MULTI-TIME SCALE REAL-TIME VOLTAGE AND VAR CONTROL USING REAL-TIME CO-SIMULATIONS PLATFORM

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OUTLINE

- Overview of Electric Power Distribution Network
- Concept of Volt/VAR Control
- Time Horizon Control
- Multi-Time Scale Control
- Real-Time Implementation
- Real Time Co-Simulation Framework
- Conclusion and Future Work

OVERVIEW OF ELECTRIC POWER DISTRIBUTION NETWORK

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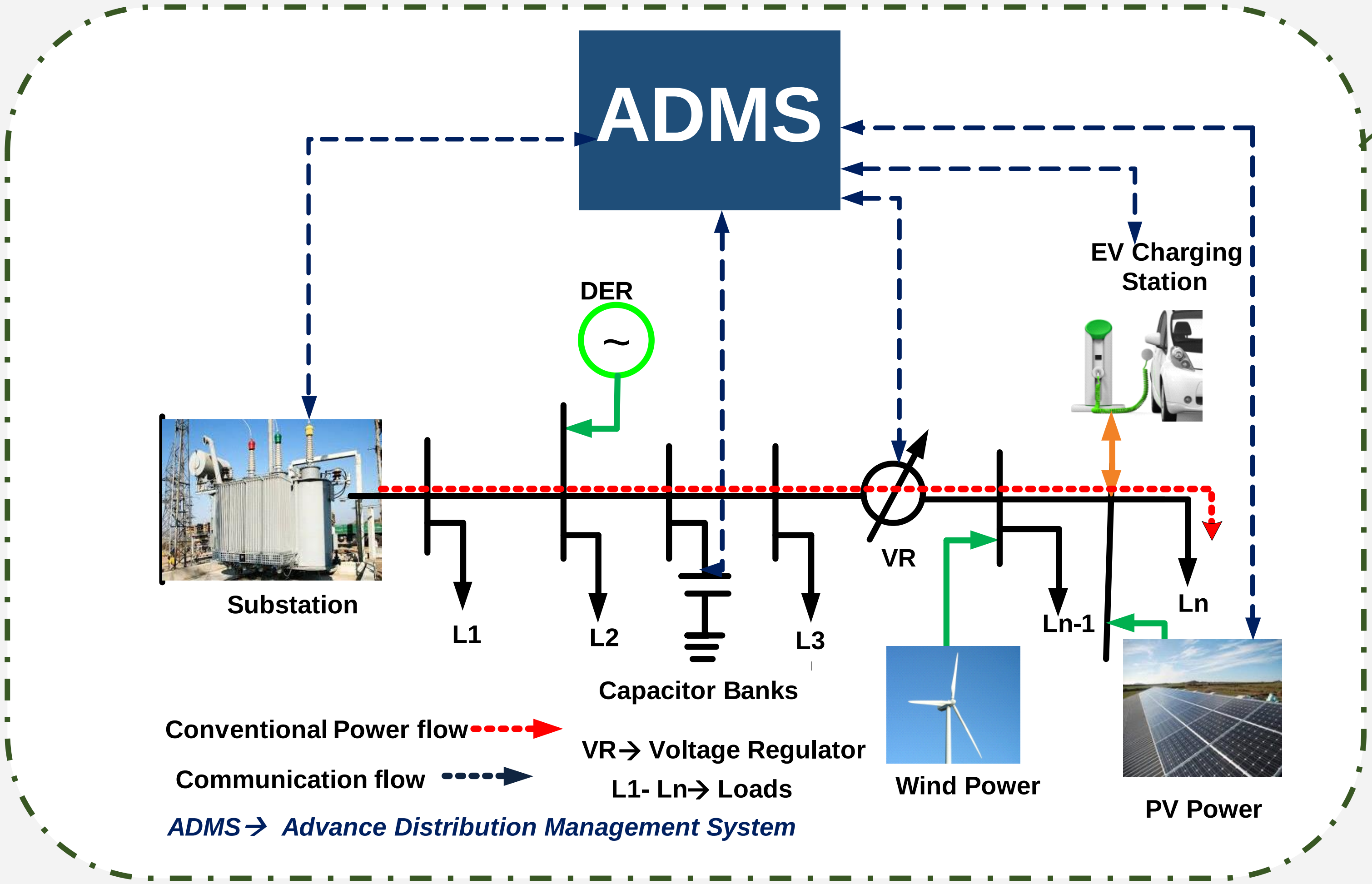
ELECTRIC POWER DISTRIBUTION NETWORK

Passive Distribution Network

Active Distribution Network



Smart Volt/VAR /Watt Control

CONCEPT OF VOLT/VAR CONTROL

TRADITIONAL VOLT/VAR CONTROL

❖**Volt/VAR Regulation** through tradtional devices such as:

➢OLTC transformer

➢Step Voltage Regulator (SVR)

➢Capacitor Banks (CB)

❖Using ***Line drop compensation*** Mechanism in open loop

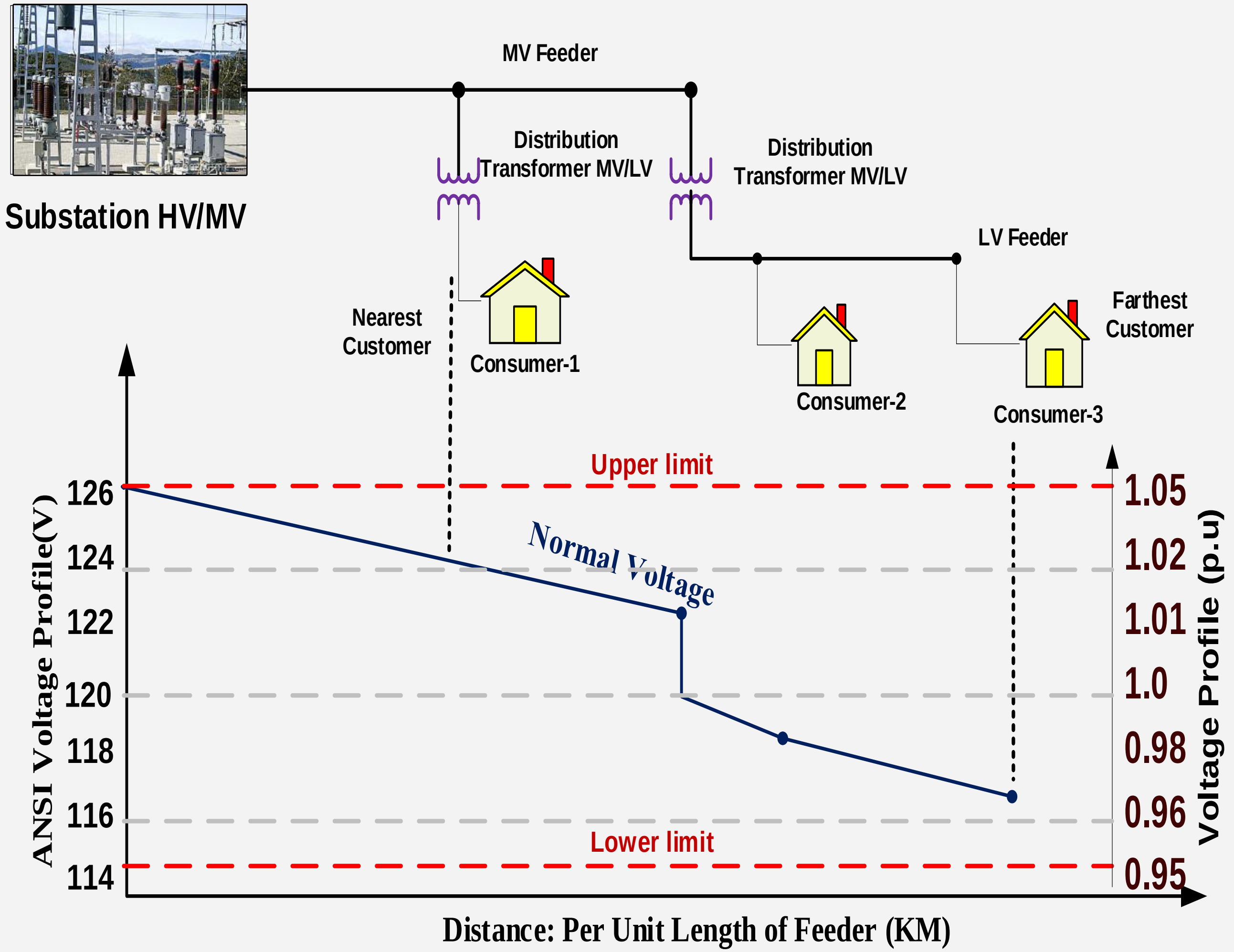
Drawbacks :

✓**Poor voltage profile at end users**

✓**Inaccurate load modeling**

✓**Poor observability and monitoring of the system**

Voltage Distribution at feeder length

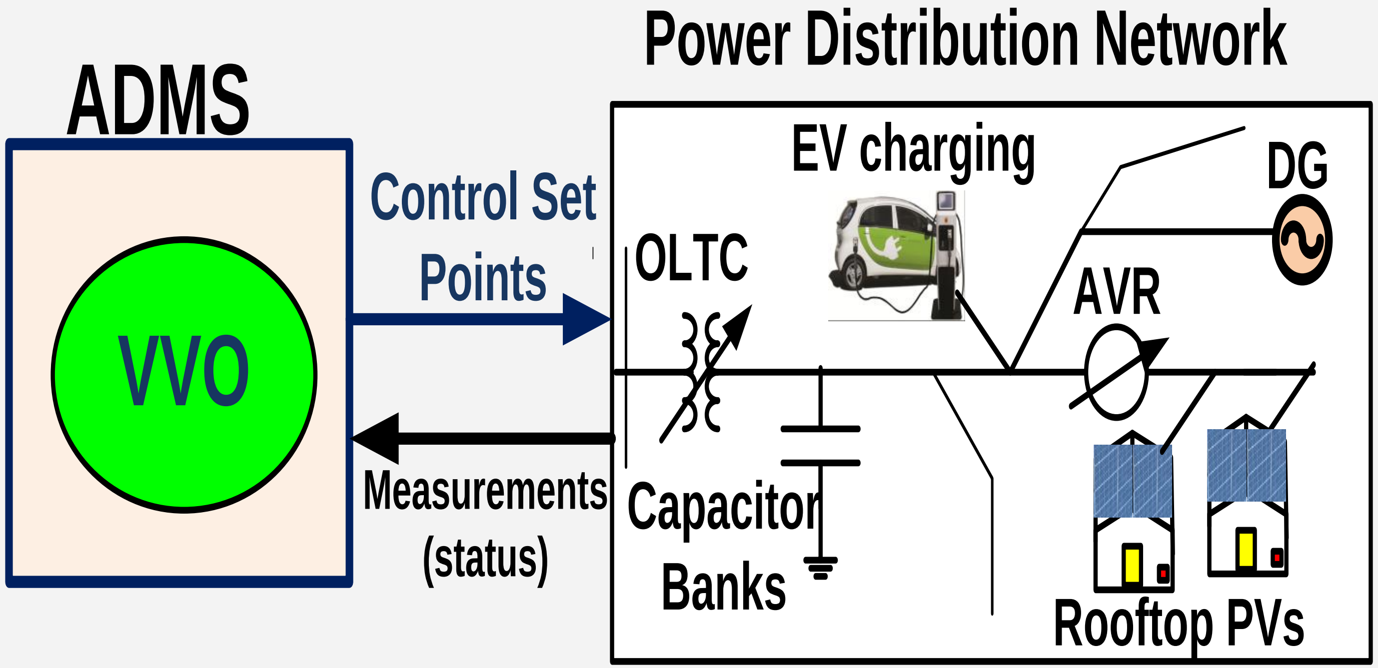


SMART VOLT/VAR CONTROL

- ❖**Volt/VAR Regulation** through tradtional devices and utility assets such as ***distributed energy resources*** (devices as: ***Smart Inverter)***
- ❖Using **Volt/VAR Optimization (VVO)** Methods in closed loop framework

Benefits :

- ✓ Healthy service voltage
- ✓ Optimized the set points
- ✓ High observability and monitoring
- ✓ AMI data enabled load model
- ✓ Closed loop control



TIME HORIZON CONTROL

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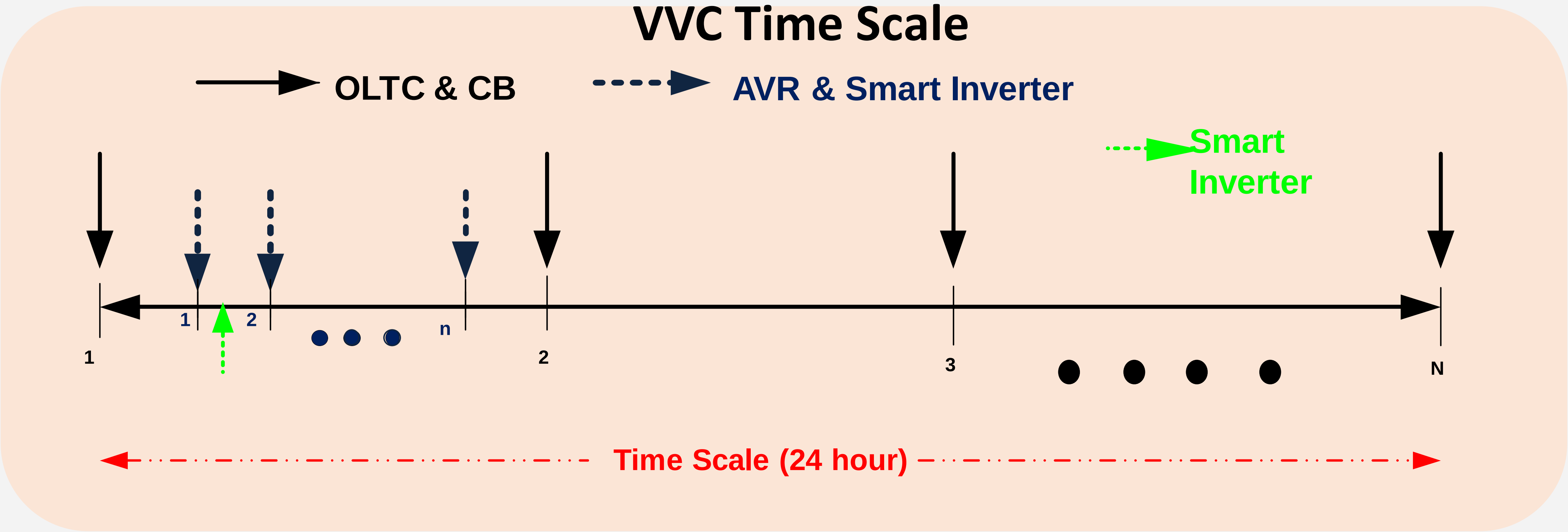
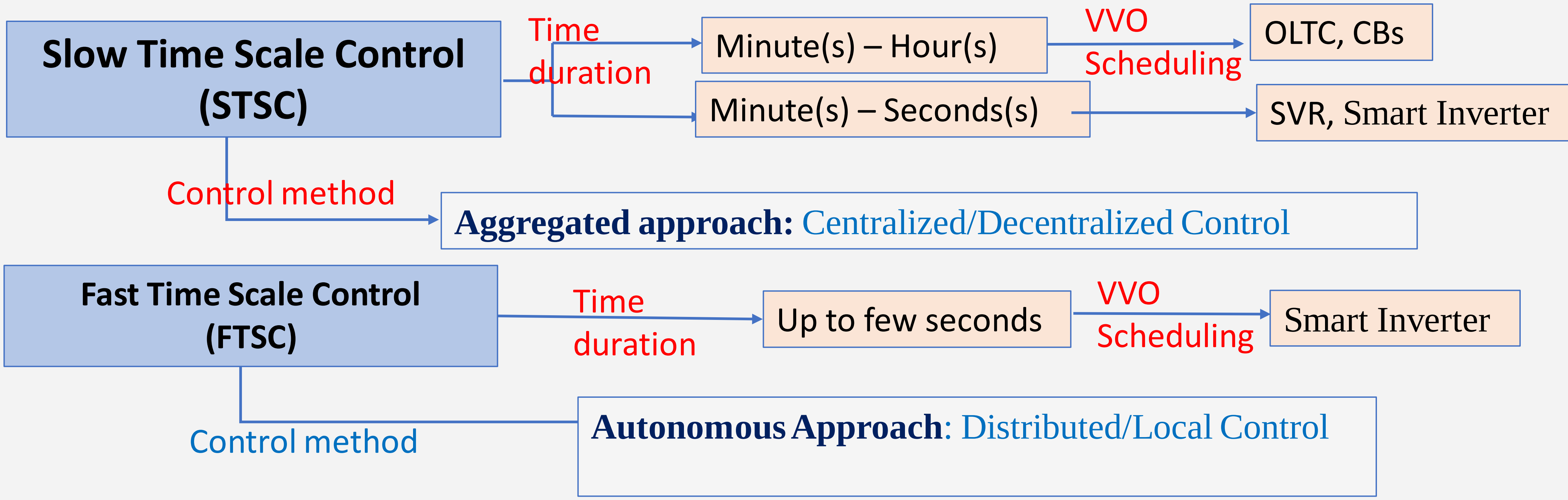
MULTI-TIME SCALE CONTROL

Slow and Fast Time Scale Control using network devices/assets

- Slow acting devices : OLTC, SVR and CBs
- Fast acting devices : **Smart inverter**



CONTROL FRAMEWORK

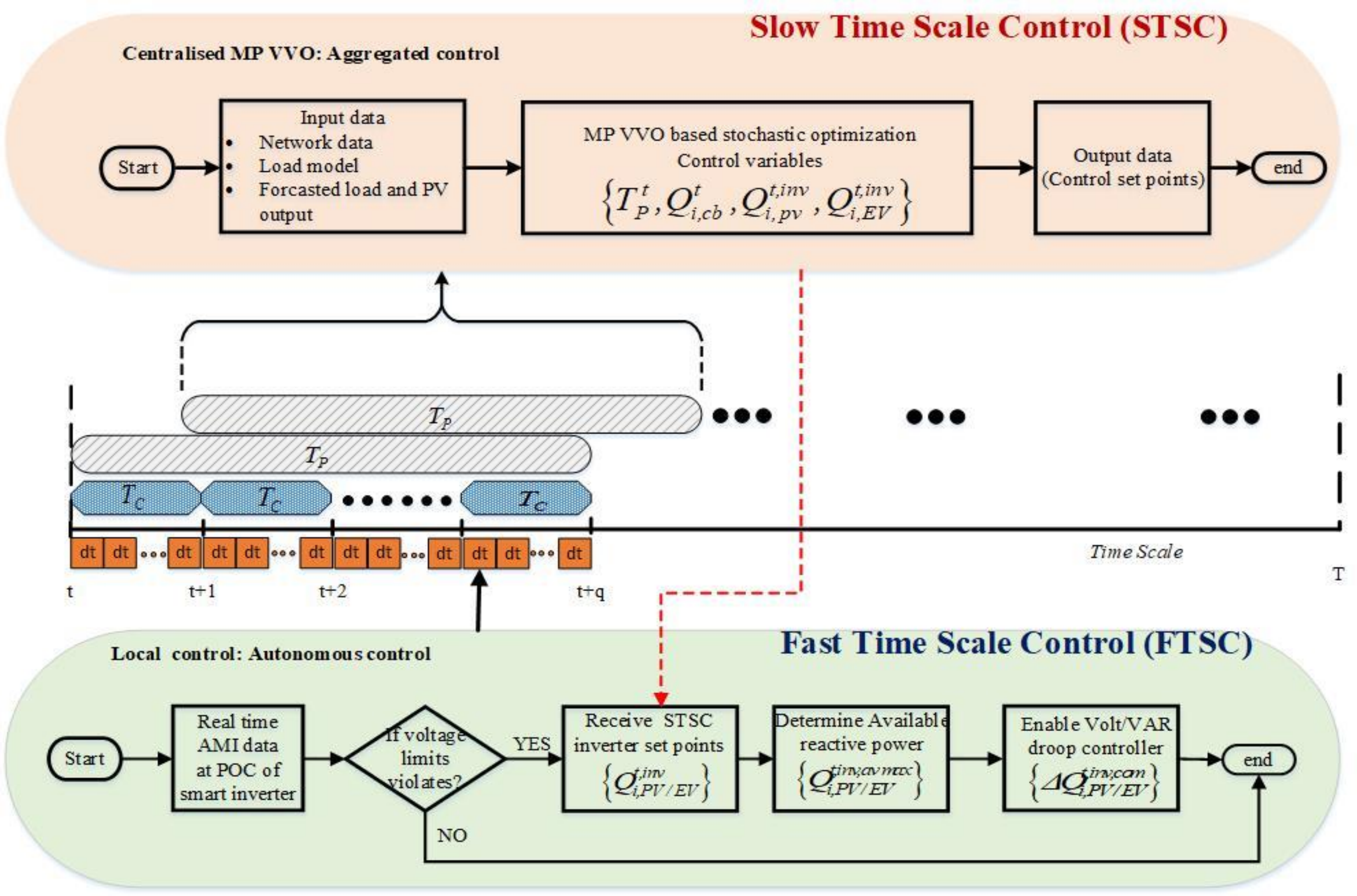


METHODOLOGY

Centralized with local control Framework

STSC : Centralized Model Predictive VVO

FTSC : Local using Droop Control



Fast Time Scale Control (FTSC)

- Unexpected situations such as
  - ✓ Sudden dynamic change in network configuration
  - ✓ Transient cloud movements
  - ✓ Sudden cloud appearing and disappearing
  - ✓ Solar eclipse

Consequently, it may cause violation of system limits.

- Traditionally, VVO control devices limitation:
  - ✓ OLC, AVR and capacitor banks (CB) have slow time operation constraints
  - ✓ Frequent operations of these devices will reduce their life cycles.

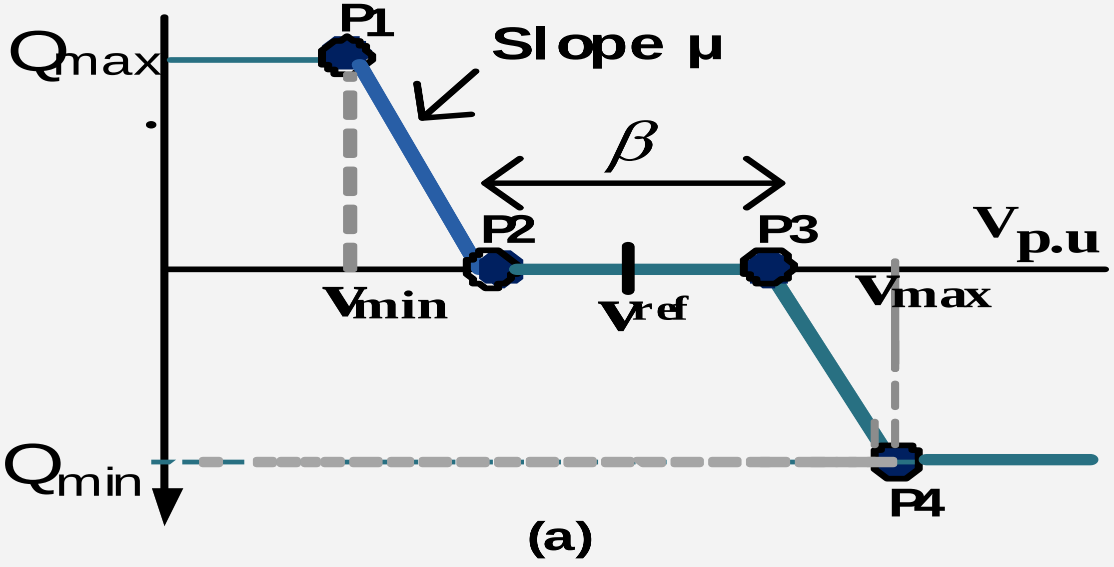
Solution:
Decentralized/ autonomous controls using ***Smart Inverter***

VOLT/VAR DROOP (VVD) CURVE : LOCAL CONTROLLER

- ✓The revised IEEE 1547 (2018) report that each DER must have VAR compensation provision when asked by power system operators

- ✓The standard droop function f(.) at k^th bus that is a piecewise linear function with a dead band β and droop points (P1, P2, P3 and P4)

Standard Volt/VAR droop Curve



REAL-TIME IMPLEMENTATION

IMPLEMENTATION OF CONTROL ALGORITHMS

RTDS Platform

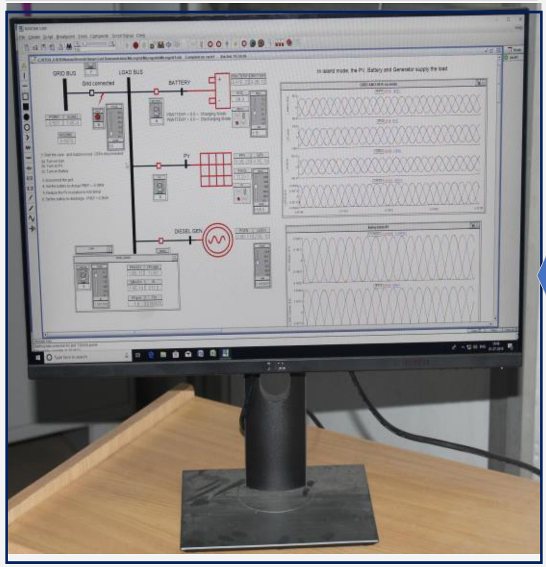
- ***Local Control*** using volt/VAR droop methods in real-time
- **Centralized with local control** in near real-time

Realizing using Real-Time Digital Simulator (RTDS) Platform

Distribution Mode

Software

RSCAD/Visualization in Run time



Network Connection (Ethernet)

Hardware

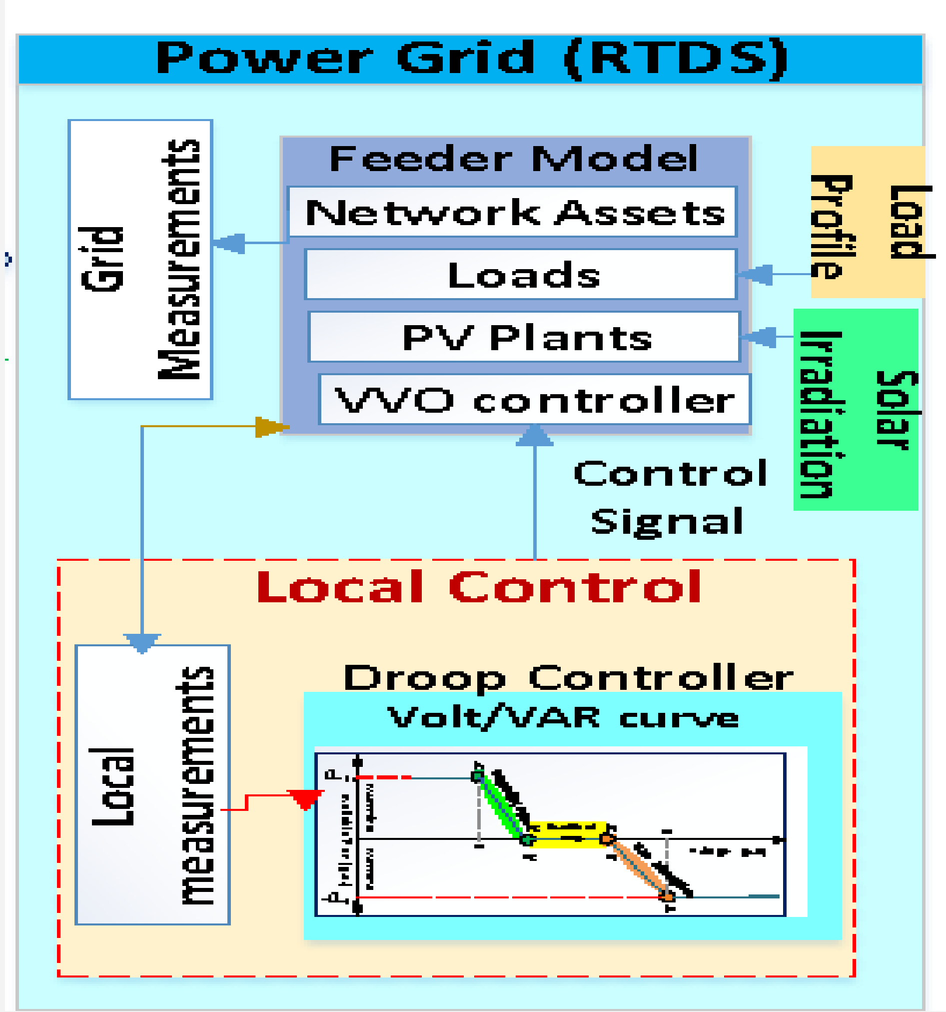
RTDS

LOCAL CONTROL : AUTONOMOUS APPROACH

Dynamic Voltage control in FTSC using Smart Inverter

- ***A Volt/VAR droop control*** algorithm executed locally in real-time
- Inverter based DER Model using ***Average model***
- Simulation time step of 150 micro-seconds in ***distribution mode***

RTDS Platform



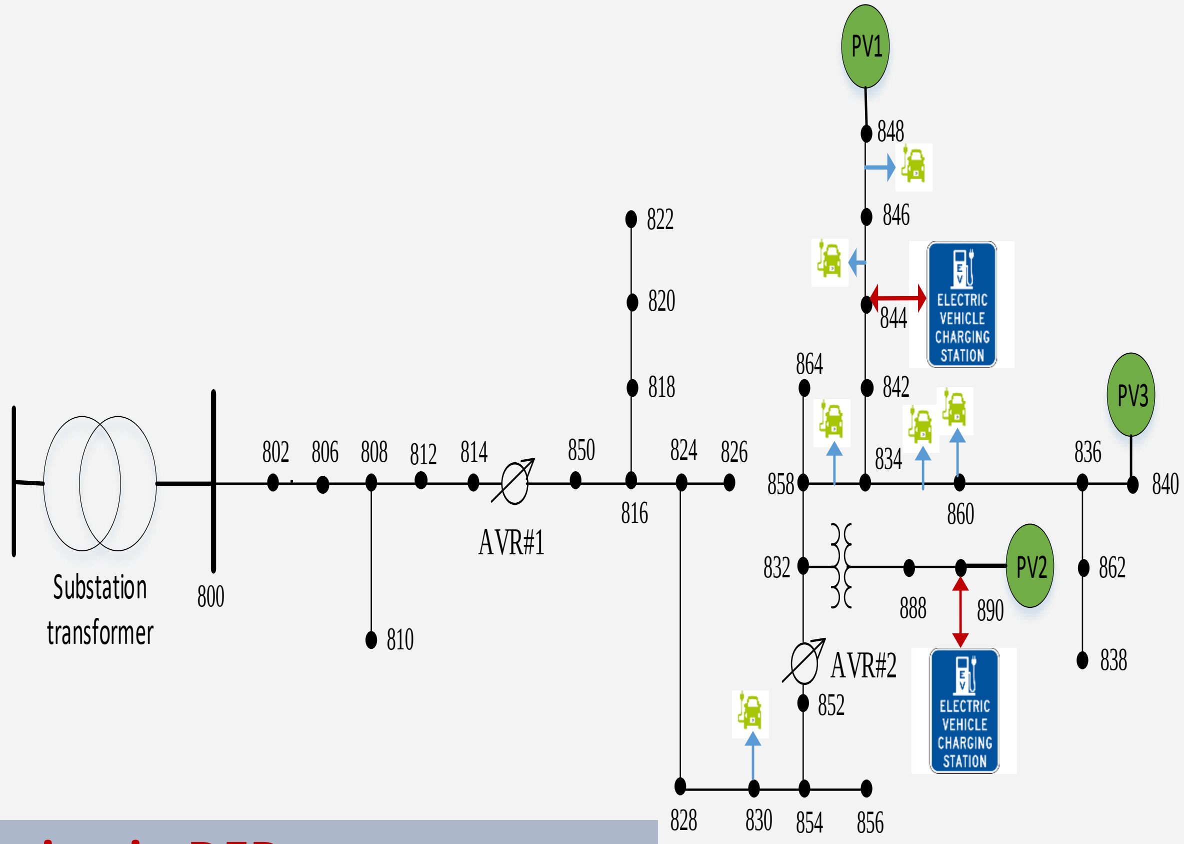
CASE STUDY AND SIMULATION

Test System: **Modified IEEE 34 bus unbalanced test system**

Cases:

Cloud transient impact during solar irradiations form 0.8 p.u. to 0.3 p.u:

- ➢ In absence of EV loads
- ➢ In presence of EV loads
- ✓ Three, 3 phase PV plants at nodes 848 (PV1), 890 (PV2) and 840 (PV3) having inverter ratings 200kVA, 300kVA and 200kVA respectively

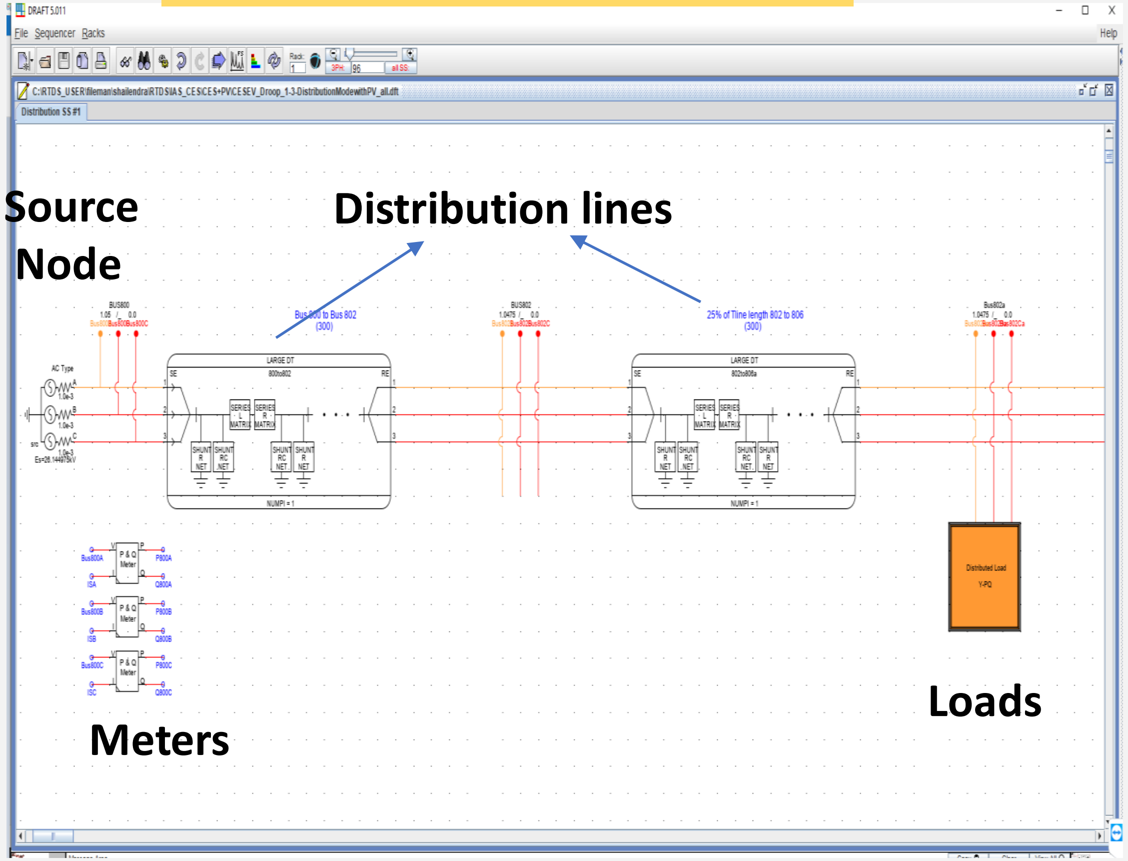


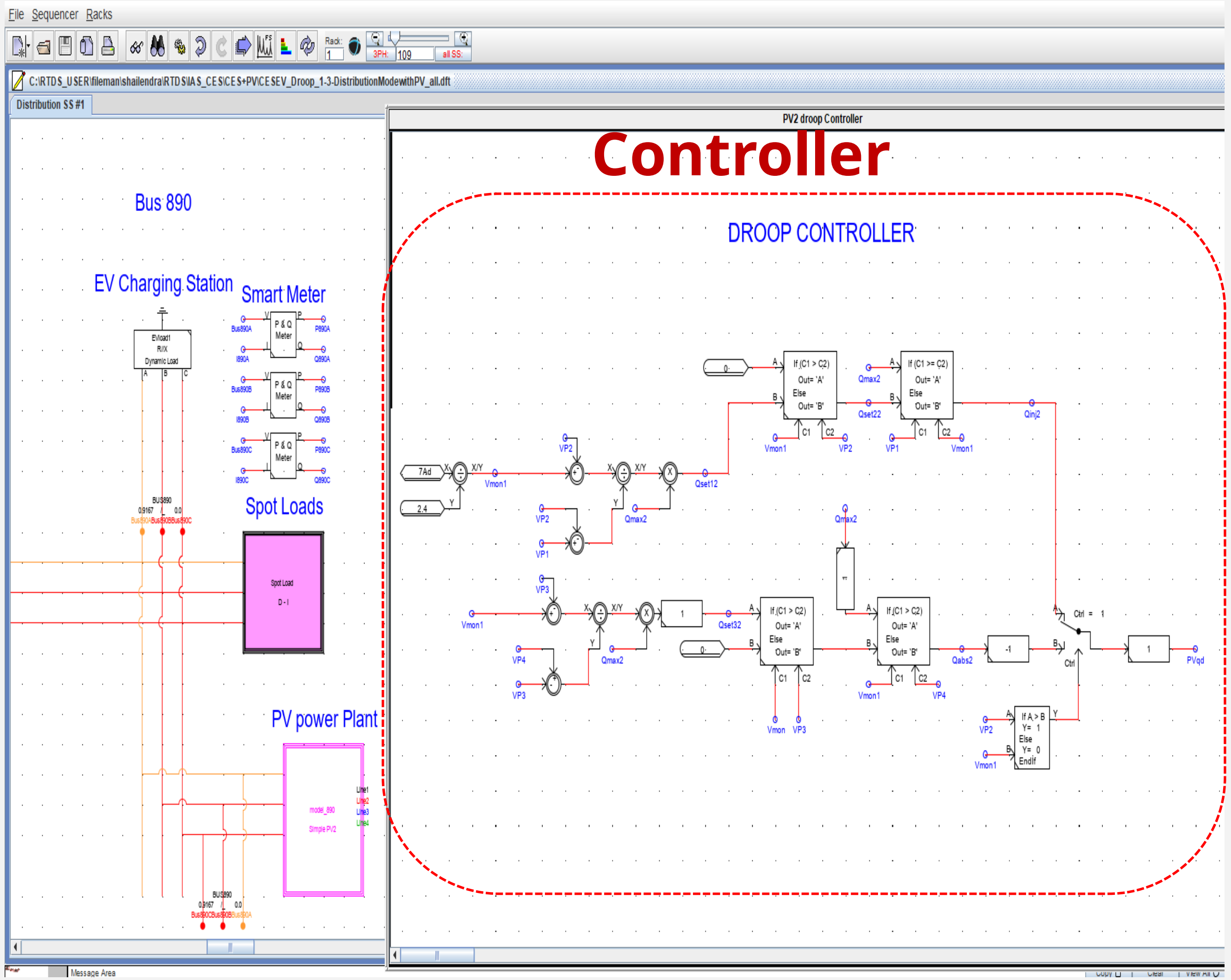
- **Node 890 voltage is highly vulnerable for any reduction in DER power output**

Shailendra Singh, Vijay Babu P, and S. P. Singh, "Time Horizon-based Model Predictive Volt/VAR Optimization for Smart Grid Enabled CVR in Presence of Electric Vehicle Charging Loads", in **IEEE Transactions on Industry Applications**. doi: 10.1109/TIA.2019.2928490, 2019.

MODEL DEVELOPMENT IN RSCAD/RTDS

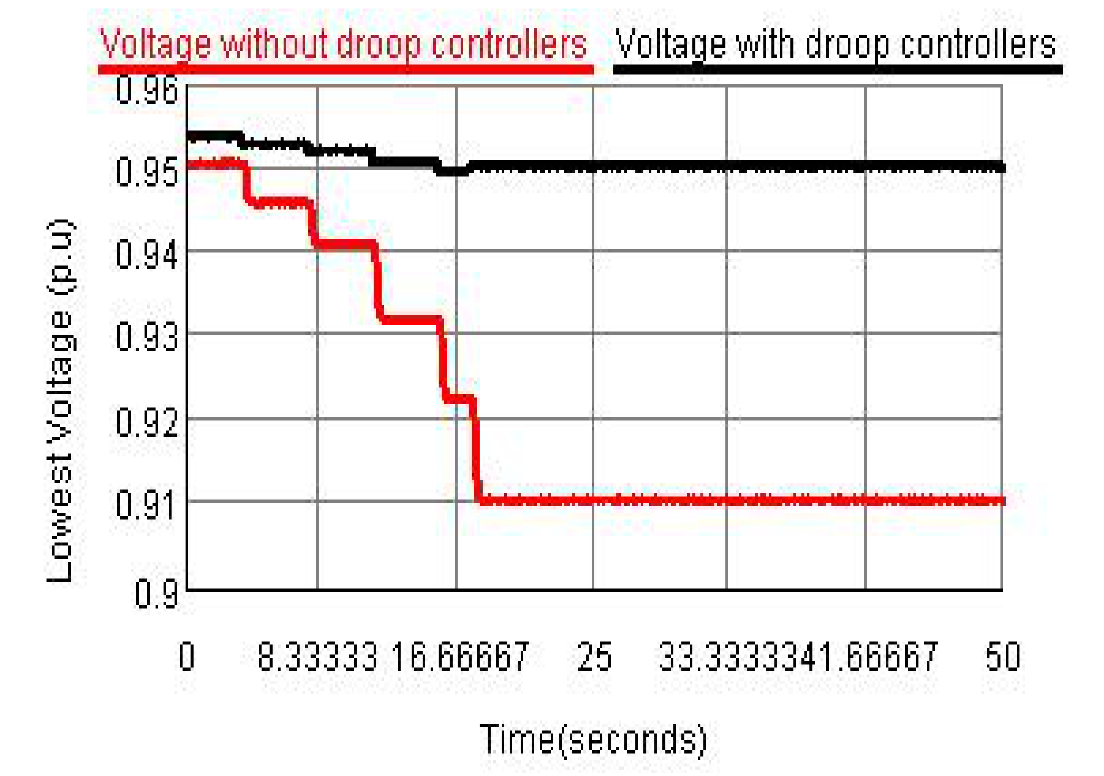
Test System and Controller



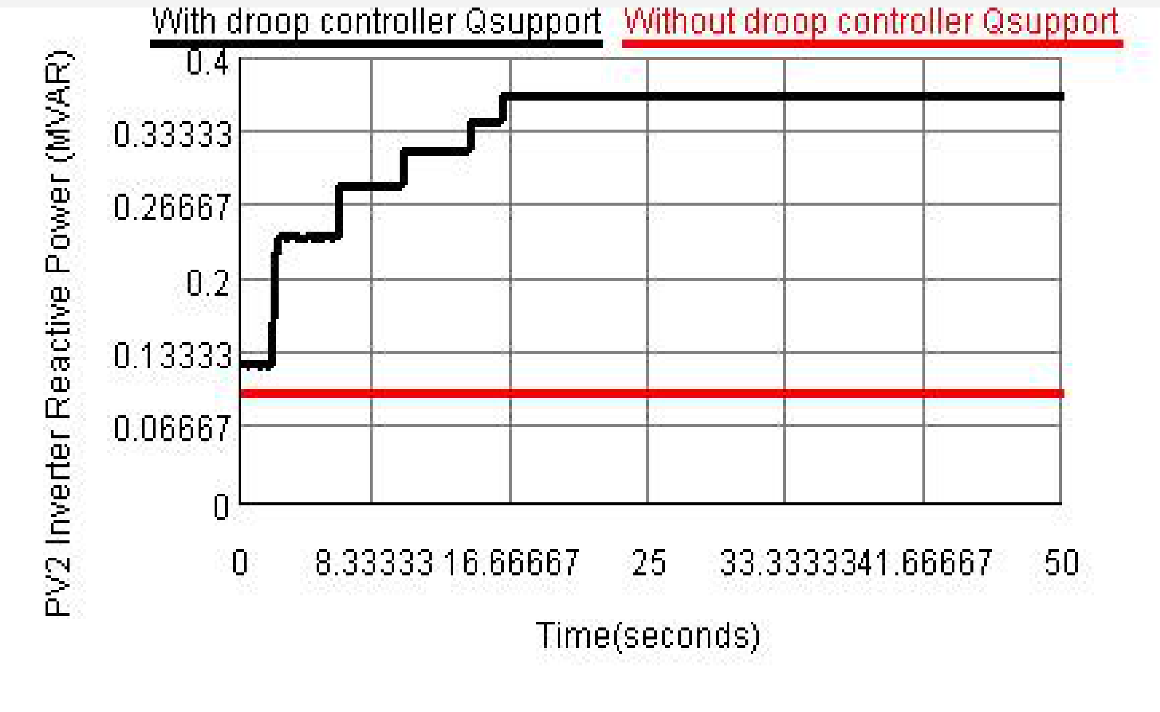


CASE I: CLOUD TRANSIENT IMPACT IN ABSENCE OF EV LOADS:

Lowest voltage profile without and with droop controllers

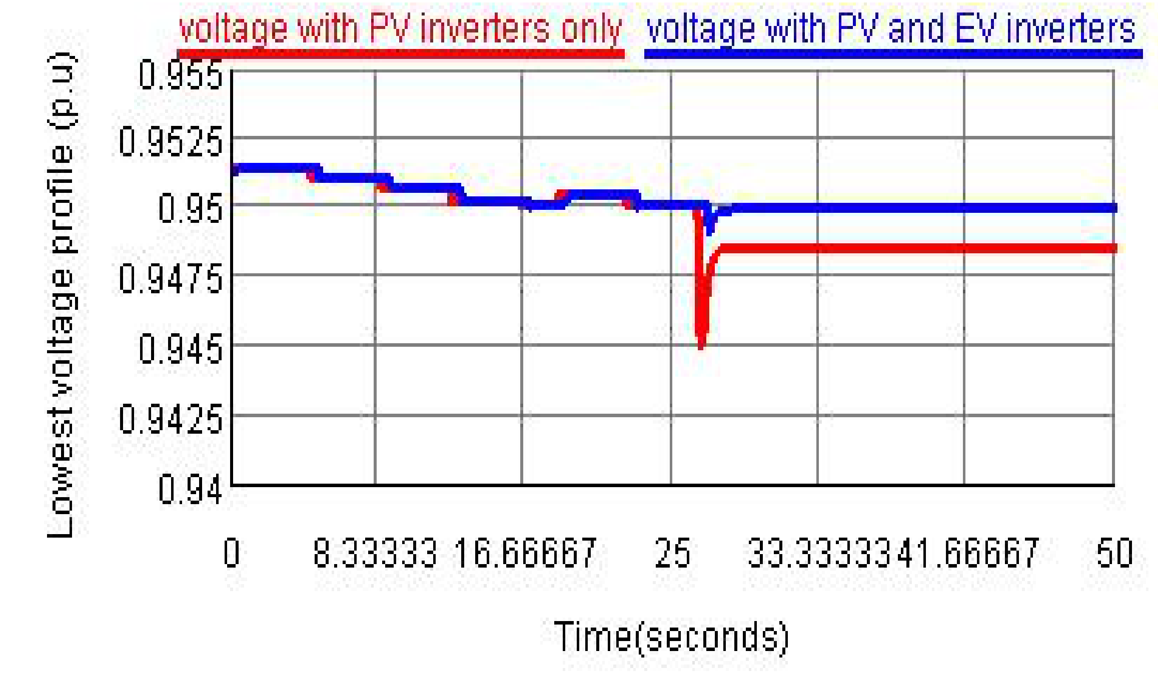


PV Inverter reactive power compensation without and with droop controls

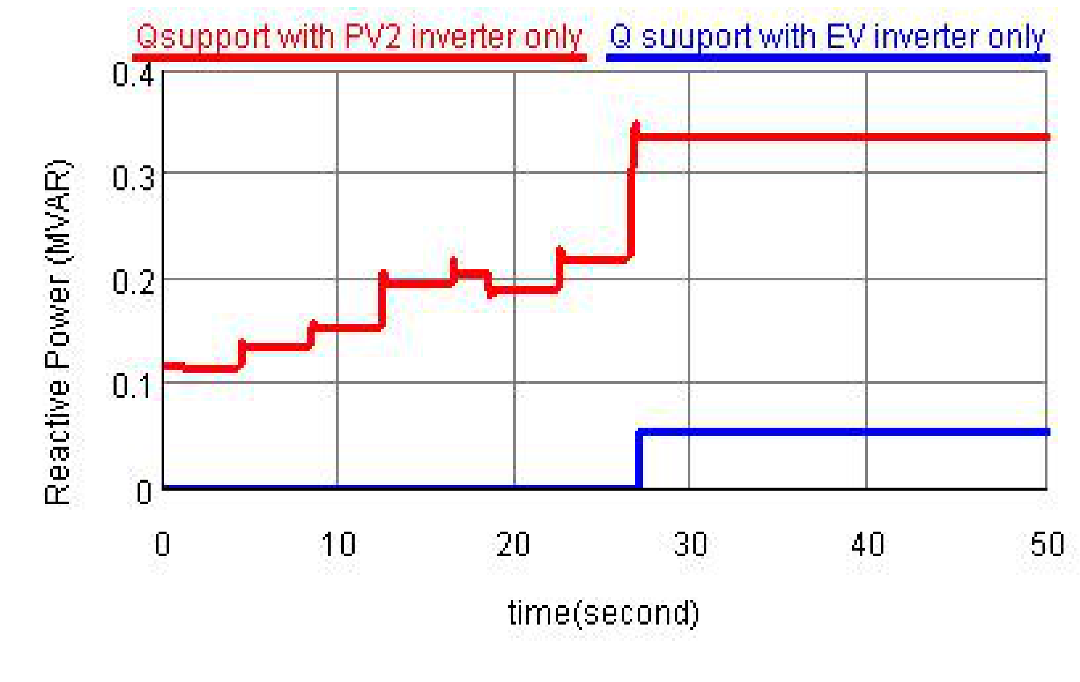


CASE II: CLOUD TRANSIENT IMPACT IN PRESENCE OF EV LOADS:

Lowest voltage profile with PV and EV inverters VAR support



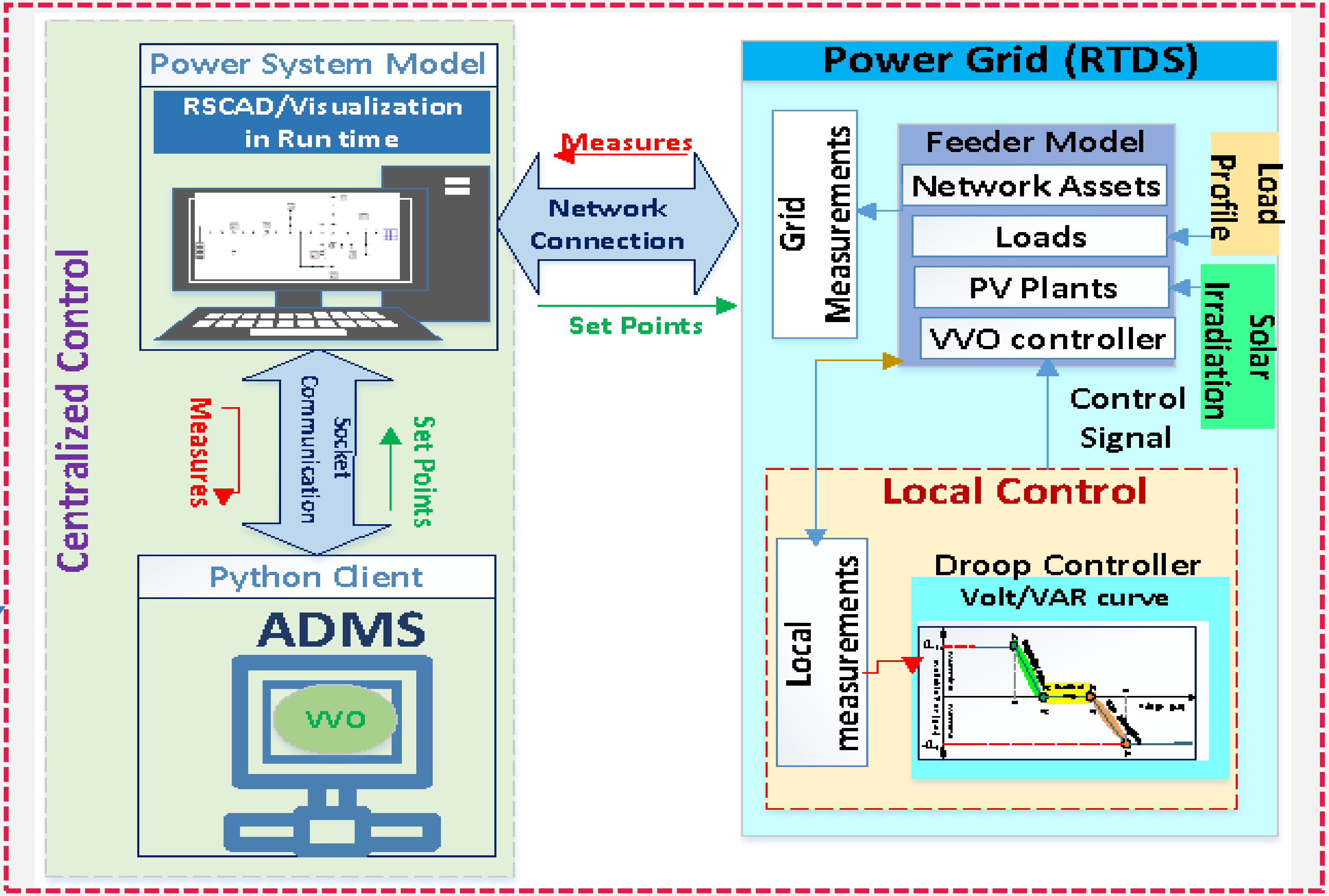
Compensated VAR support from PV2 and EV inverter at node 890



CENTRALIZED WITH LOCAL CONTROL

Voltage control in both STSC and FTSC using Traditional VVC and Smart Inverters

Using Real-time co-Simulations Platform



REAL-TIME CO-SIMULATIONS

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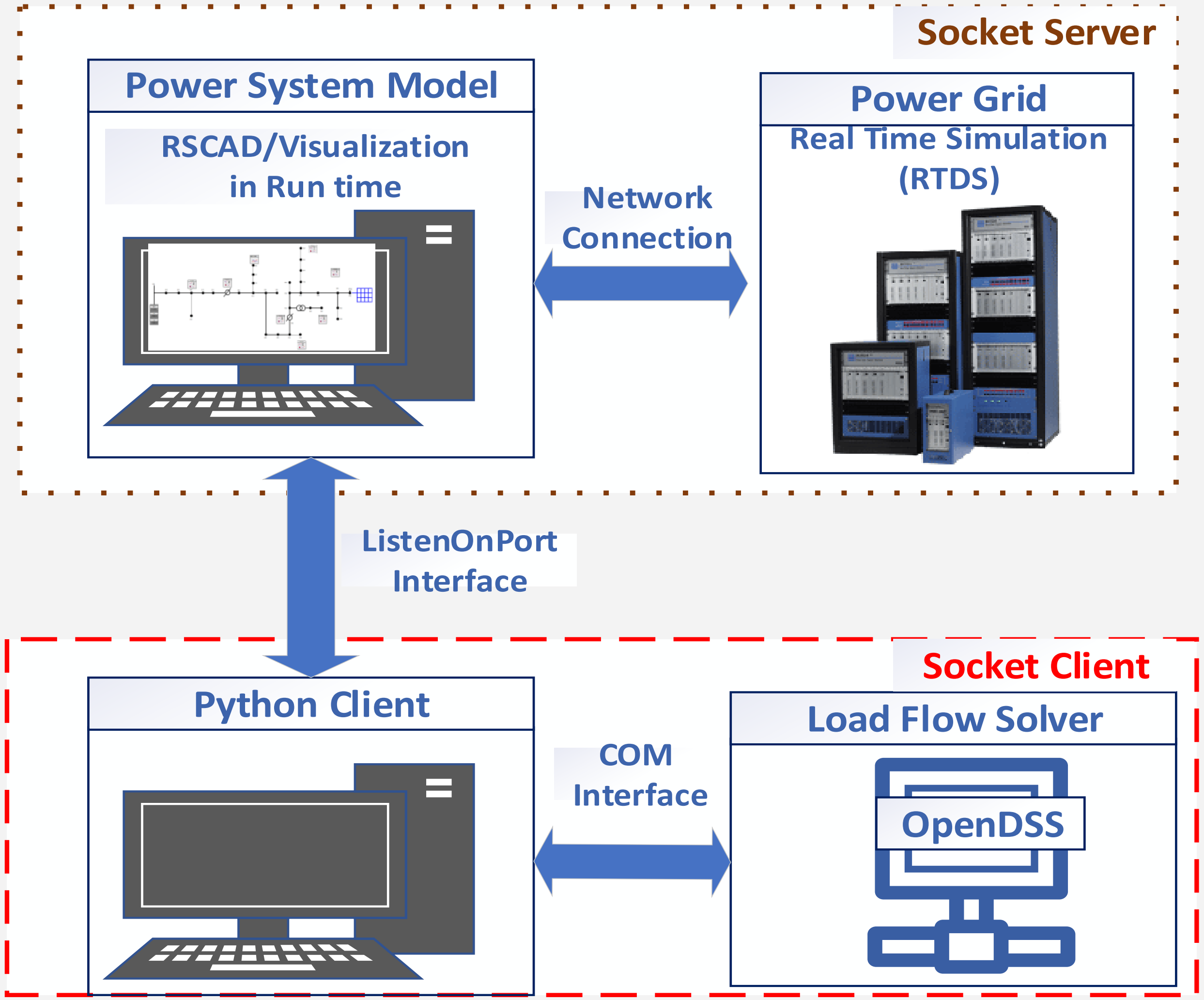
REAL -TIME CO-SIMULATION PLATFORM

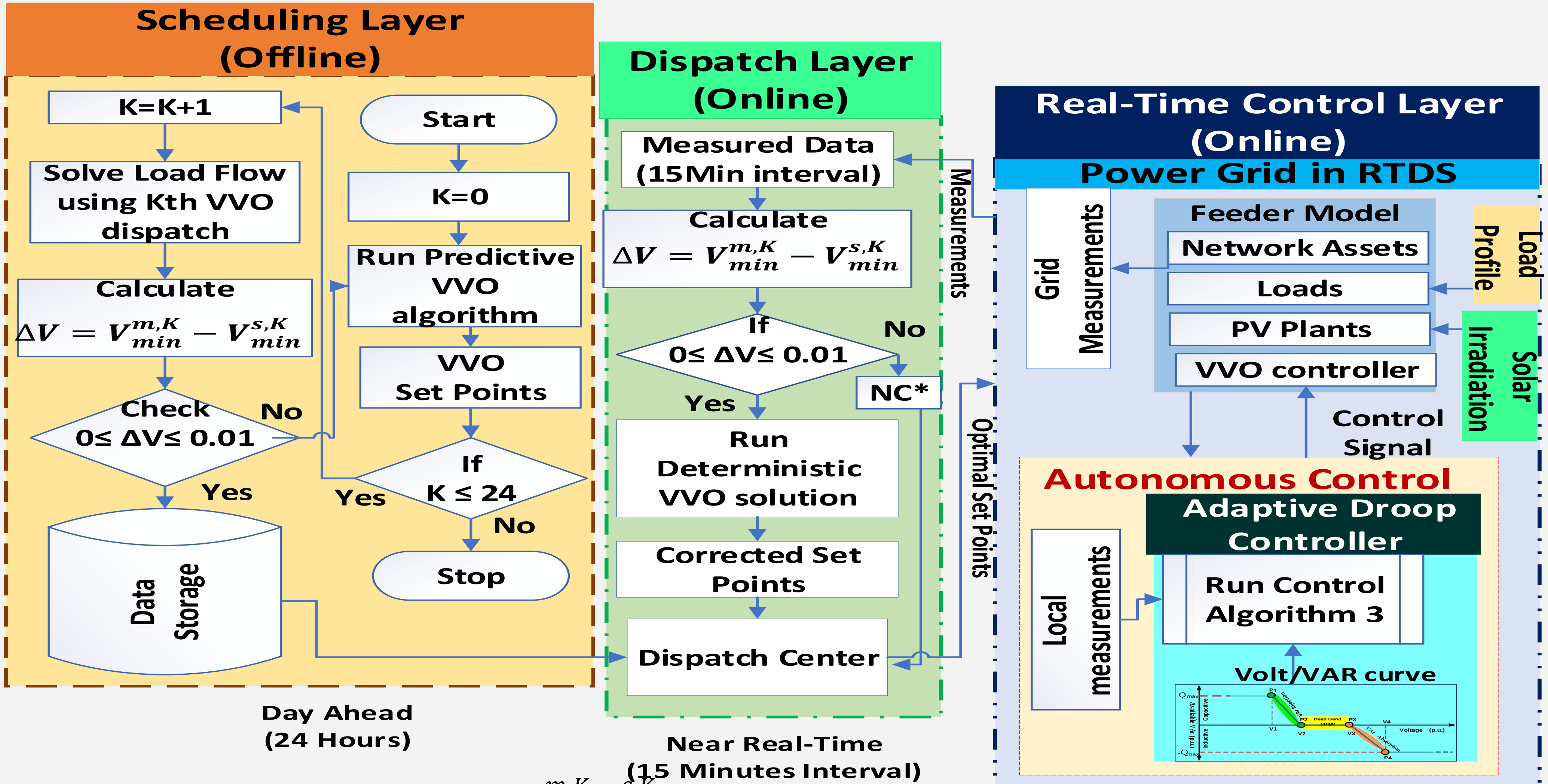
Co-Simulations RTDS – Python – OpenDSS

- **Real-Time Simulation using RTDS**
  - ✓ Distribution mode with time step of 150 micro-second
- **External Agents**
  - ✓ Python and OpenDSS
- **Communication Interface and Simulation Set up**
  - ✓ Socket Communication
  - ✓ ListenOnPort Interface
  - ✓ Uses TCP/IP Protocol

Real Time Co-Simulation Framework



IMPLEMENTATION VIA THREE LAYER DISPATCH MODEL



dt simulation time step

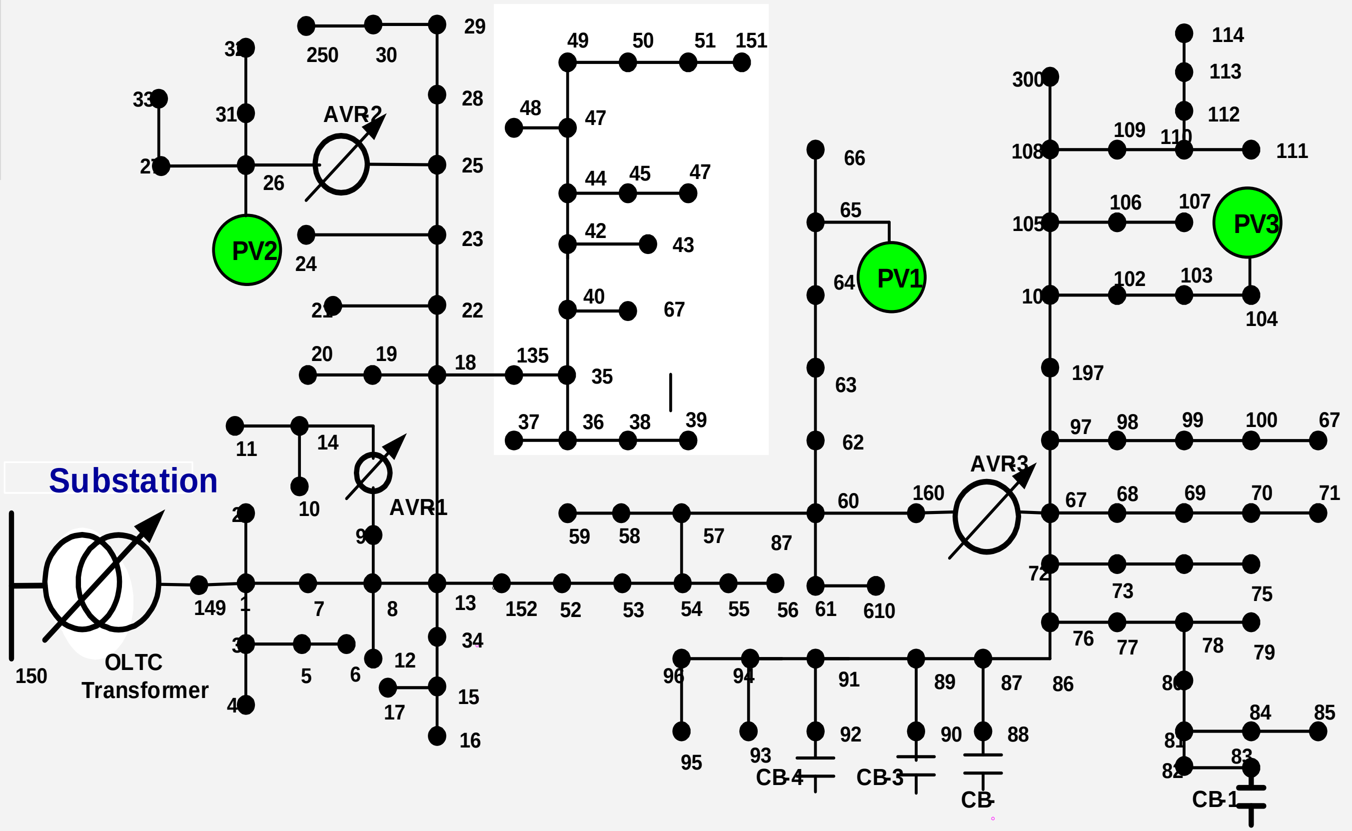
(*NC – No change required. Already at optimal state, $V_{min}^{m,K}$, $V_{min}^{s,K}$ are the minimum measured and specified voltage, respectively.)

TEST CASE STUDY:

Modified IEEE 123 Node Unbalanced Distribution Feeder

Cases:
STSC: Forecasting Error Impact
FTSC: Cloud Transient Impact

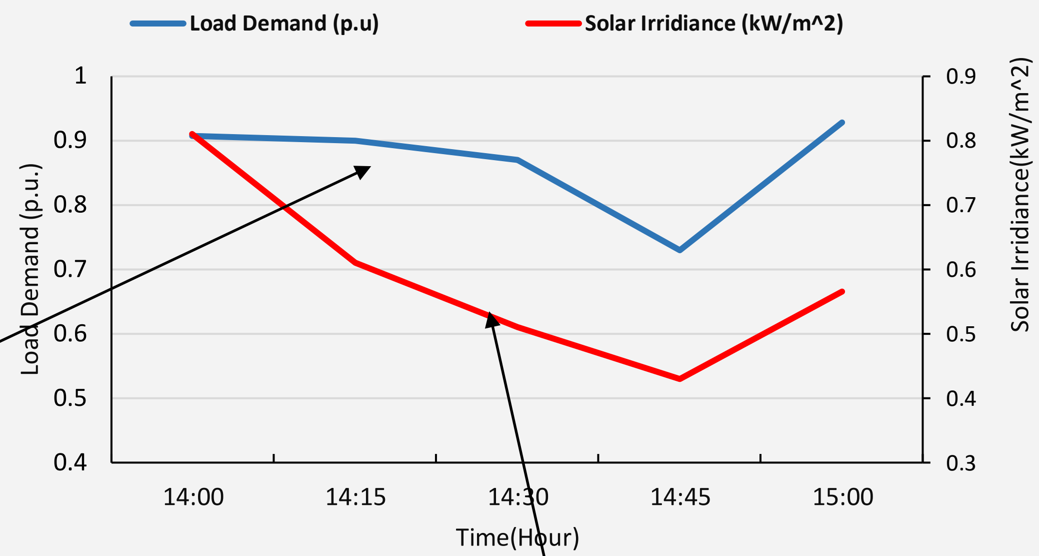
- PV Plants Rating:
  PV1: 1MVA,
  PV2: 800KVA,
  PV3: 400KVA,
- Load Model:
  Constant ZIP load model
- Mode of VVC operation
  - Predictive VVO method

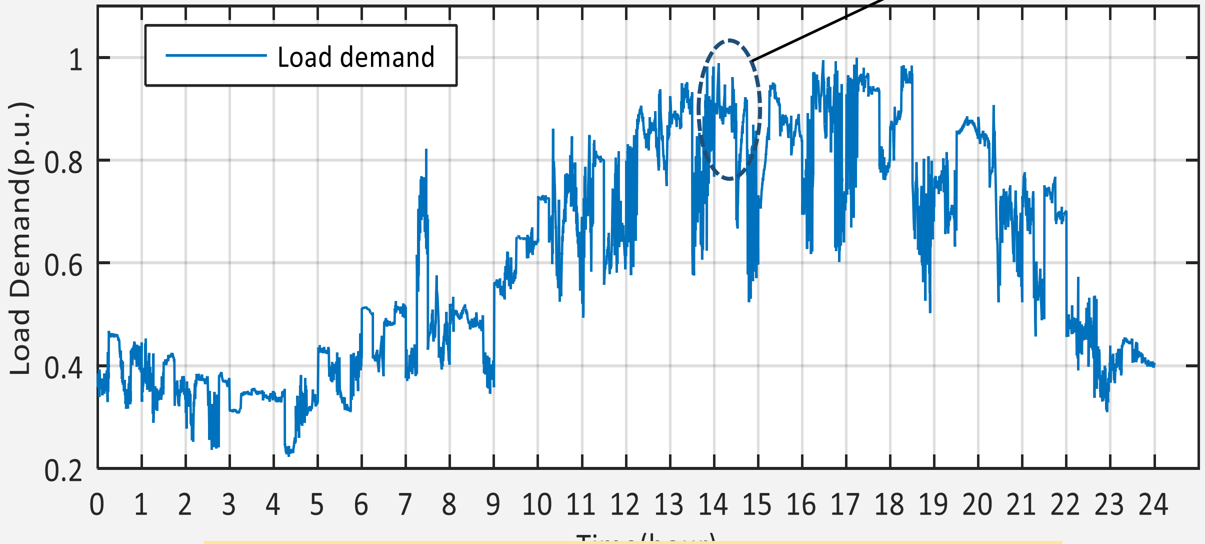


Shailendra Singh, Vijay Babu P, A,K, Thakur and S. P. Singh,. "Multistage Multi-objective Volt/VAR Control for Smart Grid-Enabled CVR With Solar PV Penetration." *IEEE Systems Journal,2020* (Early Access).

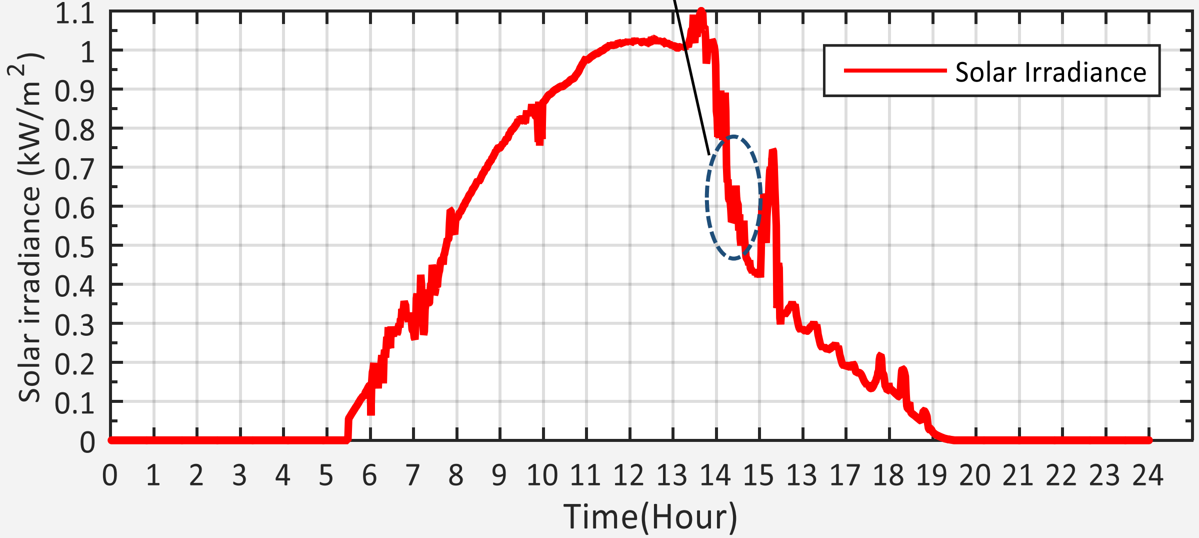
LOAD AND SOLAR IRRADIANCE PROFILES

Realistic load and PV profile from NREL Smart-DS project



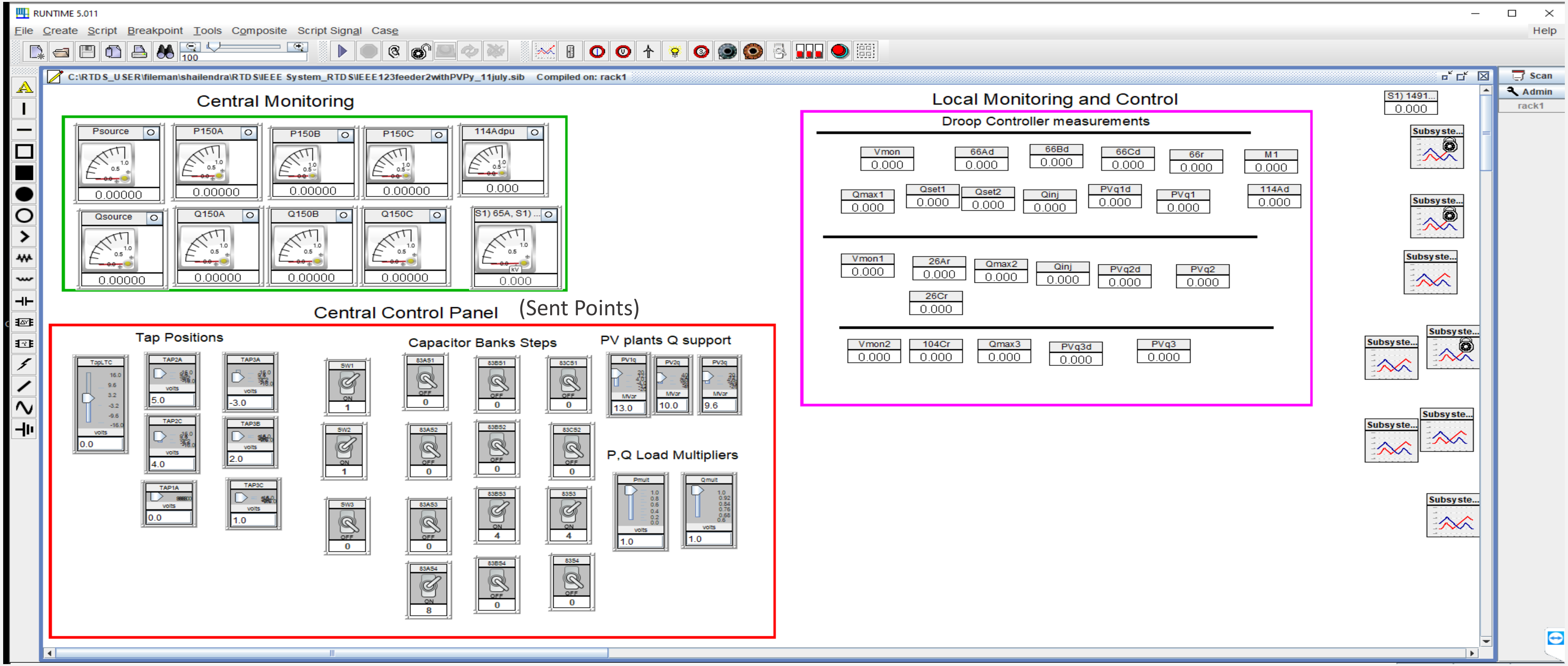


Load demand for a typical day



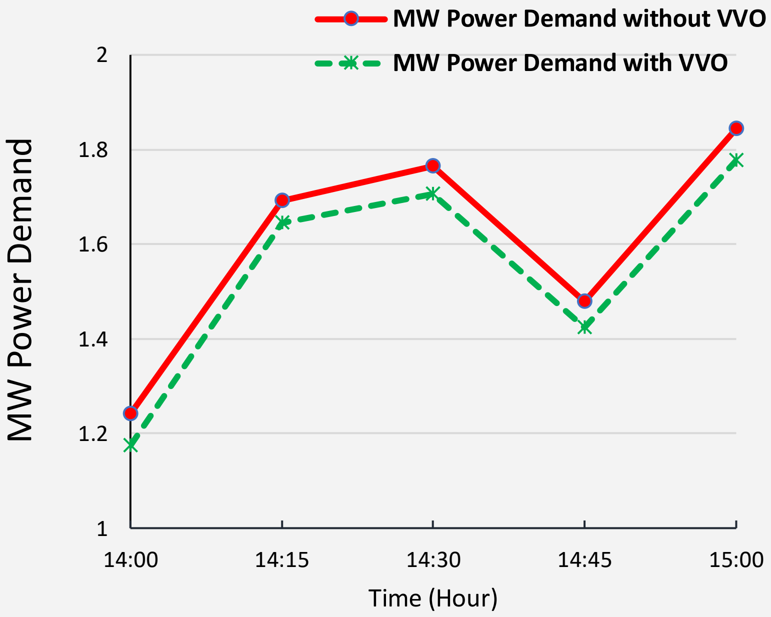
Solar irradiance for a Typical day

RUN TIME WINDOW IN RTDS

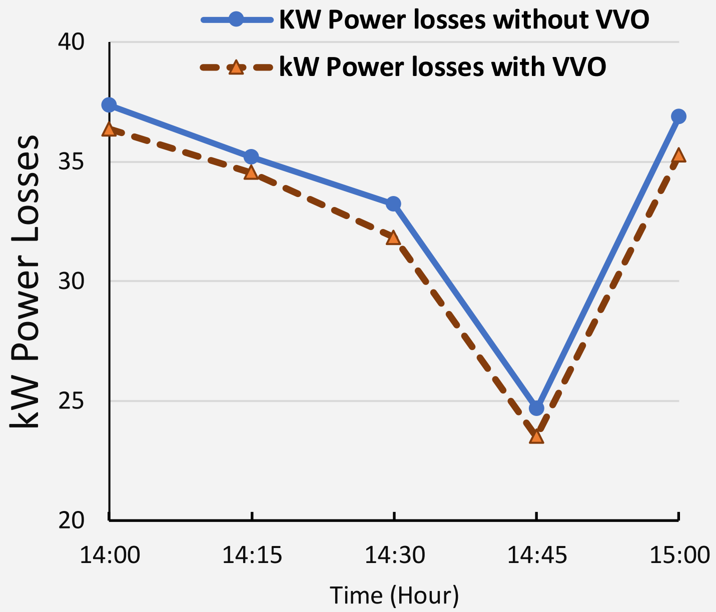


ONLINE VALIDATION UNDER STSC: CORRECTIVE ACTION

The MPC based VVO reduces about 3.66% energy demand and 1.69 % energy losses in one hour CVR duration



- **Active Power Demand**



Active Power Losses

Table : VVO Set Points change

Device/ Time	14:00 -14:15	14:15 -14:30	14:30 -14:45	14:45 -15:00
OLTC	*NC, (Hourly)			
CB	NC, (Hourly)			
AVR	NC	1	2	NC
PV (Q) Inverter	NC	NC	NC	NC

*NC – No change required. Already at optimal state

ILLUSTRATION UNDER FTSC: EMERGENCY ACTION

Case Study:

Case I: Sudden cloud transient Appearance:

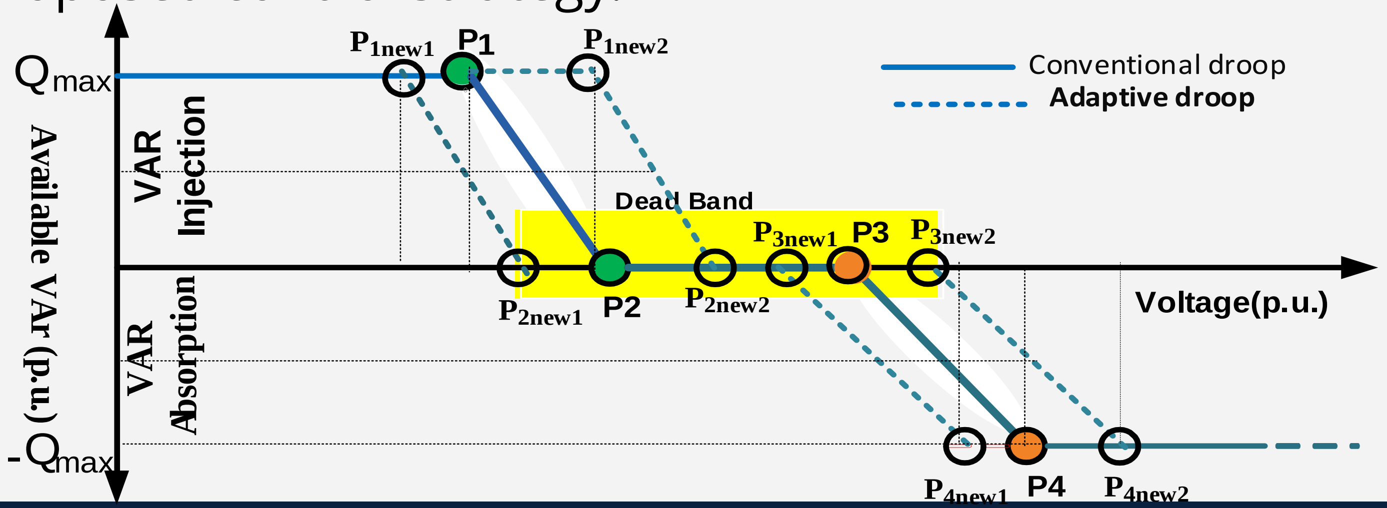
- An arbitrary instantaneous point between time intervals from 14:00 to 14:15 is selected.
- The load demand is 1.0 p.u., and solar irradiation is 0.81 kW/m^2 at this instant.
- The solar irradiation reduces from 0.81 to 0.1 kW/m^2 because of the sudden appearance of cloud transients.
- During this time span, the lowest voltage profile at **Node 114a** becomes vulnerable to any reduction in kilowatt power.

AUTONOMOUS REAL-TIME CONTROL : ADAPTIVE VVD

Selection of VVD curve:

- Traditional VVD control have **fixed droop** and **uncontrol parameters** hence may not able to control voltage properly
- An **adaptive VVD controller** has been introduced in which droop parameters are adopted according to the **operating scenario**.
- The **new droop parameters (P_{1new1}, P_{1new2}, P_{2new2}, P_{3new1}, P_{3new2}, P_{4new1} and P_{4new2})** are flexible and adaptive in nature using proposed control strategy.

Volt/VAR droop (VVD) characteristics



CASE I: SUDDEN CLOUD TRANSIENT APPEARANCE:

Subcase-1:
Single PV power Outage

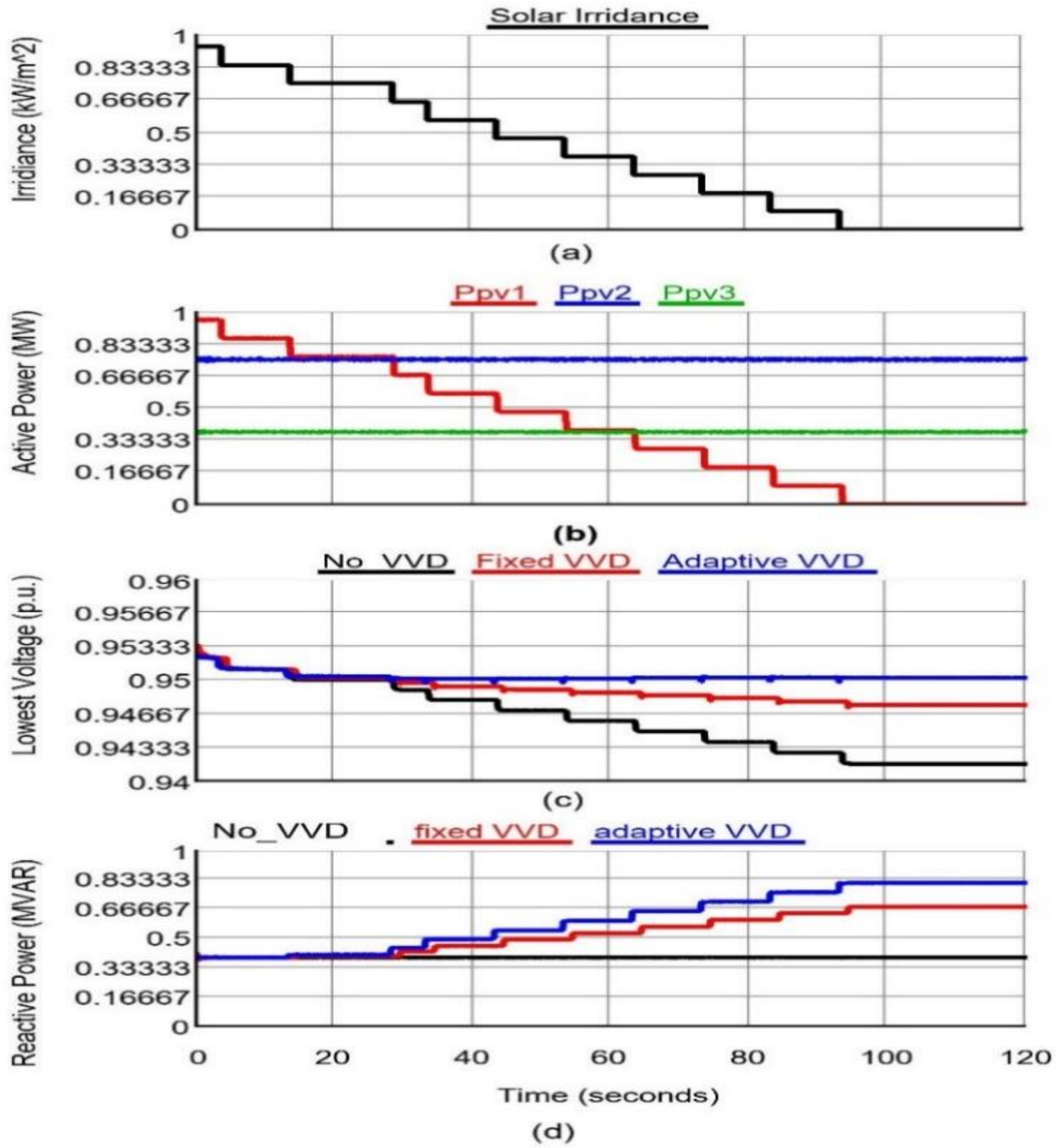
Fig. Real-time simulation results for Subcase 1

(a) Solar irradiation reduction

(b) Active power production profile under cloud transient (only PV1)

(c) Lowest voltage profile at node 114a with No_VVD, fixed VVD, and with Adaptive VVD control

(d) Reactive power compensation through only PV1 system under No VVD, fixed VVD and with Adaptive VVD control



Subcase-2: Multiple PVs power Outage

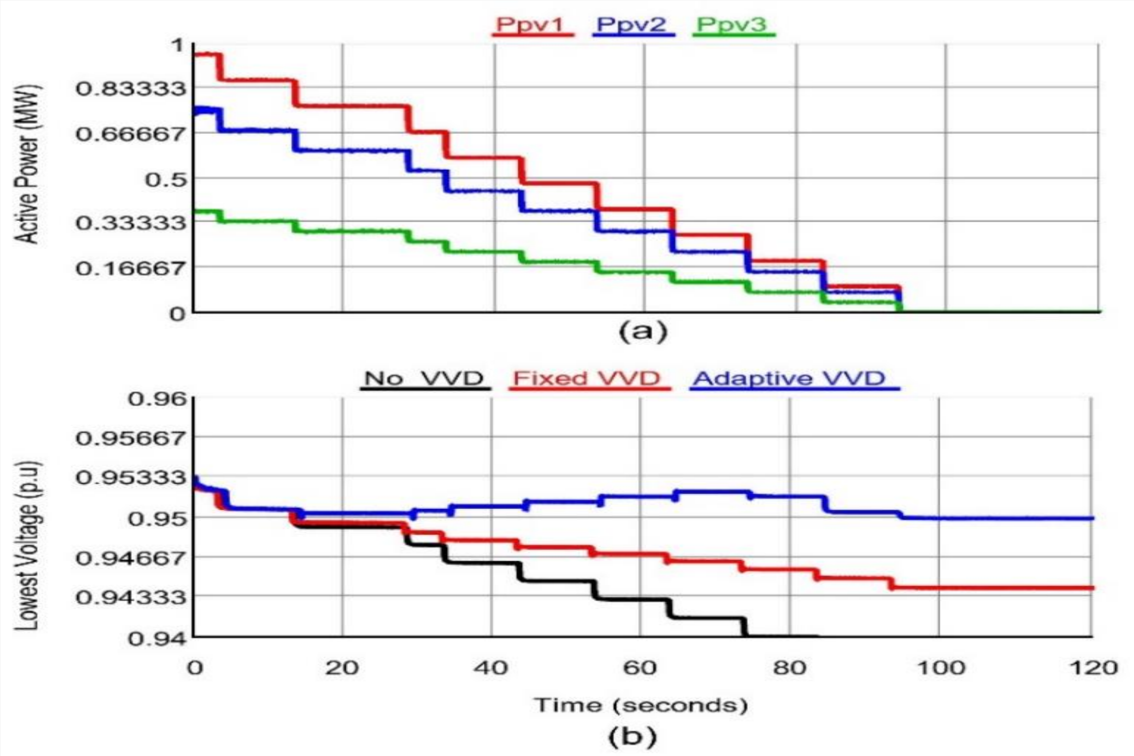


Fig.1 Real-time simulation results for Subcase 2

(a) PVs Active power production profile under cloud transient

(b) Lowest voltage profile at node 114a with No_VVD, fixed VVD, and with Adaptive VVD control

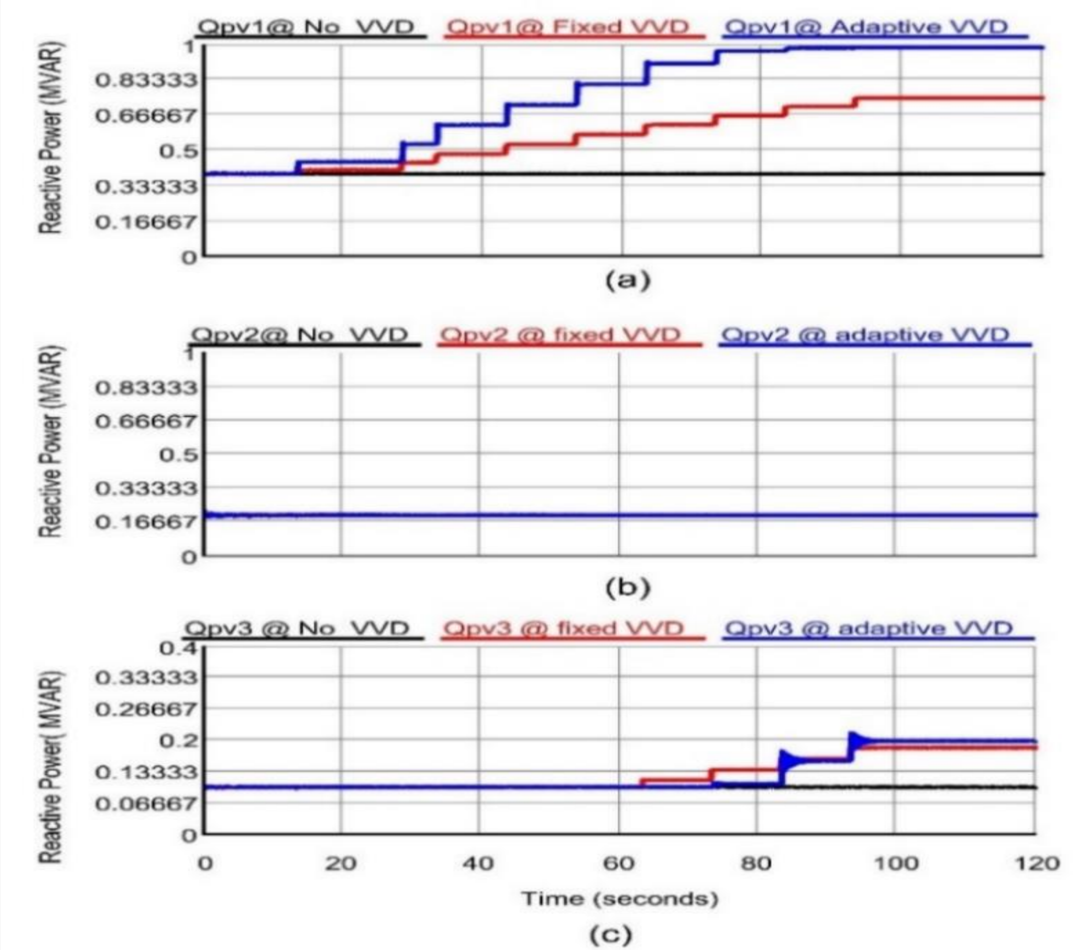


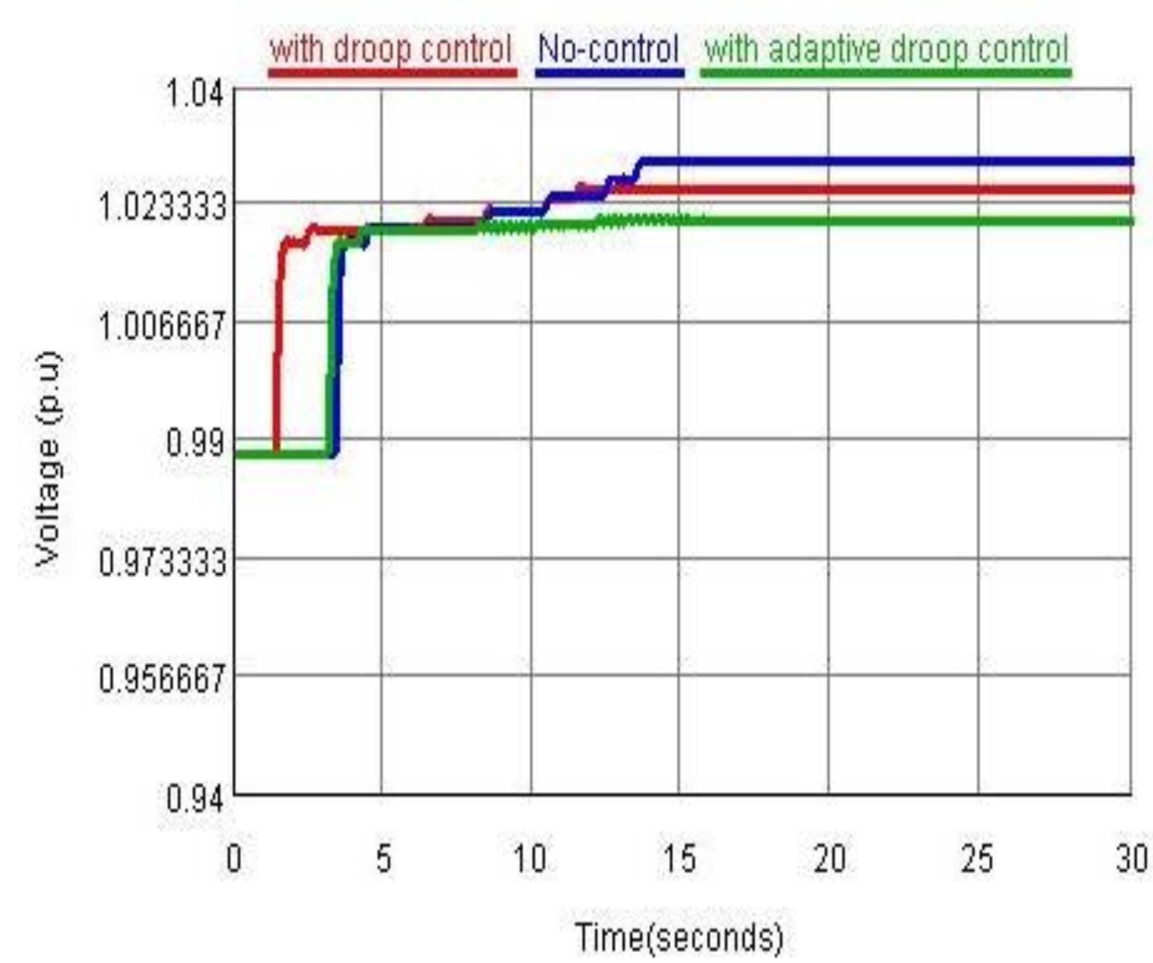
Fig.2 Reactive power compensation through

(a) PV1 (Qpv1) (b) PV2 (Qpv2) (c) PV3 (Qpv3) system under No VVD, fixed VVD and with Adaptive VVD control

CASE II: SUDDEN CLOUD TRANSIENT DISAPPEARANCE:

Voltage at PV3 node No control, with fixed droop and with adaptive droop control

- An arbitrary instantaneous point between time intervals **15:00 to 15:15** is selected.
- The load demand is 0.40 p.u., and solar irradiation is 0.41 kW/m2 at this instant due to cloudy weather.
- The sudden cloud disappearance and solar irradiation vary from **0.41 to 0.8** kW/m2
- The PV3 power plant located at **104c** is most affected and it violates the maximum voltage limit (1.02 p.u) at point of connection.
- Other PV power plant voltage remains within range.



CONCLUSION AND FUTURE WORK

CONCLUSION

- Multi-time scale VVC scheme comprising **centralized as well as local control** is suitable for voltage regulation.
- Time-Horizon based **MP-VVO** along with **droop controller** works well under **aggregated** and **autonomous controls**.
- The developed control methodology is proficiently capable of handling the **disturbances (uncertainty and intermittency)** of the active distribution networks.
- **Adaptive VVD controller** can handle the voltage fluctuation under changing operating scenarios
- The developed **real-time co-simulations platform** using the **RTDS** (distribution mode) could be useful for the study of **large-scale practical distribution systems**.

NEXT STEPS

- Models and control algorithms are **scalable** for **Microgrids Applications**
- Validations of algorithms in **Controller Hardware in loop (CHIL)** and **Power Hardware in loop (PHIL)**
- Real-Time co-simulations platform for **Integrated Transmission and Distribution System**

ACKNOWLEDGEMENT

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Thank You!

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