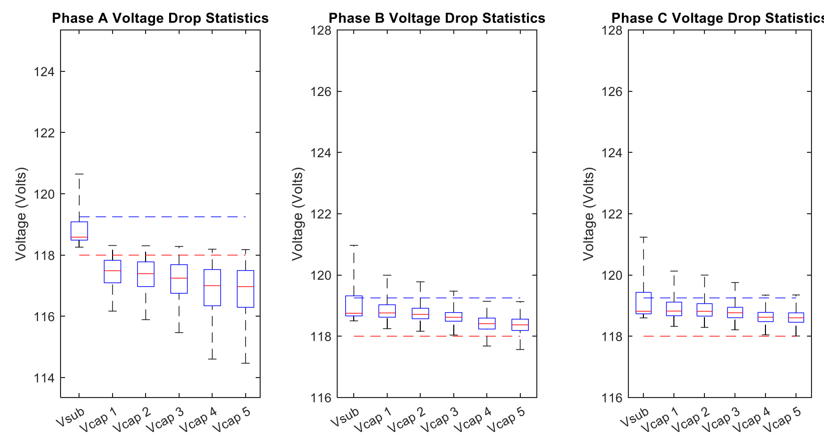
Results – Three Phase : A vs C phase

Three phase VO – A



Three phase VO – C



A phase – Heavily Loaded, C phase – lightly loaded

Comparison between monitored phases shows how three phase VO can lead to over/under compensation of system voltage

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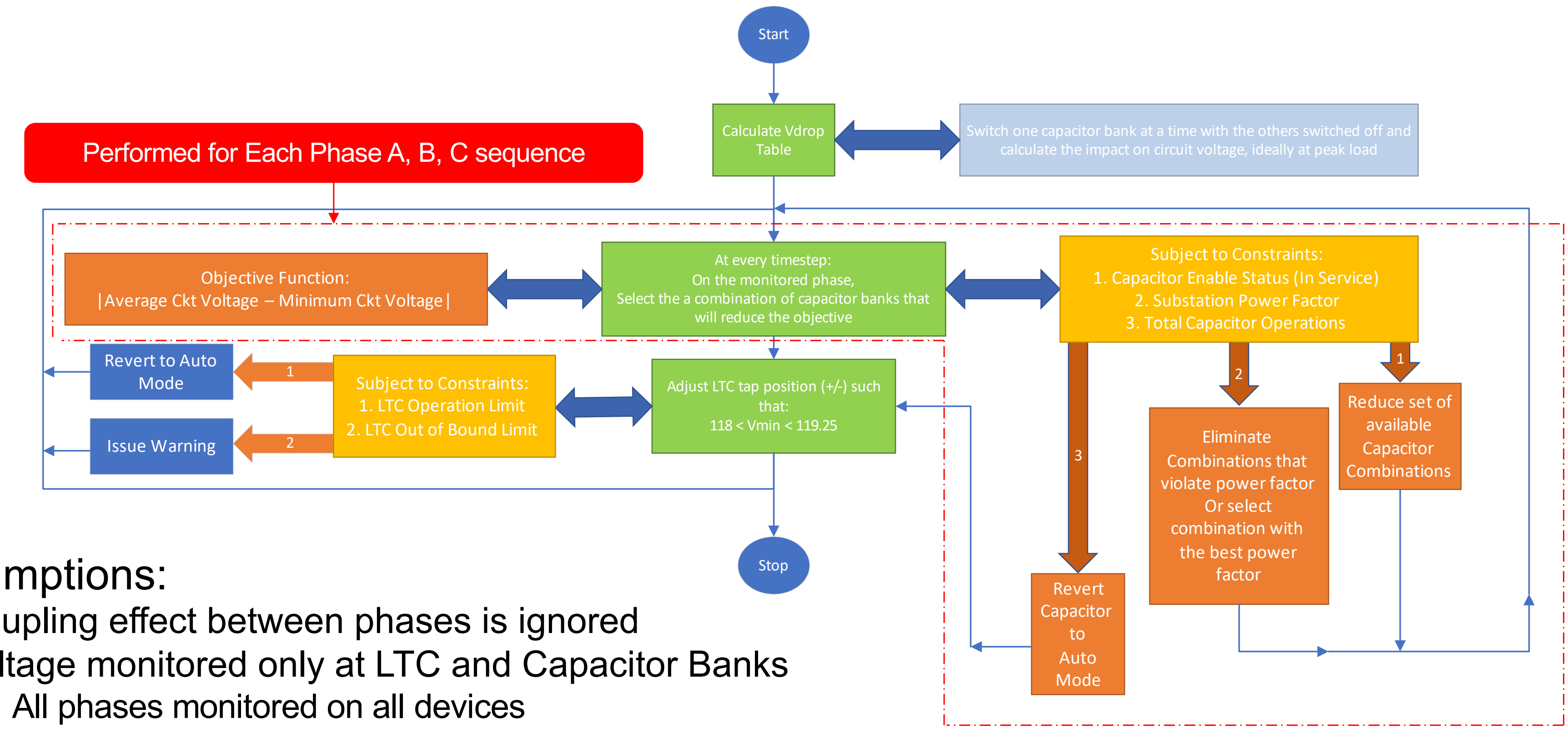
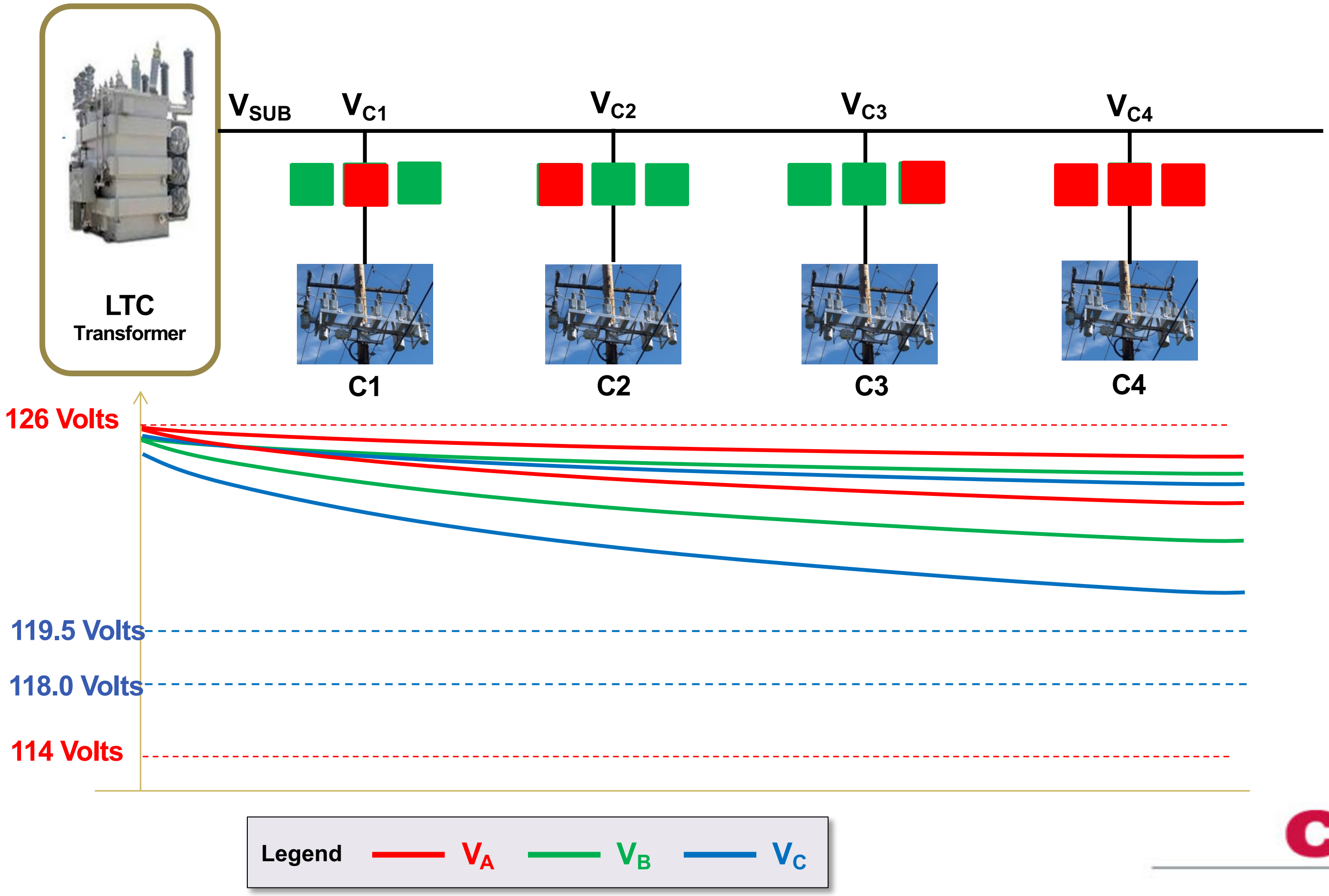
Algorithm – Single Phase



Assumptions:

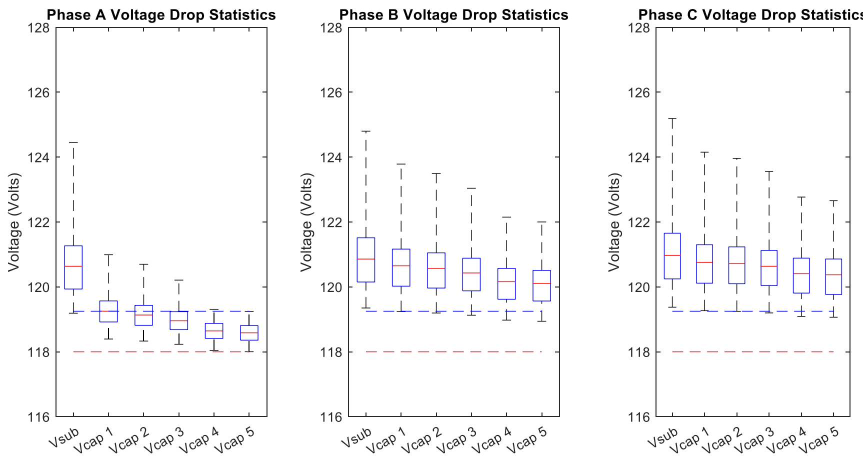
- ❑ Coupling effect between phases is ignored
- ❑ Voltage monitored only at LTC and Capacitor Banks
  - All phases monitored on all devices
  - Objective function calculated as individual phase-wise objectives
- ❑ Capacitor status would be obtained from DMS/SCADA

Single-phase capacitor bank switching

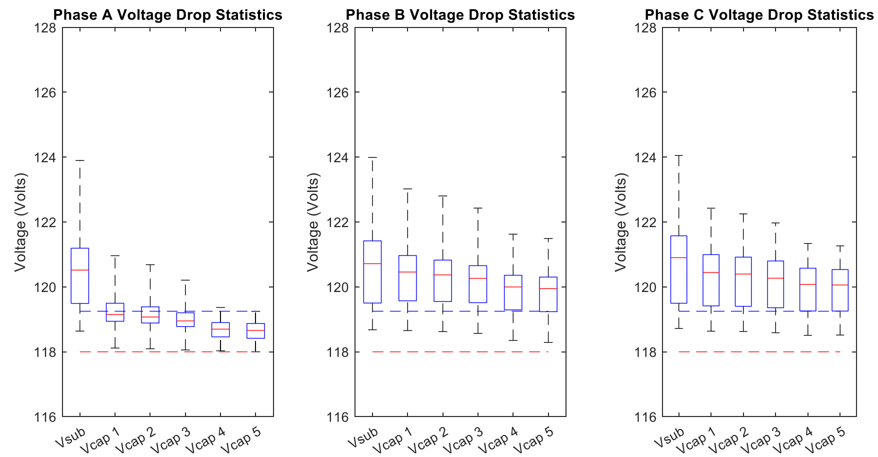


Results – Single-Phase : Voltage profile statistics

Three phase VO (A)



Single phase VO



Comparison between single-phase VO and three-phase VO shows lower overall system voltages

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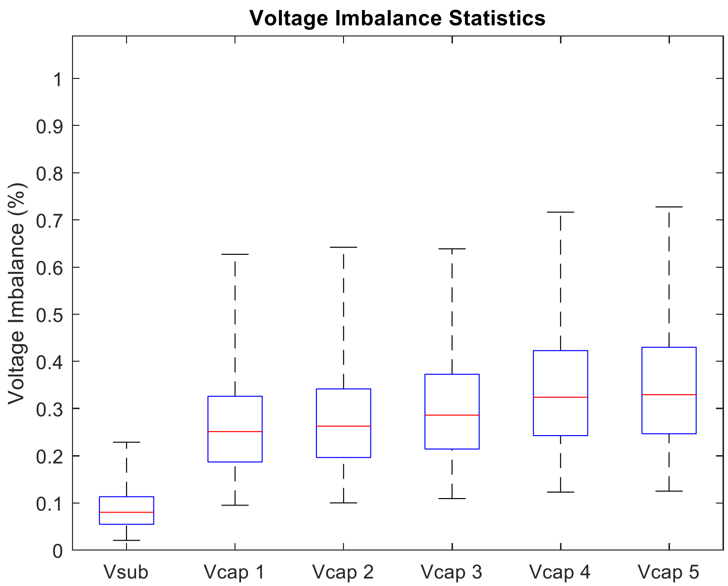
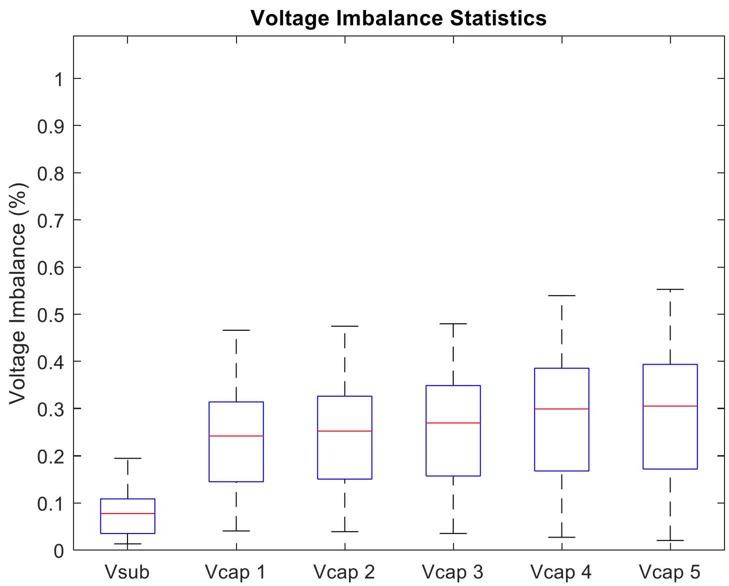
Results – Single Phase : Voltage imbalance statistics

Three phase VO (A)



Single phase VO



Three phase VO cannot correct voltage imbalances while single phase VO is able to significantly reduce it.

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Single Phase : Implementation Issues & Resolution

- Capacitor bank health monitored via neutral current magnitude
  - In unbalanced/single phase operation, possibility of false positive exists, if the switch status is not actively monitored

- Alternative: monitor neutral current magnitude and angle
  - Neutral current angle on each phase leads the voltage by 90° +/- the deviation due to neutral current transformer cable length
  - Due to the 120° phase shift between the phases, under the normal operating conditions, the magnitude of neutral current for any single capacitor switch being closed or any two capacitor switches being closed is approximately the same
  - Excessive neutral current (i.e. higher than the expected range) is a sign of capacitor can failure (as capacitor cans fail, their impedance is lower, resulting in higher currents)
  - Lower than expected neutral current could imply potential switch failure (as the switch contacts do not properly close, there is a higher impedance that results in lower current)

Results: Overall Summary & Conclusion

Sr. No.	Metric	Units	Base Case	3 Phase (A)		Single Phase	
				Value	% Change wrt BC	Value	% Change wrt BC
1	Peak Demand	MVA	7.34	7.13	-2.9%	7.06	-3.8%
2	Peak Demand	MW	6.72	6.73	0.1%	6.71	-0.1%
3	Peak Demand	MVAR	3.02	2.37	-21.5%	2.24	-25.8%
4	Total Real Losses	MWh	3.07	2.55	-16.9%	2.52	-17.9%
5	Total Reactive Losses	MVARh	137.67	39.8	-71.1%	34.2	-75.2%
6	Total LTC Operations	Nos	6	54	800.0%	51	750.0%
7	Total Capacitor Operations	Nos	4	28	600.0%	67*	1575.0%
8	Min Ckt Voltage	pu	117.37	118	0.5%	11	0.5%
9	Max Ckt Voltage	pu	125.54	125.19	-0.3%	124.05	-1.2%
10	Max Voltage Imbalance	%	0.73%	0.73%	0.0%	0.55%	-24.7%

*Individual operations of each capacitor bank

- Three-phase VO savings are lower in unbalanced systems
- Single-phase VO overcomes the problem of over/under compensation of system voltage
- Single-phase VO leads to lower losses, peak demand, and voltage imbalance but results in an increase in LTC operations
- Single-phase VO will require modifications to capacitor health monitoring

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~THANK YOU~

Q&A

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