High Penetration PV Control Comparisons and Model-Centric Smart Grid CBA

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Model-Centric Smart Grid CBA

Model-Centric Smart Grid

Reliability, Efficiency, Capacity, Protection, Controllability

Performance Analysis **+**

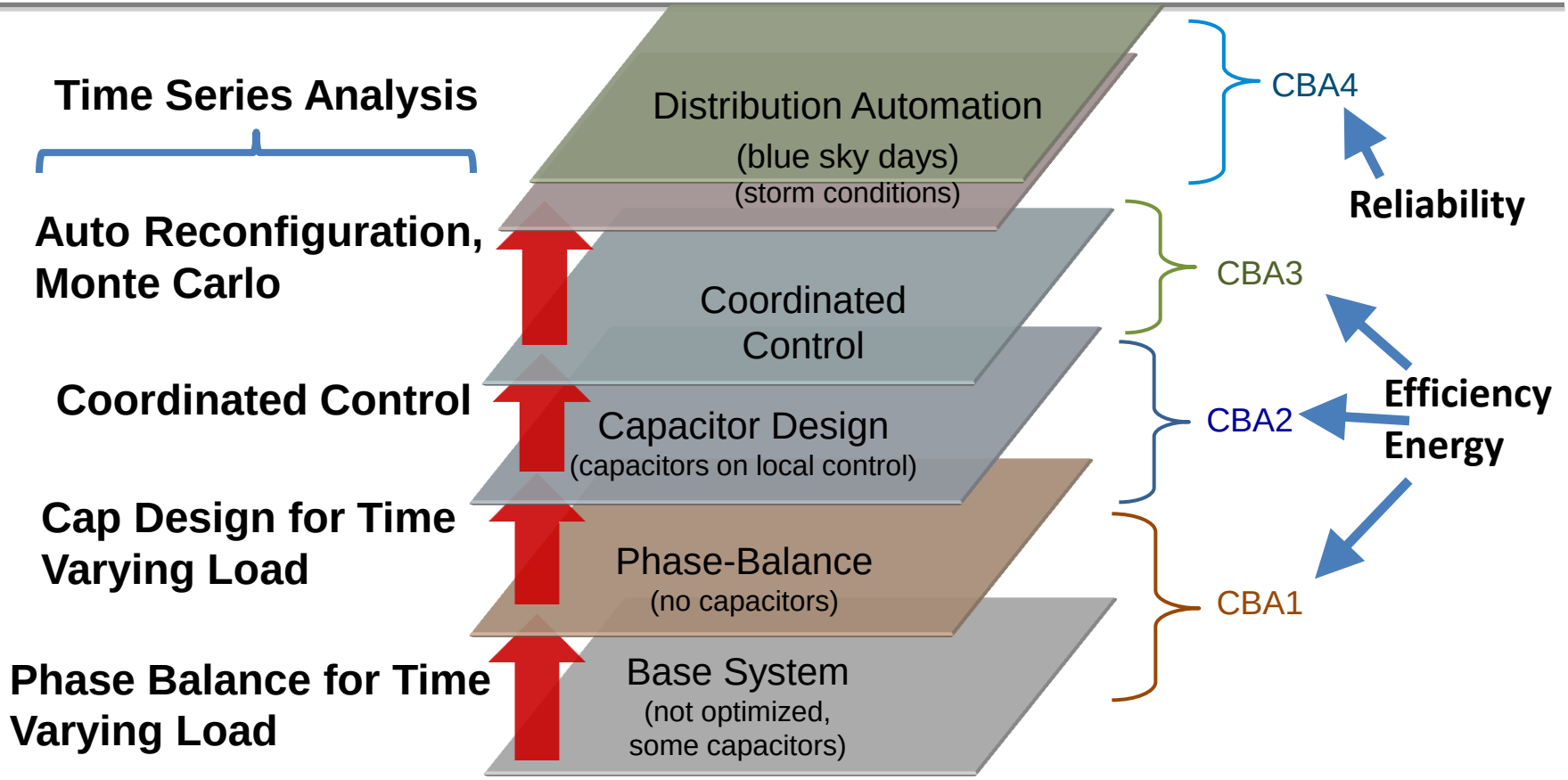
Economic Analysis **+**

Lab Testing **+**

Field Validation **=**

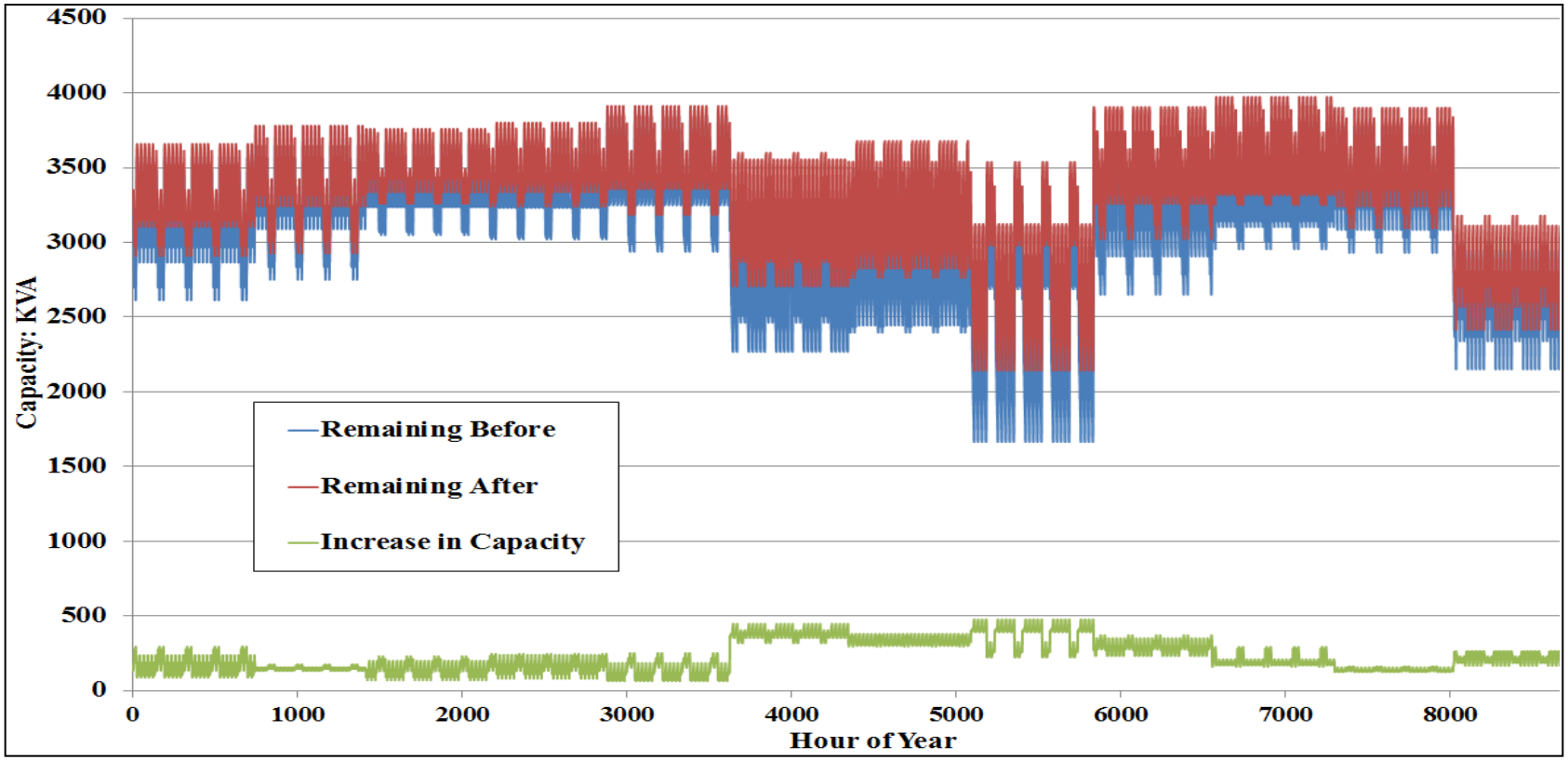
Model-Centric Smart Grid

Incremental Grid Modernization CBA



"Dependency Ordering" of Investments

Time Series Analysis Example



% Errors between Load Factor and Time Series Analysis

Present Value Savings for 10 Years

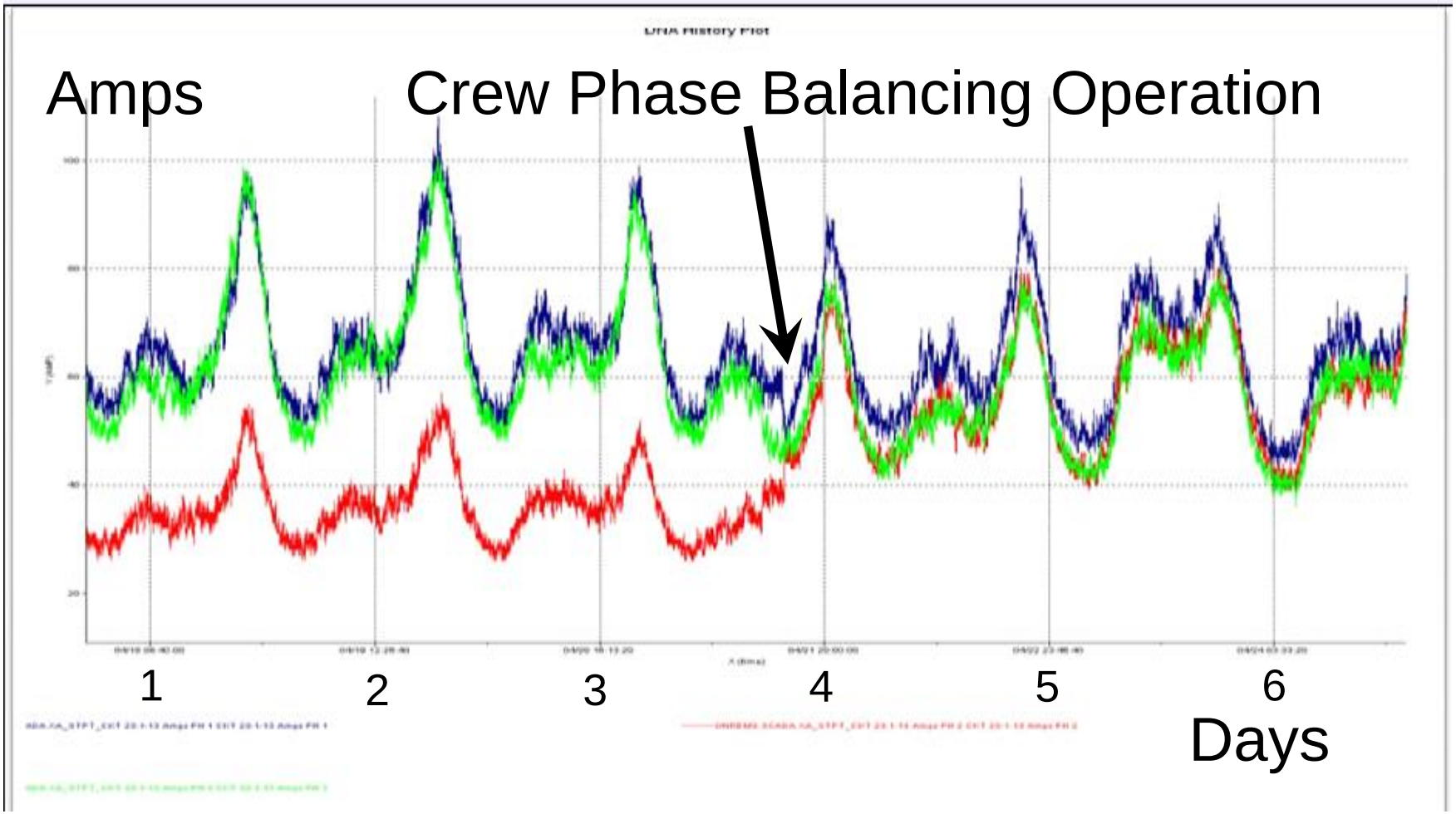
Case	Cost (Inc/Total) ($000)	Savings Type					Case Savings ($000)	$ Saved / $ Invested (Inc/Total)
		Efficiency (Inc/Total) ($000)	Energy (Inc/Total) ($000)	Capital ($000)	Operation ($000)	CI ($000)		
CBA1	163/163	94/94	29/29	NA	NA	NA	123	0.75/0.75
CBA2	564/727	227/321	2,234/2,263	NA	NA	NA	2461	4.36/3.55
CBA3	68/795	88/409	2,064/4,328	NA	NA	NA	2,132	31.65/5.74
CBA4	1,953/2,748	NA	NA	7,014	7,646	9,566	24,226	12.4/10.54

Estimated CO_2 reduction = 76,330 tons

Societal Benefits

$1.4 ~ Residential
$230 ~ Commercial
$650 ~ Industrial

Validation of Phase Balancing

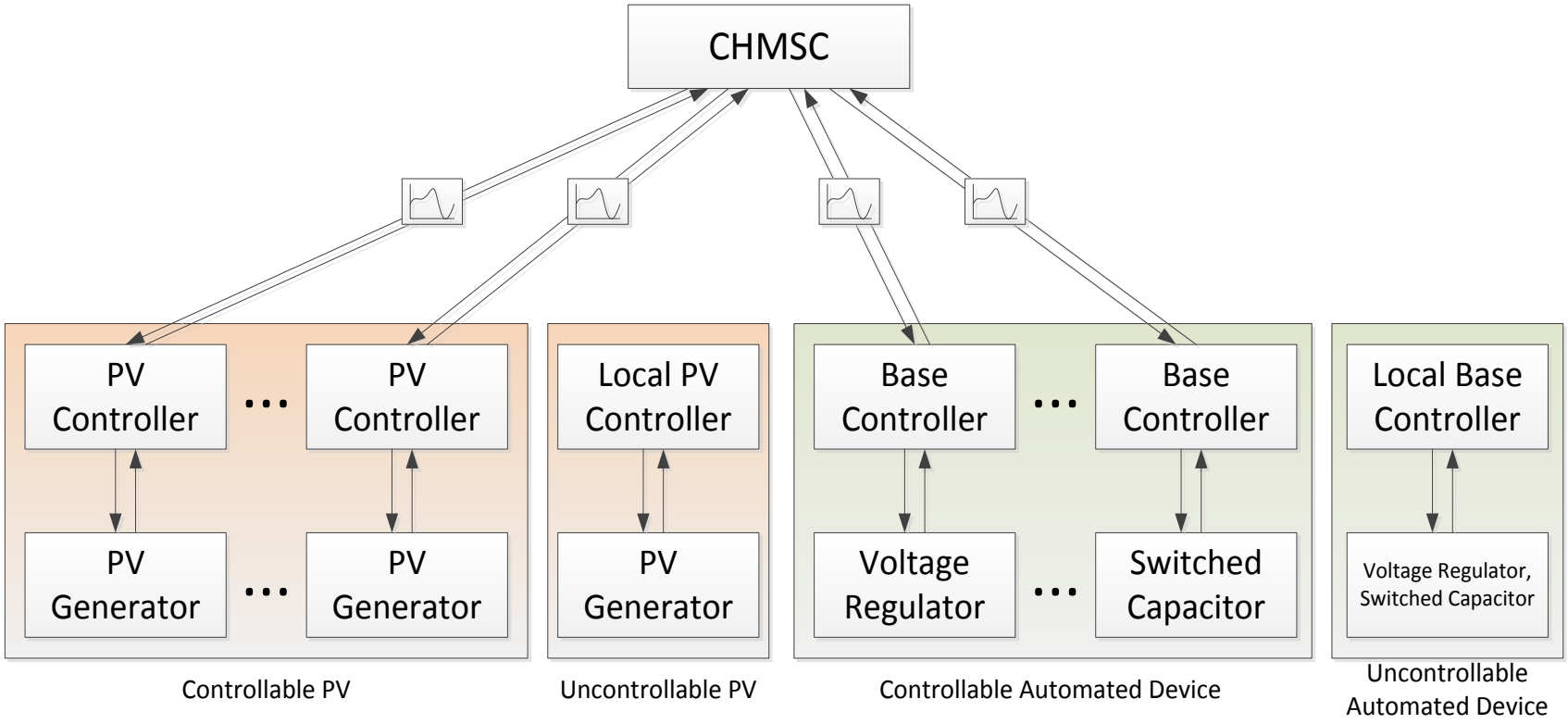


High Penetration PV Control Comparisons

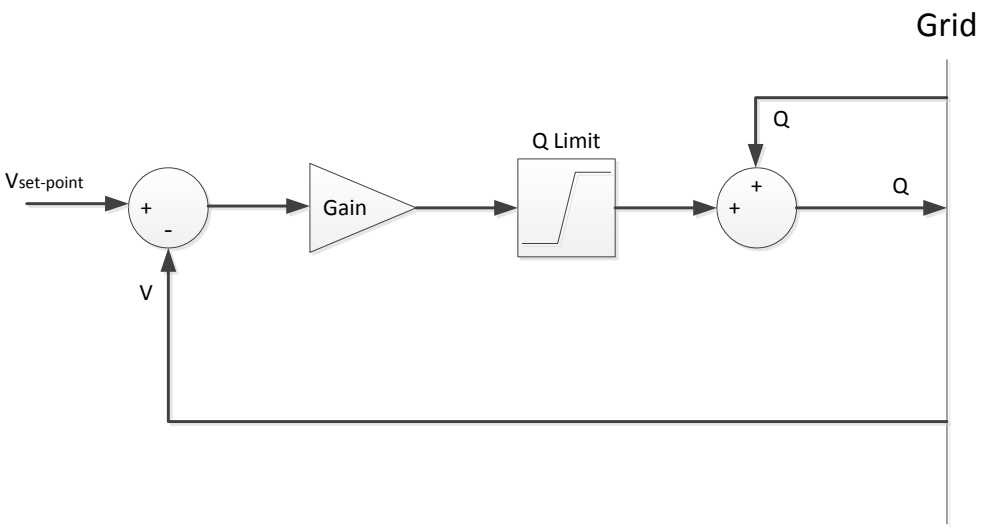
Control Approach

- **C**onfigurable, **H**ierarchical, **M**odel-based, **S**cheduling **C**ontrol = **F**orecast – **M**onitor – **S**chedule - **A**djust
- Collects circuit-wide information and uses model to calculate set-points for control devices
- Sends control set-points to both utility control devices and PV controllers
- Strives to maintain the voltage profile that exists without PV generation while minimizing circuit losses and reducing the motion of utility control devices

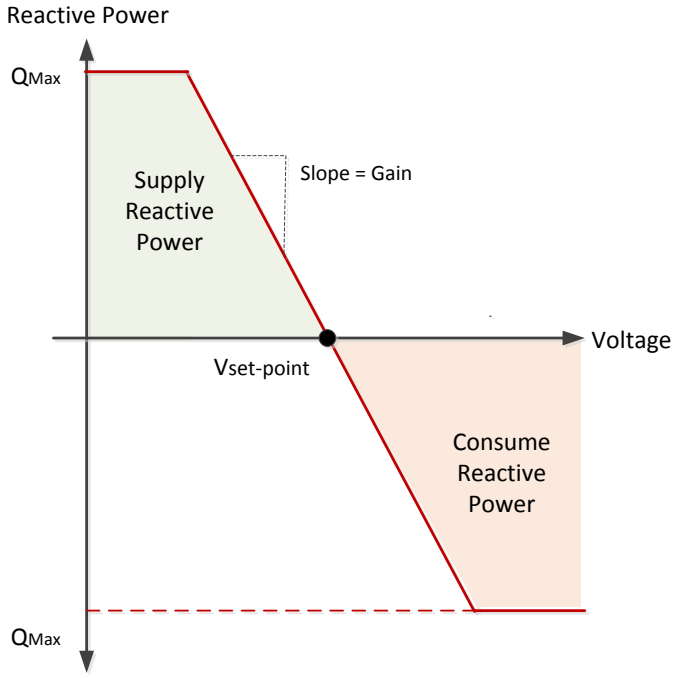
CHMSC Control Architecture



Local Voltage Controller



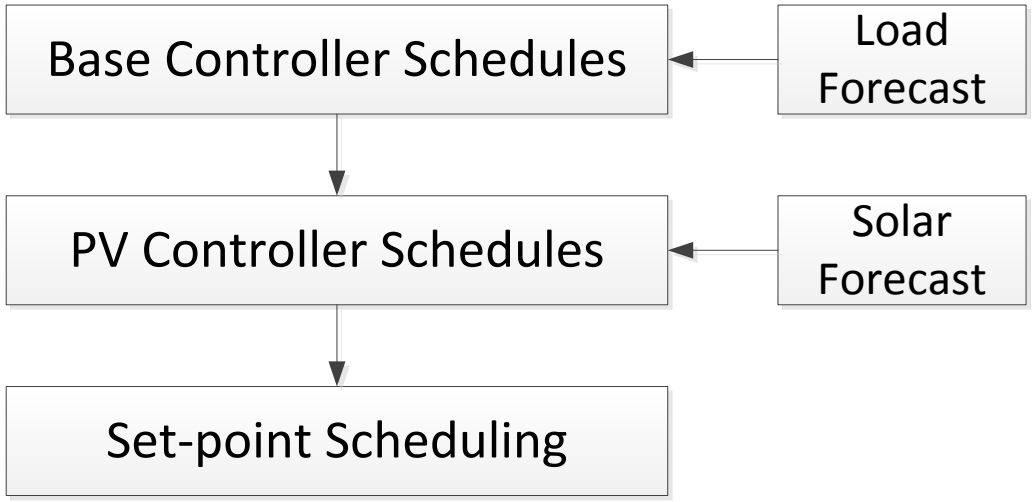
(a) voltage-reactive power control block diagram



(b) voltage-reactive power characteristics

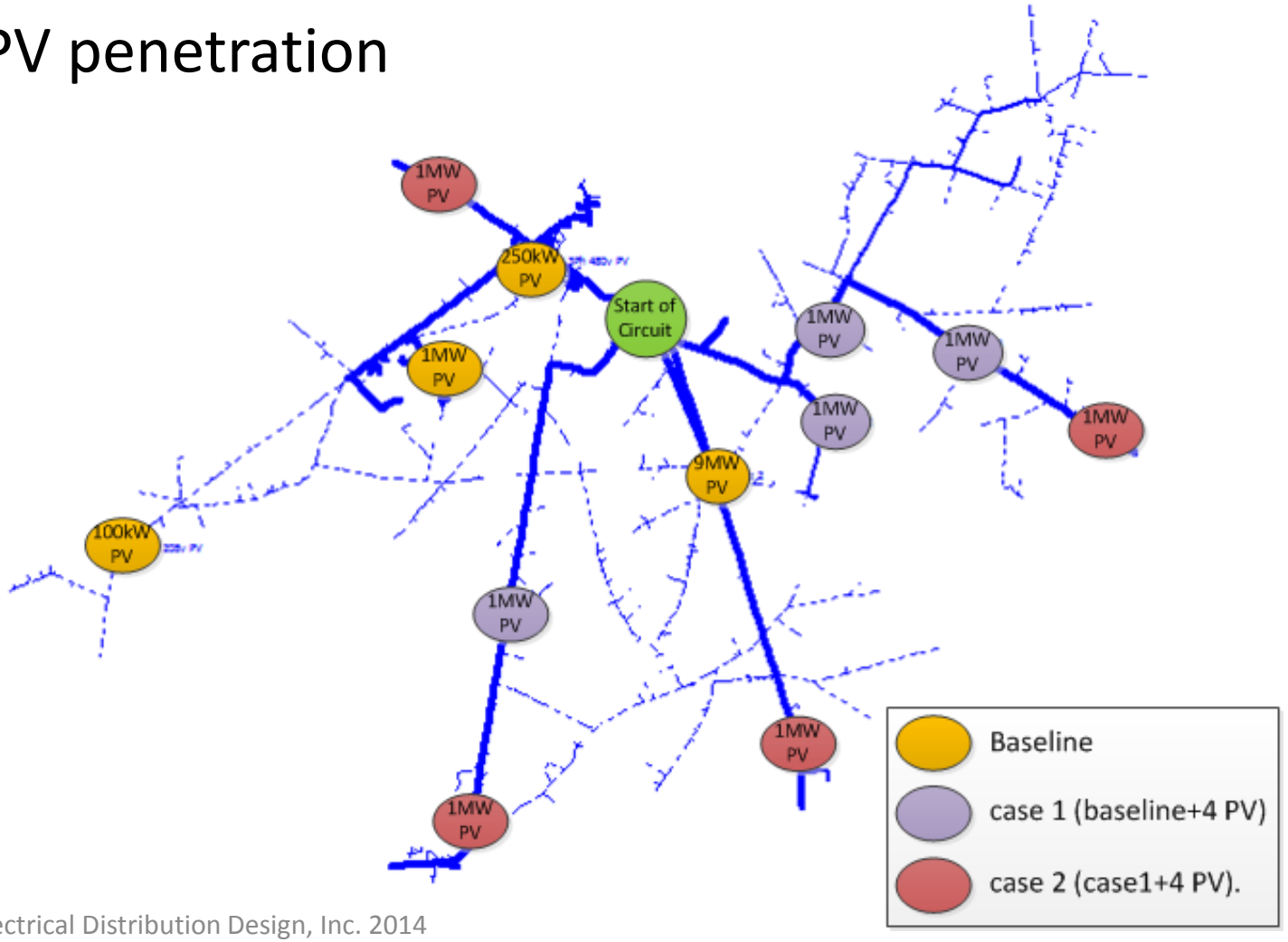
CHMSC Algorithm

- ✓ Updates periodically, where every five minutes is currently used
- ✓ Updates set-point schedules for base and/or PV control only if schedules change significantly
- ✓ If a communication failure occurs, the local controllers continue to work against the previously provided schedule as long as local constraint violations do not occur

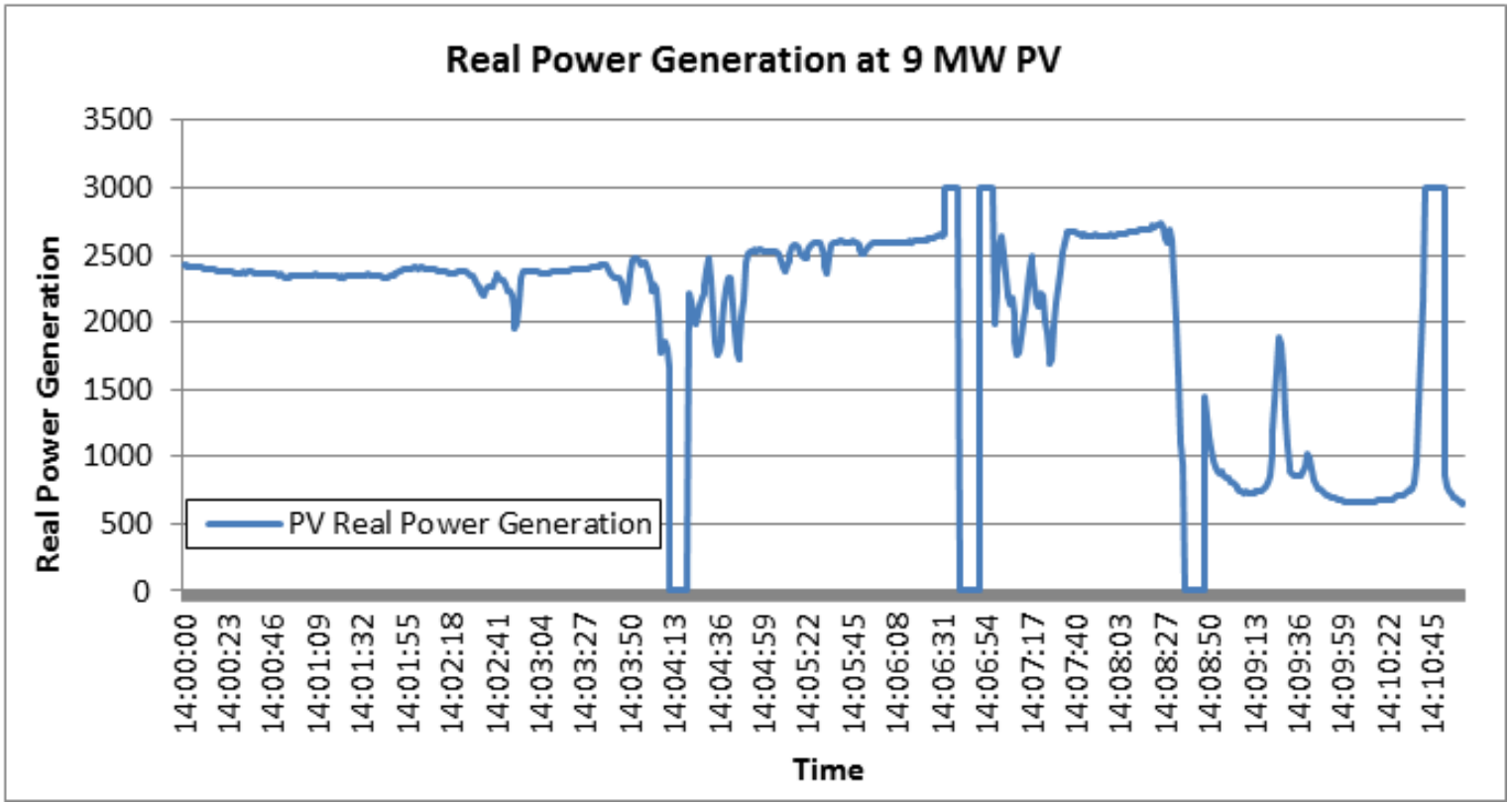


Circuit Model

123% PV penetration



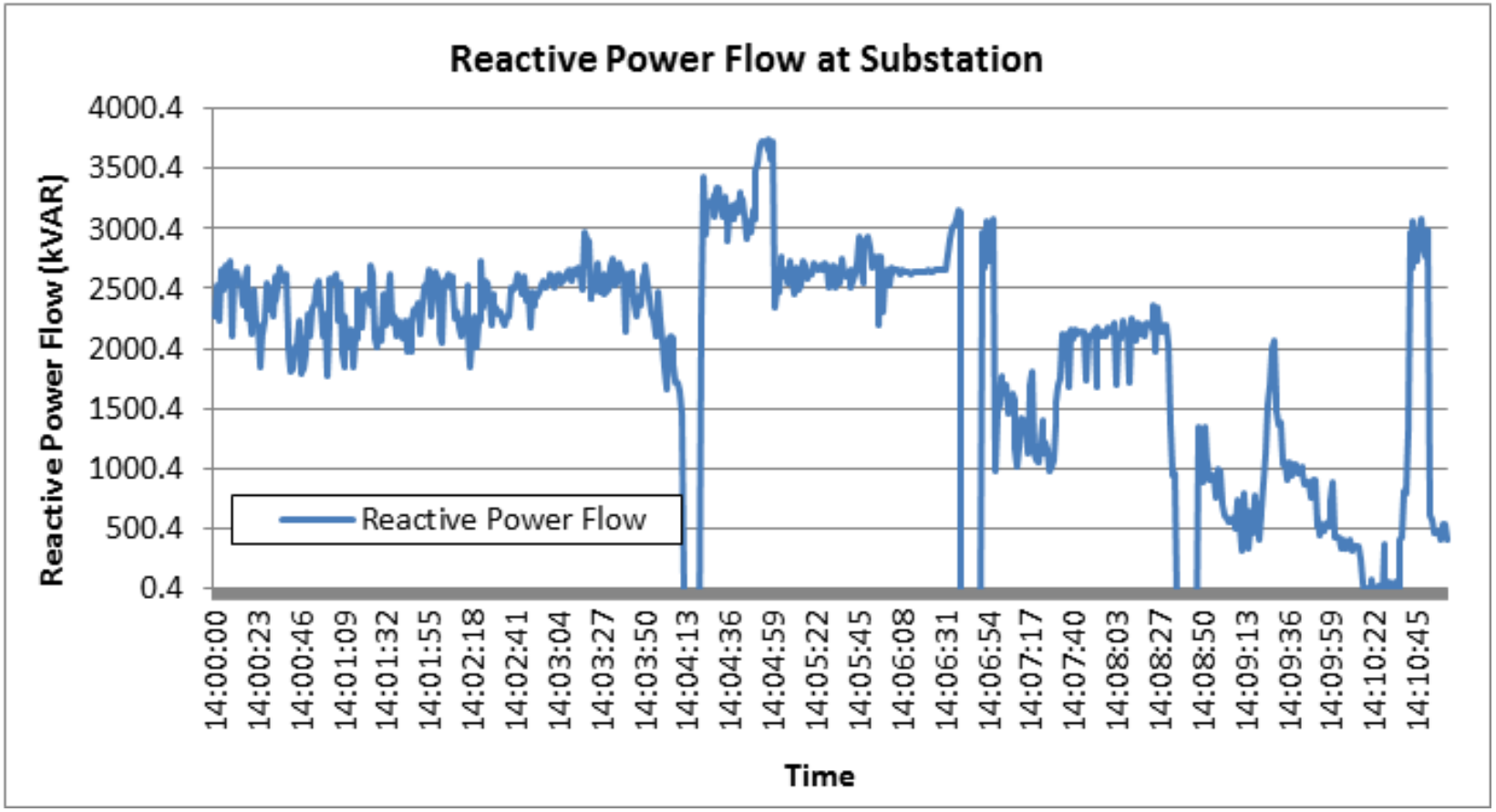
1 Second PV Generation Data



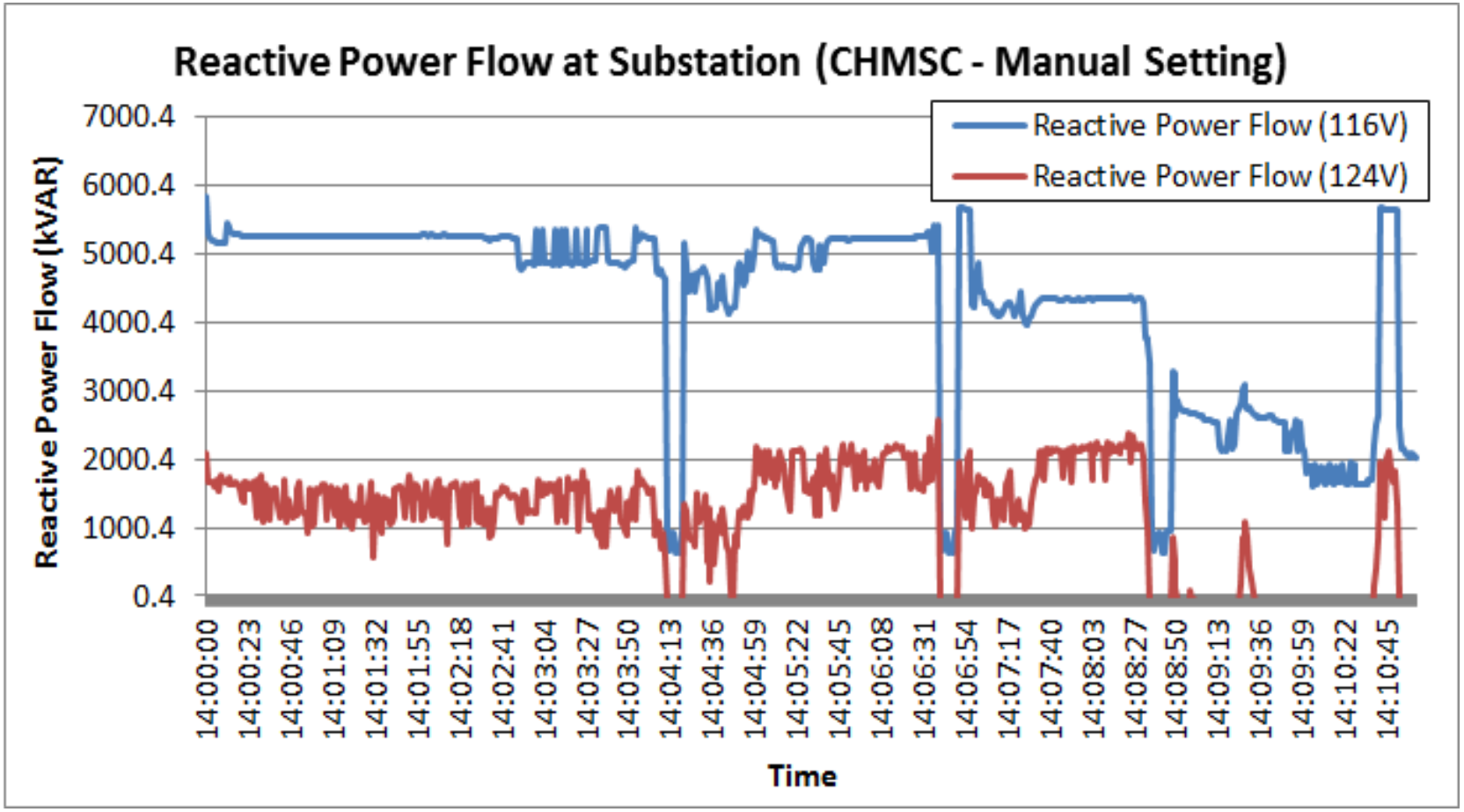
Controls Evaluated

- ✓ **CHMSC**: Feeder losses and utility controller motion are minimized and voltage set-points are used for PV generators
- ✓ **CHMSC – 116V**: Average customer voltage set-point at 116V
- ✓ **CHMSC – 124V**: Average customer voltage set-point at 124V
- ✓ **CHMSC (PF set)**: Power factor set-points used for PV generators
- ✓ **CHMSC – 116V (PF set)**: Average customer voltage set-point at 116V with power factor set-points provided to PV generators
- ✓ **CHMSC – 124V (PF set)**: Average customer voltage set-point at 124V with power factor set-points provided to PV generators
- ✓ **Local control only (116V)**: 116V set-point used by all PV generators
- ✓ **Local control only (124V)**: 124V set-point used by all of PV generators

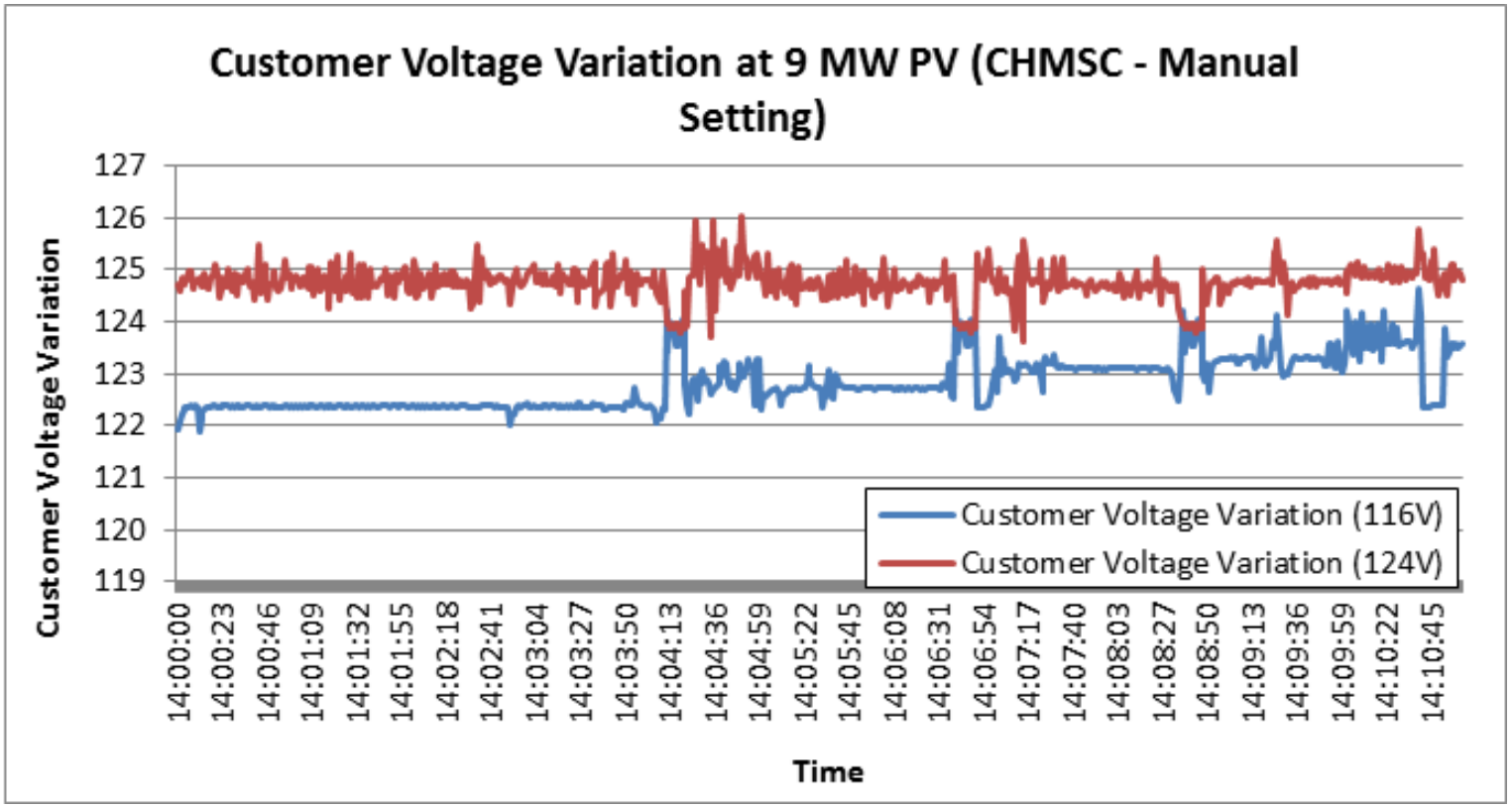
CHMSC Results: Sub Q Flow



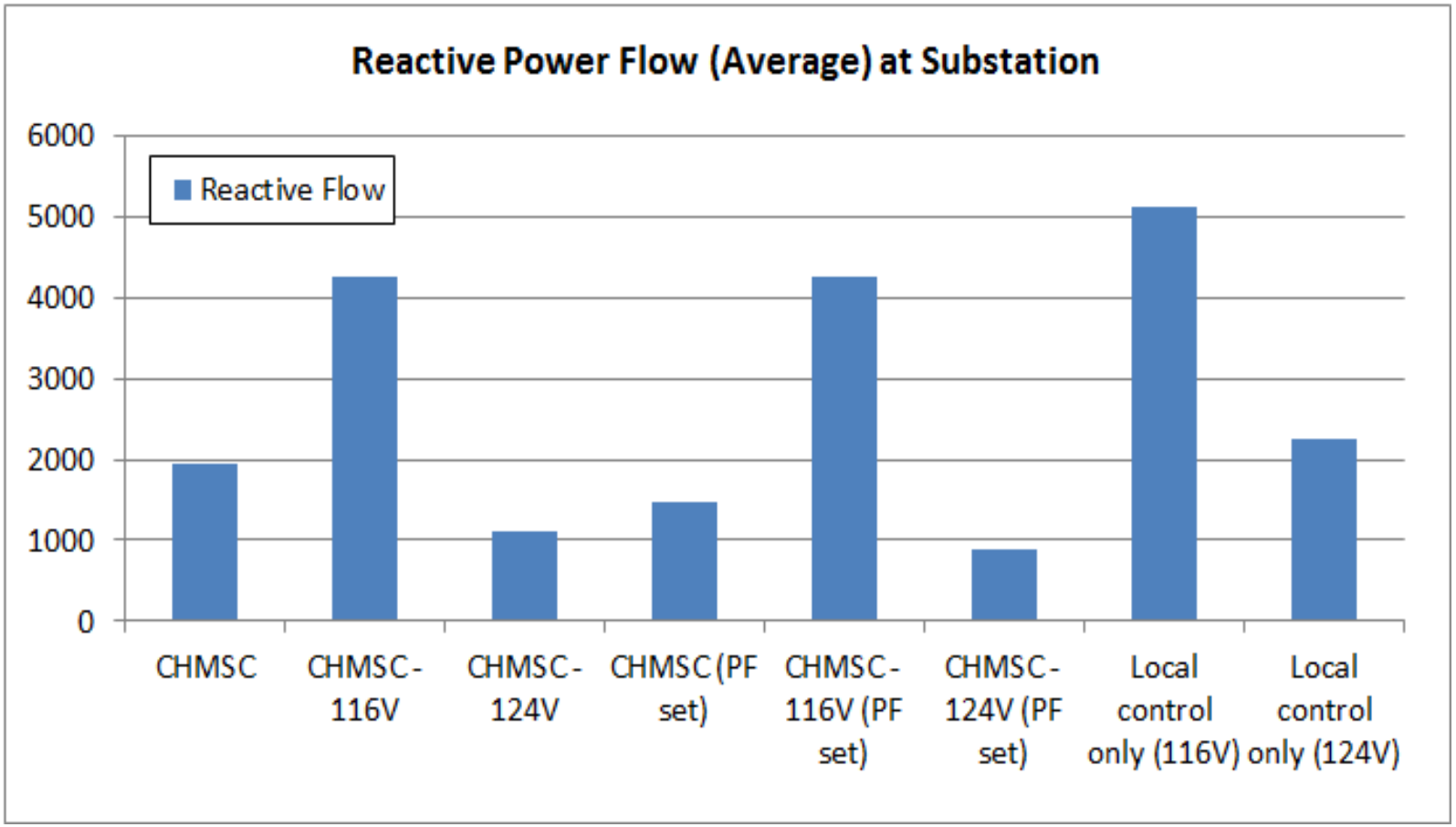
CHMSC with 116V/124V SPs: Sub Q Flow



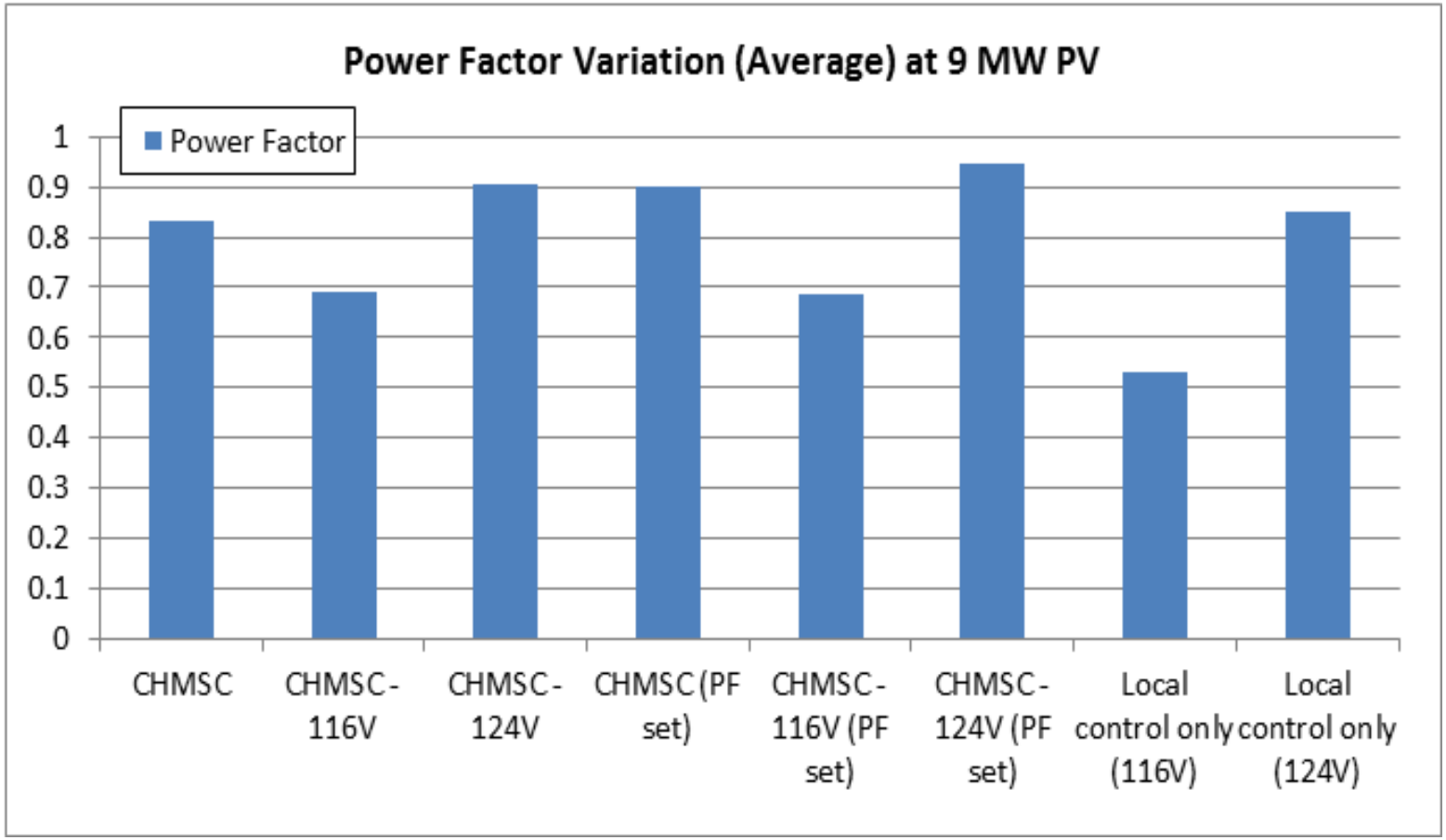
CHMSC with 116V/124V SPs



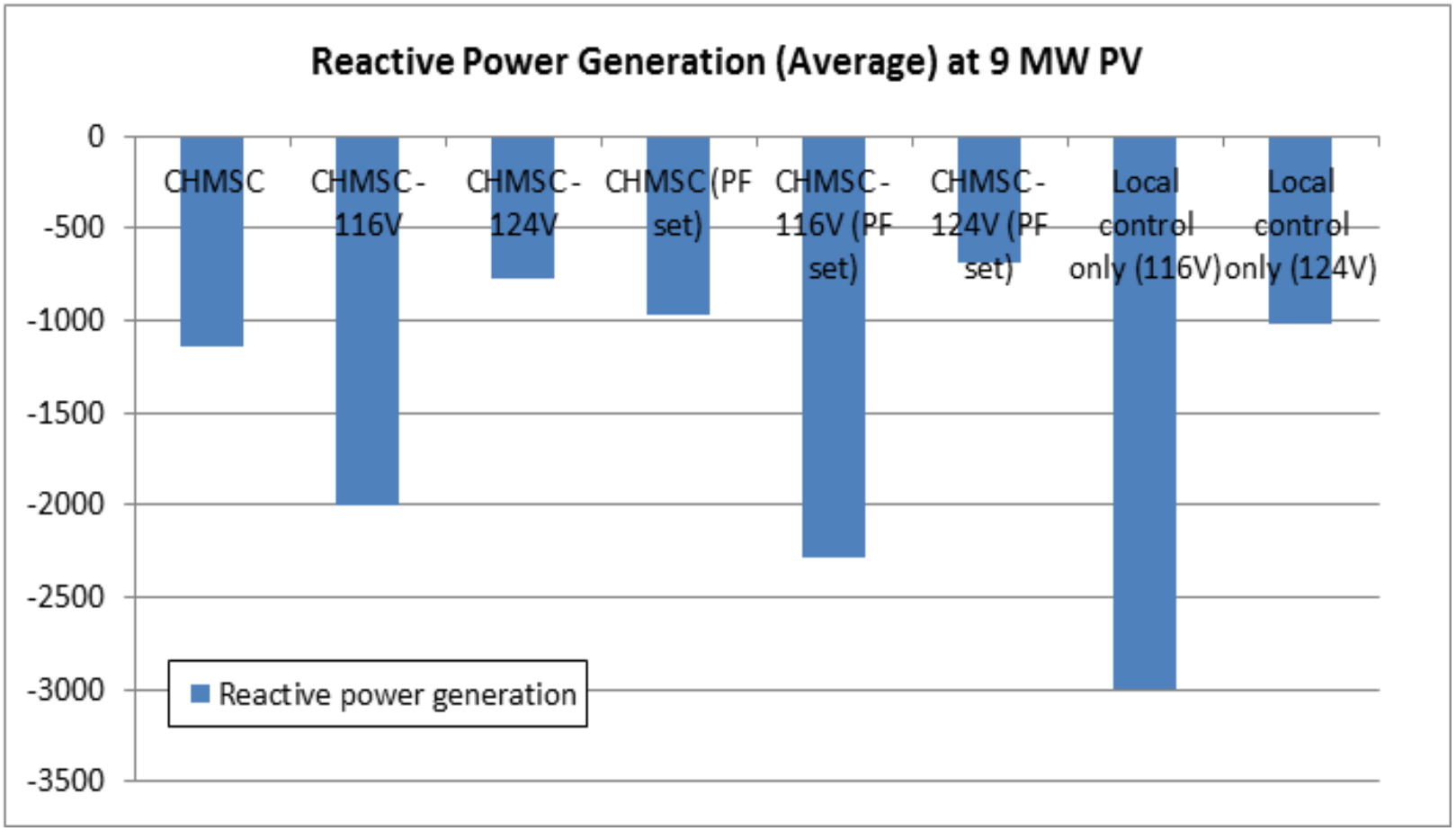
Sub Q Flow Comparison



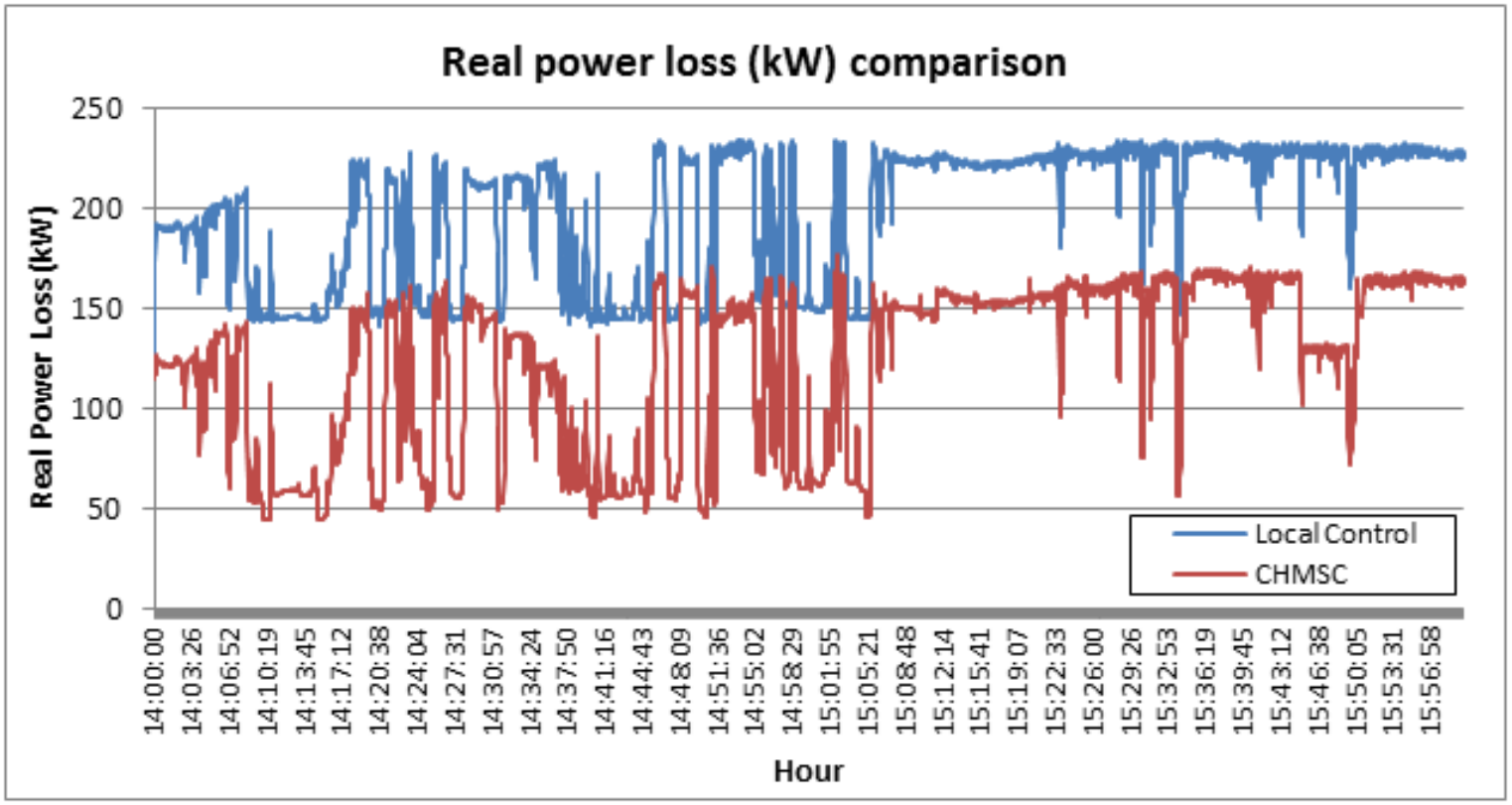
Average PF Results Comparison



Average Q Generation Comparison



Circuit Loss Comparison



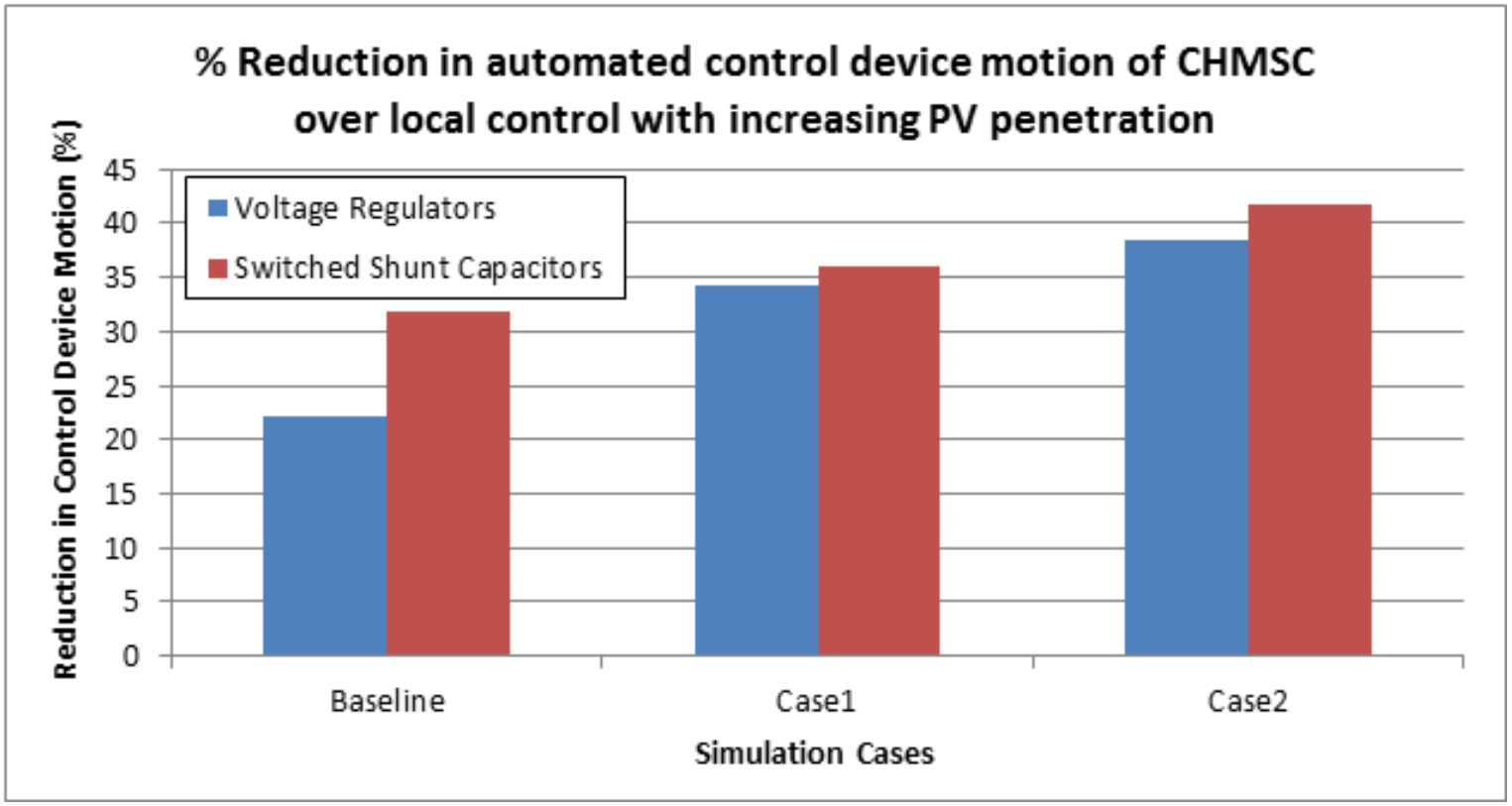
Real power loss (kW) comparison between local control and CHMSC

Circuit Loss Comparison

	Local Control	CHMSC	Improvement
Real Power Loss (kW-hr)	198.98 kW-hr	123.25 kW-hr	38.06%
Reactive Power Loss (kVAR-hr)	240.69 kVar-hr	130.38 kVar-hr	45.83%

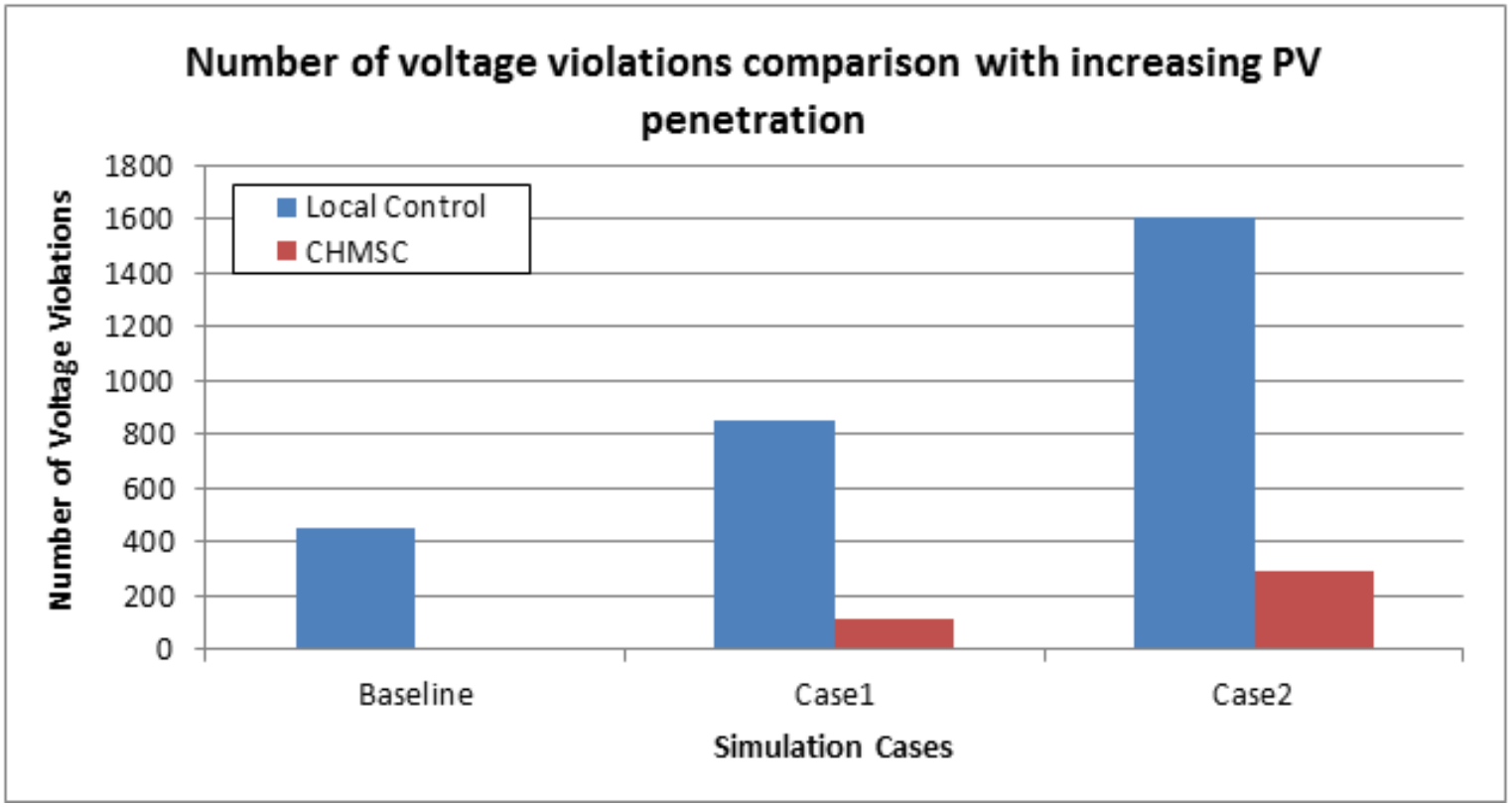
Comparing CHMSC with Local Control with Increasing PV Penetration – 2 Hour Study

Control Device Motion Comparison



Reduction in control device movement with CHMSC with increasing PV penetration

Voltage Violation Comparison



Number of voltage violations during 2 hour period with increasing PV penetration

Conclusions

- ✓ CHMSC requires less reactive power flow at substation
- ✓ CHMSC provides higher power factor at PV
  - CHMSC has less reactive power generation at PV generator
- ✓ CHMSC results in lower circuit loss
- ✓ CHMSC results in fewer utility device controller steps
- ✓ CHMSC results in fewer voltage and overload violations