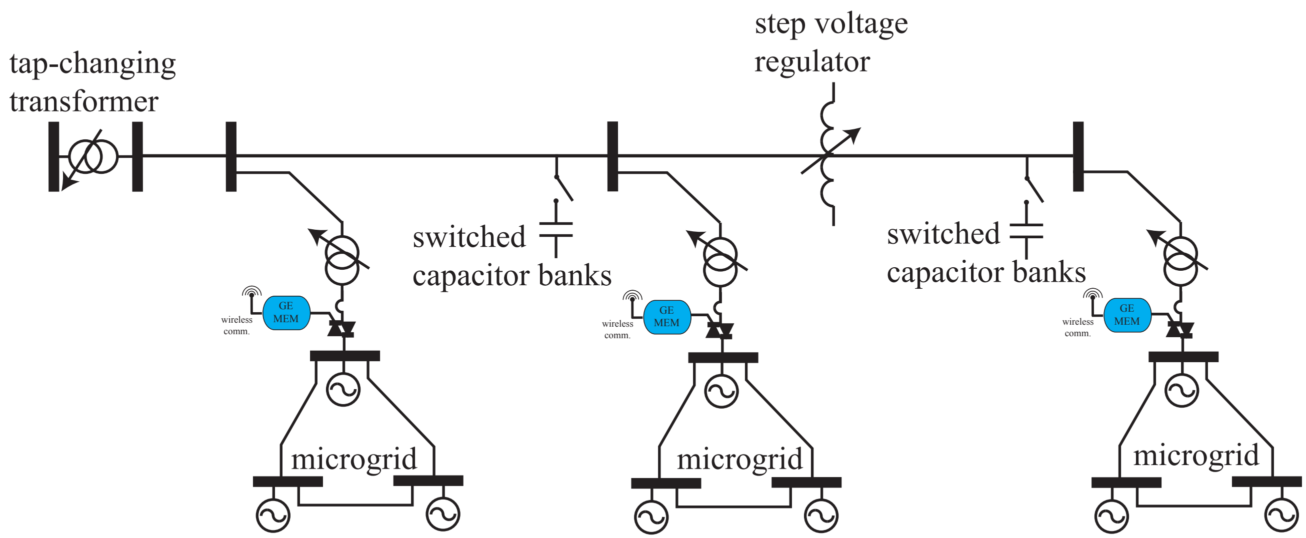
Distributive Reactive Control in Coupled Microgrids

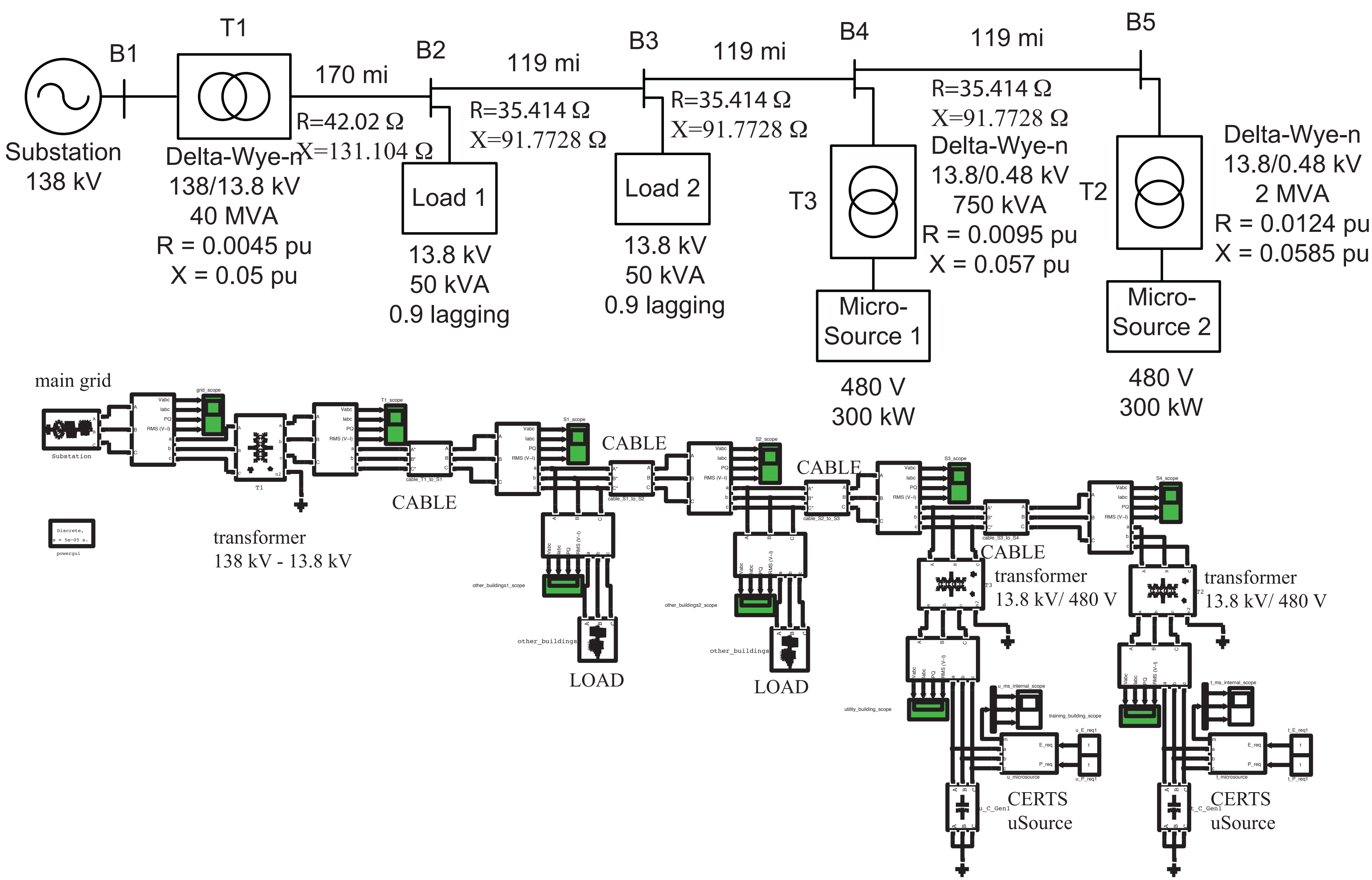
- Task Objectives and Approach
- simPower Model of MV Network
- CERTS Microgrid Models
- Reactive Control of Voltage Rise
- Distributed Event-Triggered Control of Coupled Microgrids
- Deliverables
- Schedule

Task Objectives and Approach

- Task will develop distributed methods to maximize the exported real power by controlling reactive power.
- Controls include voltage regulators, STATCOM, SVC, and CERTS uGrid controllers
- Coordination of controls will be accomplished through distributed optimization methods.

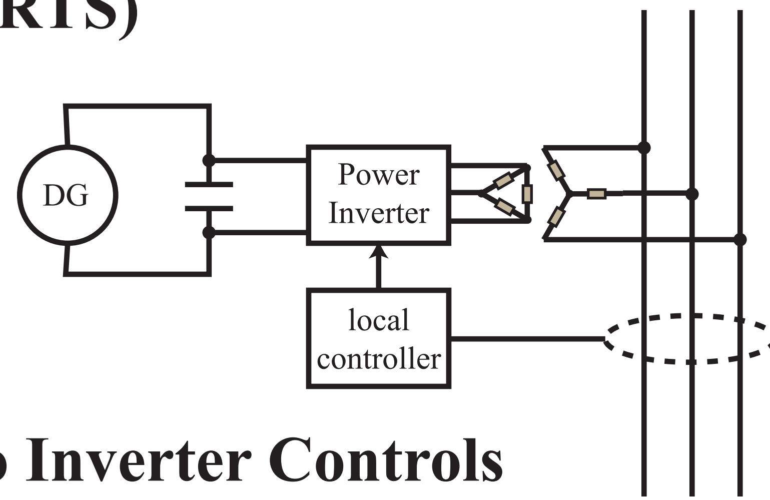


Simulation Model

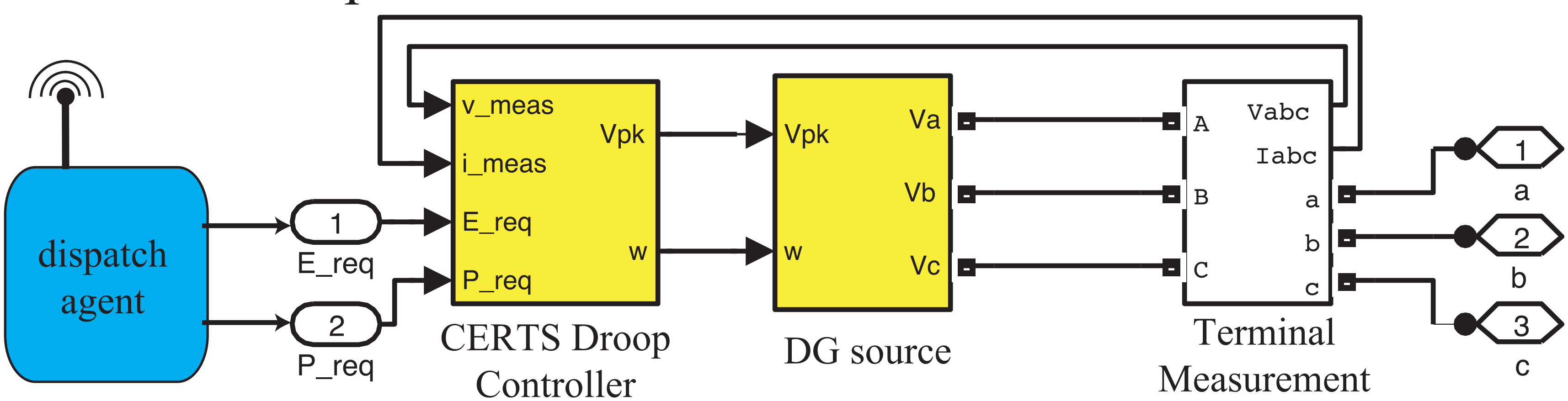


CERTS Microsource Controller

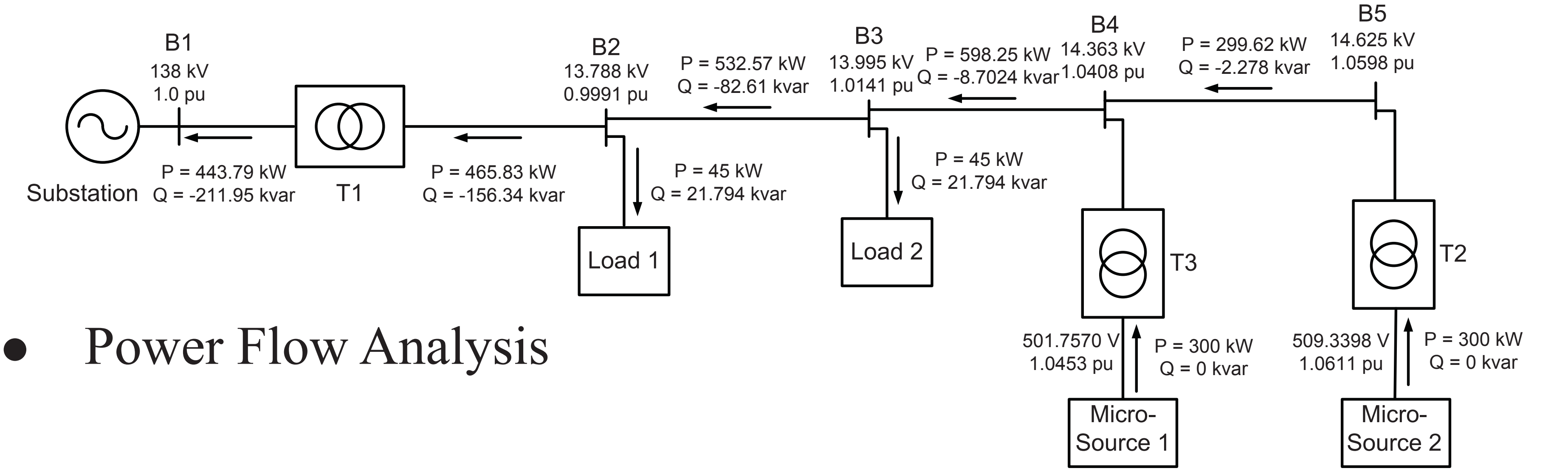
- **Decentralized Inverter Controls (CERTS)**
  - provides small-signal stability
  - mimic P-freq and Q-V droop control
  - interface to any DG unit
  - load-shedding on frequency droop



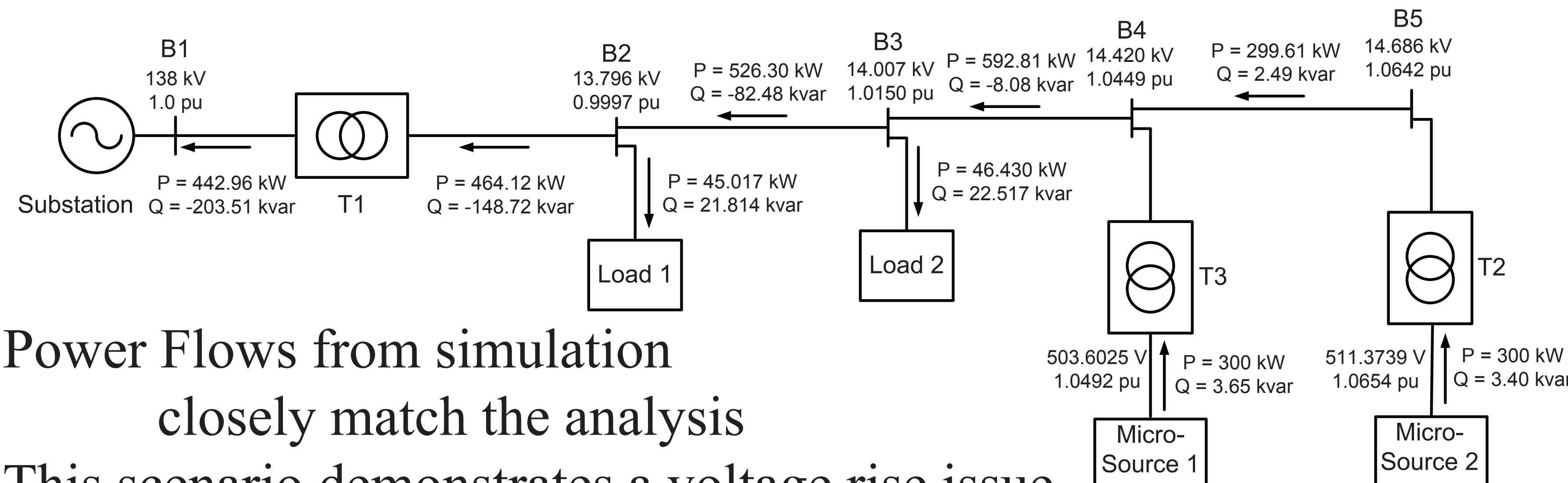
- **Peer-to-Peer Dispatch integrates into Inverter Controls**
  - dispatcher generates power and voltage set points which are inputs to the CERTS inverter controller.



Power Flow Analysis of Simulation Model

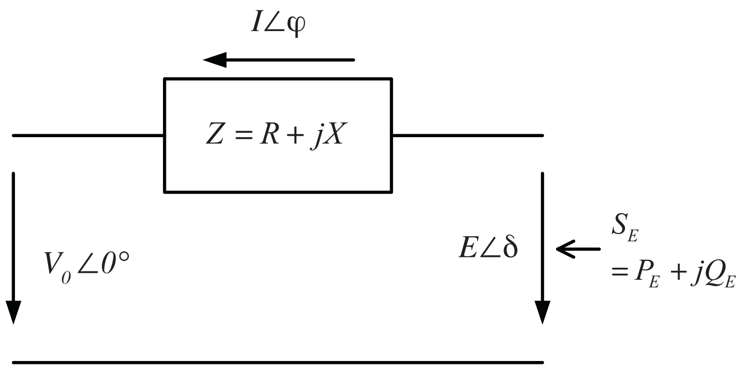


- Power Flow Analysis

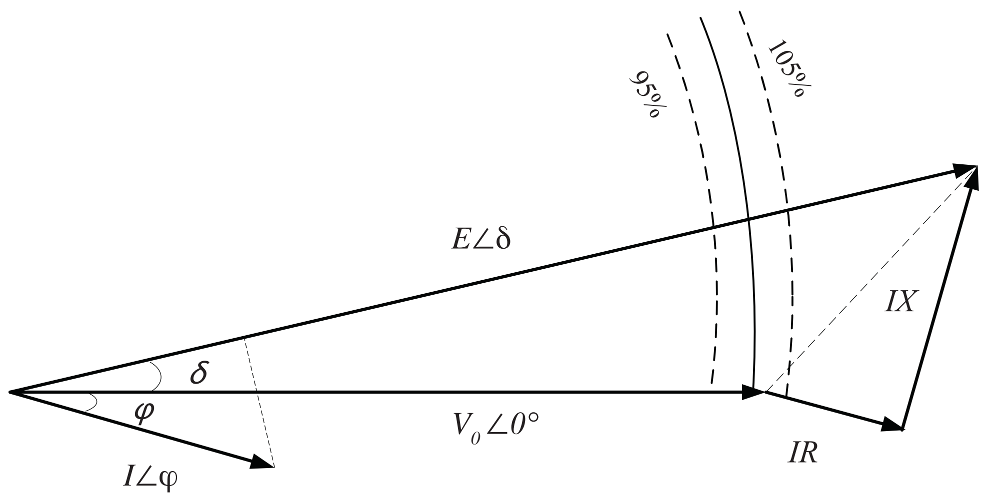


- Power Flows from simulation closely match the analysis
- This scenario demonstrates a voltage rise issue.

Voltage Rise Problem

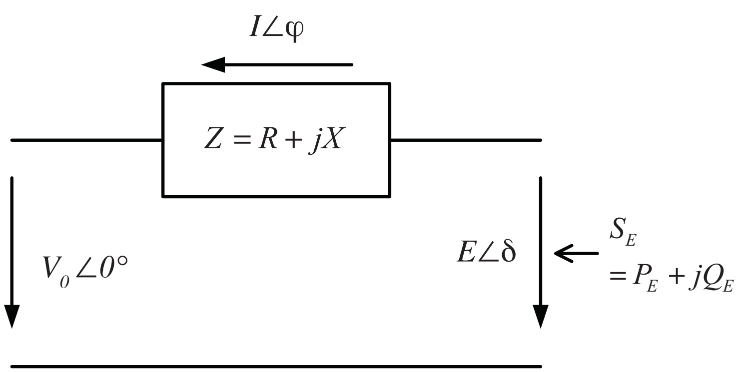


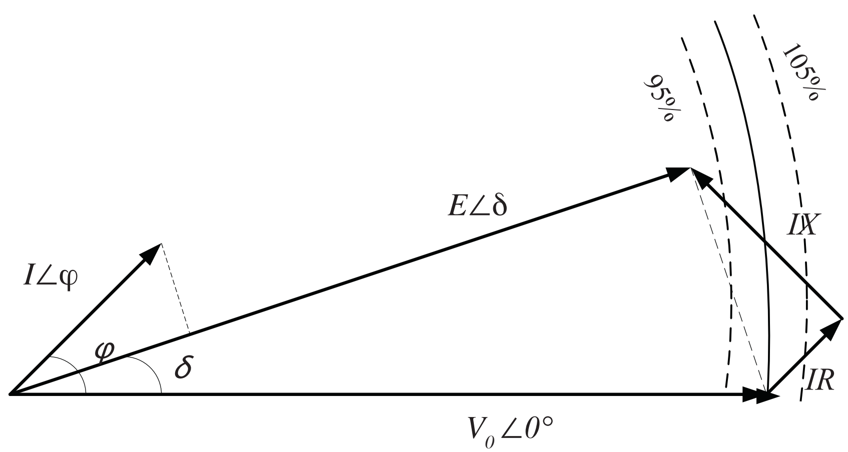
- Distribution line impedance = Z + jX
  Substation voltage $V_0\angle 0°$
  Line current = $I\angle\varphi$
- Injected Power, $S_E = P_E + jQ_E$
  Terminus voltage, $E\angle\delta$



- Phasor diagram shows how the injected power's impact on current flows may result in line voltages that exceed the 5% regulatory constraints

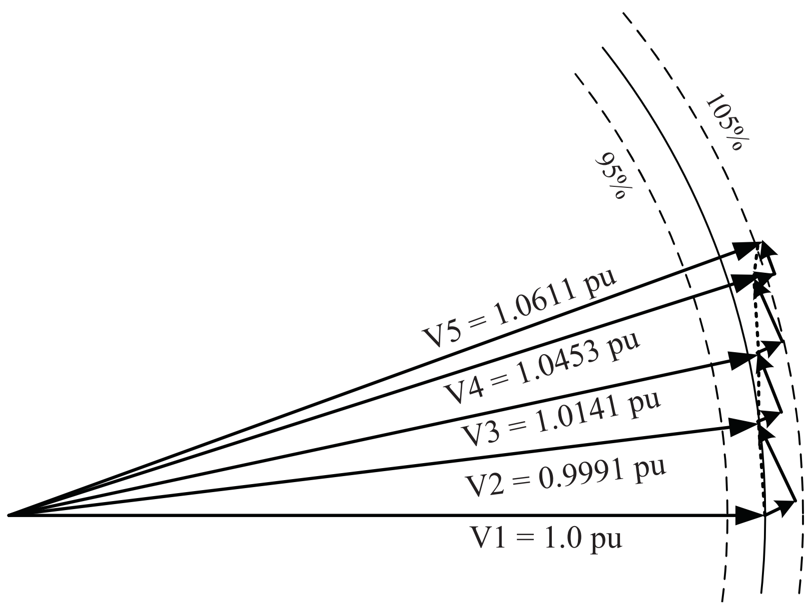
Reactive Control of Voltage Rise Problem





- Total Injected Power:
  $S_E = P_E + jQ_E = EI\angle(\delta - \phi)$
- We reduce voltage rise by forcing line current to lead terminus voltage
- This strategy implies
  $Q_e = EI\sin(\delta - \phi) < 0.$
- Voltage rise can be reduced by absorbing reactive power at the terminus
- Reactive control mechanisms
  - Static Var Compensator, VR and Capacitor banks, Q-V droop controls

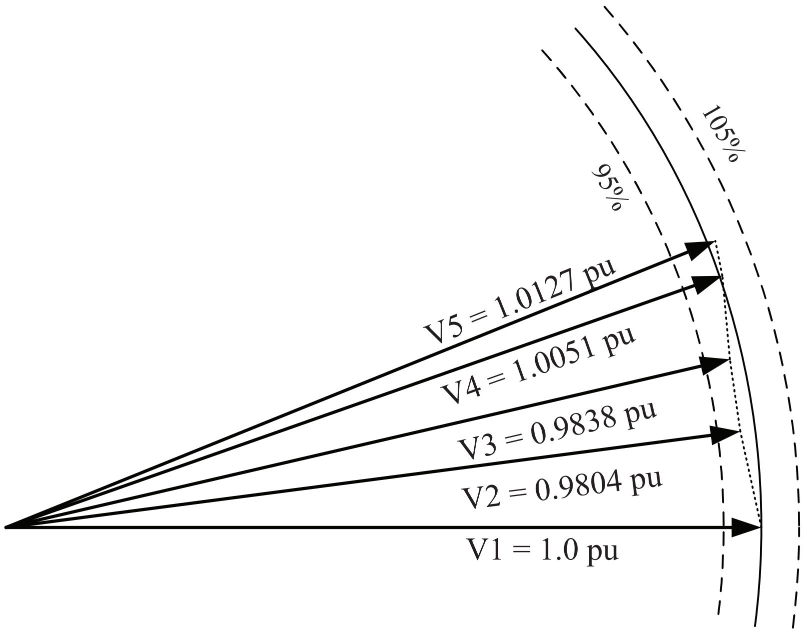
Voltage Rise Problem in Simulation Model



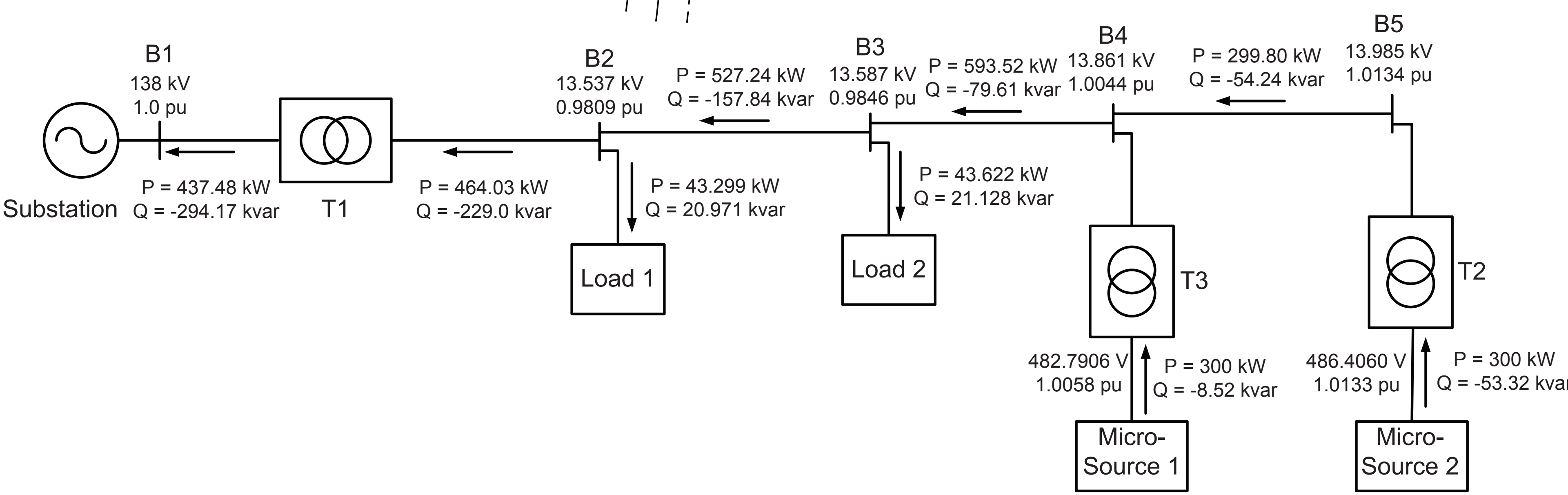
- Voltage regulation rules require voltage to remain within 5 percent of nominal value
- Simulation Scenario violates this requirement with a 6% deviation on bus 5

- To address the voltage rise issue we need to absorb reactive power. We can do this in at least two ways
  - Adjust voltage setpoint of microgrid generators
  - Use of Static Var Compensators (SVC)

Addressing Voltage Rise through Microgrid Controls

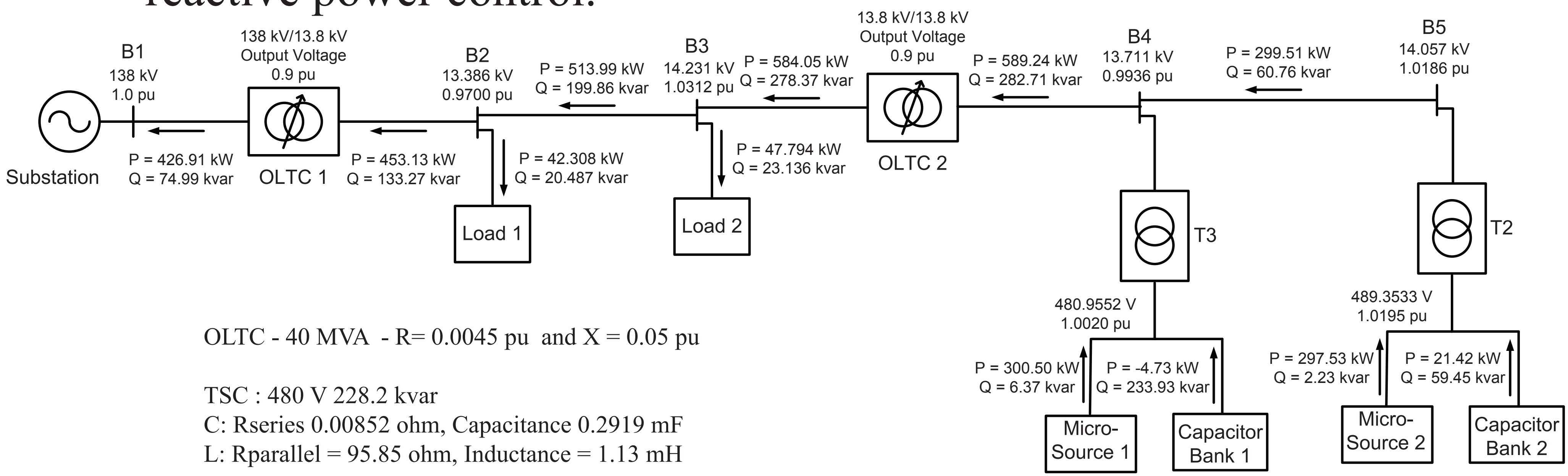


- Adjusting requested microsource voltage, $E_{req,}$ solves the problem
- A similar result is obtained by connecting a SVC ((inductor bank) consuming 76 kvar of reactive power on bus 5

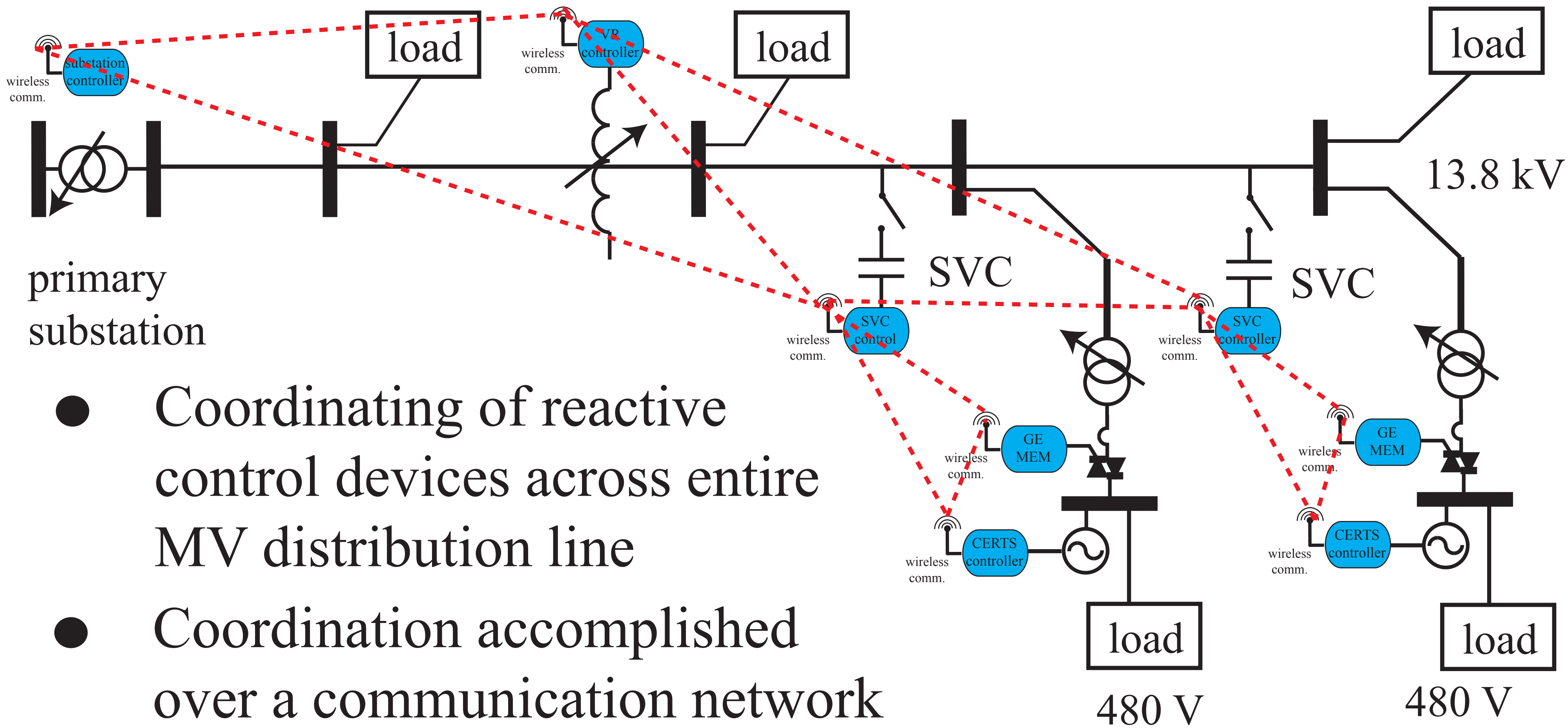


Addressing Voltage Rise through VR/SVC Controls

- Similar result obtained using tap-changing voltage regulators and capacitor banks.
- In this example, tap settings and capacitor bank size was determined from a power flow analysis. Future work will introduce automated controls
- Issue regarding interaction between legacy controls and microgrid reactive power control.



Distributed Reactive Control of MV Distribution Line



- Coordinating of reactive control devices across entire MV distribution line
- Coordination accomplished over a communication network
- Integration with existing distribution network infrastructure

Coordinating Controls across the MV Distribution Line

- Coordinating reactive power consumption across the entire MV distribution line can be treated as an optimization problem that maximizes the amount of exported real power subject to physical limitations of the system.

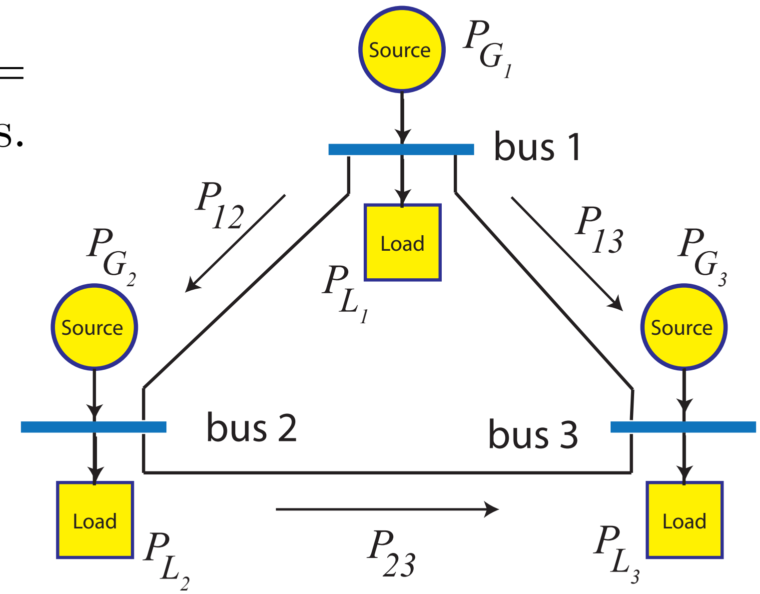
$$
\begin{array}{ll}
\text{minimize:} & \sum_{i=1}^{N} (P_{\text{loss}} + \mu G_{\text{shed}}) \\
\text{subject to:} & \underline{V} \leq V \leq \overline{V} \\
& \underline{Q} \leq Q \leq \overline{Q} \\
& \underline{P}_{\text{Ln}} \leq P_{\text{Ln}} \leq \overline{P}_{\text{Ln}}
\end{array}
$$

- The approach being proposed in the project involves a distributed event-triggered optimization
- This approach was tested on a LV mesh microgrid last year. We'll use this earlier example to explain how the approach works

Peer-to-Peer Dispatching in Microgrid

Microgrid Model

- Model grid as a directed graph (V,E) where $V = \{1, 2, \ldots, N\}$ are buses and $E \subset V \times V$ are tie lines.
- Line (i, j) impedance is $R_{ij} + jX_{ij}$
- Voltage source, i, with phase angle θ_i.
- Weighted Incidence A and Laplacian matrix, B
- Real power from bus i to j is $P_{ij} = \frac{1}{X_{ij}}(\theta_i - \theta_j)$



Economic Dispatch Problem

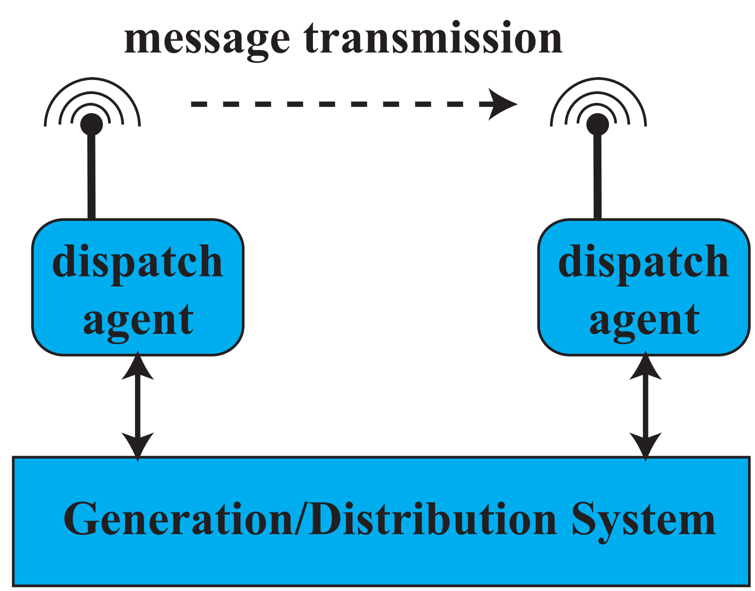
The objective is to minimize operating costs subject to power constraints. $C_i(P_{G_i})$ is the **economic cost** of bus i's source generating P_{G_i} (pu) of power.

minimize:	$\sum_{i=1}^{N} C_i(P_{G_i})$	microgrid operating cost
w.r.t.	P_G	
subject to:	$B\theta = P_G - P_L$	power balance
	$\underline{P}_G \leq P_G \leq \overline{P}_G$	generation limits
	$\underline{P} \leq A\theta \leq \overline{P}$	line limits

Event-triggered Message Passing

- **Distributed algorithm is expensive in message passing cost**
  - agents **pull** node/link states from neighbors on each update
  - expensive in terms of communication infrastructure
  - susceptible to denial of service attacks
- **Event-triggered Message Passing**
  - separate computation and communication
  - agent **pushes** node/link state to neigbhors when "novelty" in state exceeds a threshold

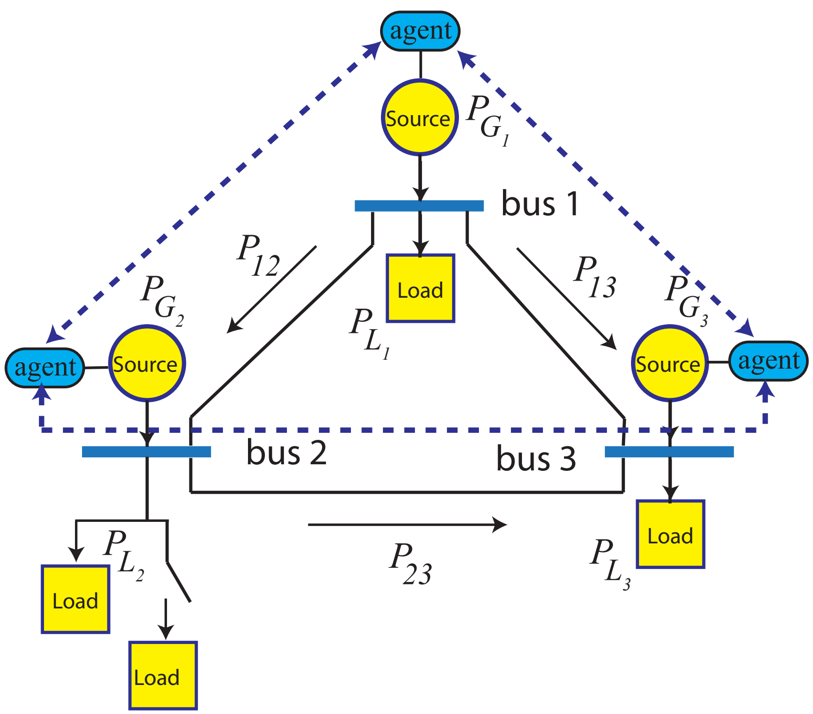
$$\left|\phi_i(t) - \hat{\phi}_i(t)\right| \leq \rho_i |z_i(t)|$$

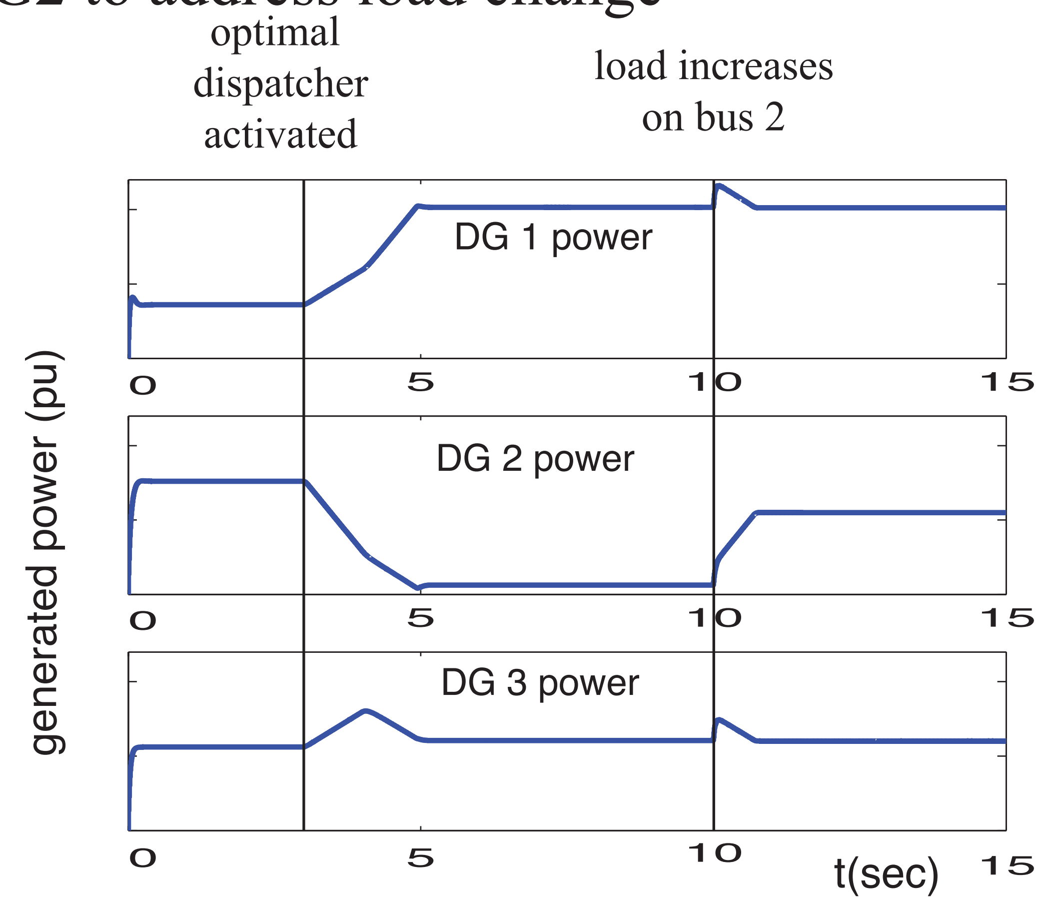


- **Benefits of Event-Triggering**
  - reduced message pasing complexity (orders of magnitude improvement)
  - sporadic transmission implies less sensitivity to denial-of-service

Case Study: event-triggered power dispatch in microgrids

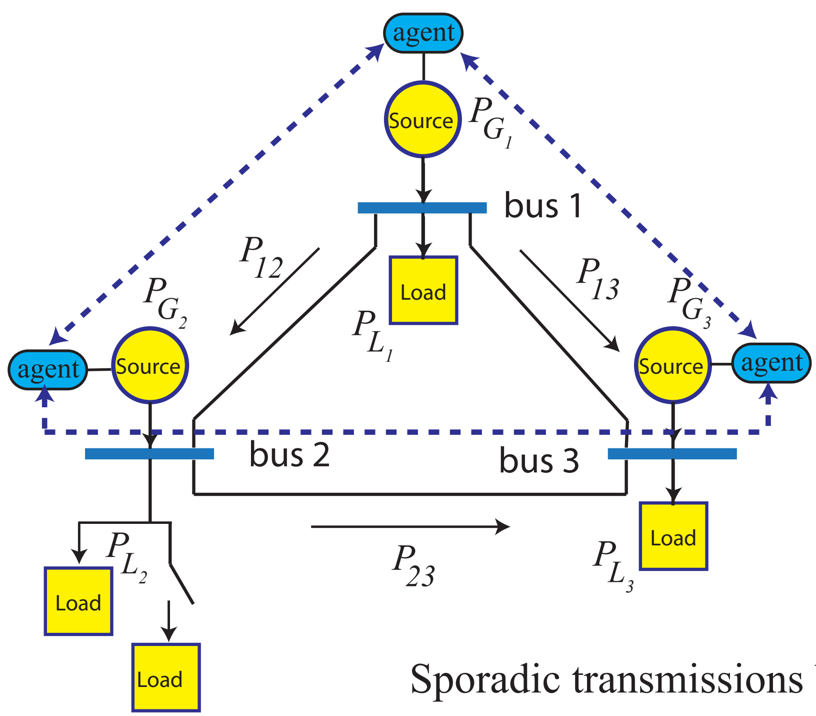
- Communication triggered by local "events" at each source
  - optimal dispatcher turned on (t = 3 sec)
  - abrupt change in bus 2 load (t = 10 sec)
  - DG2 most expensive generating unit
  - power line constraint force DG2 to address load change

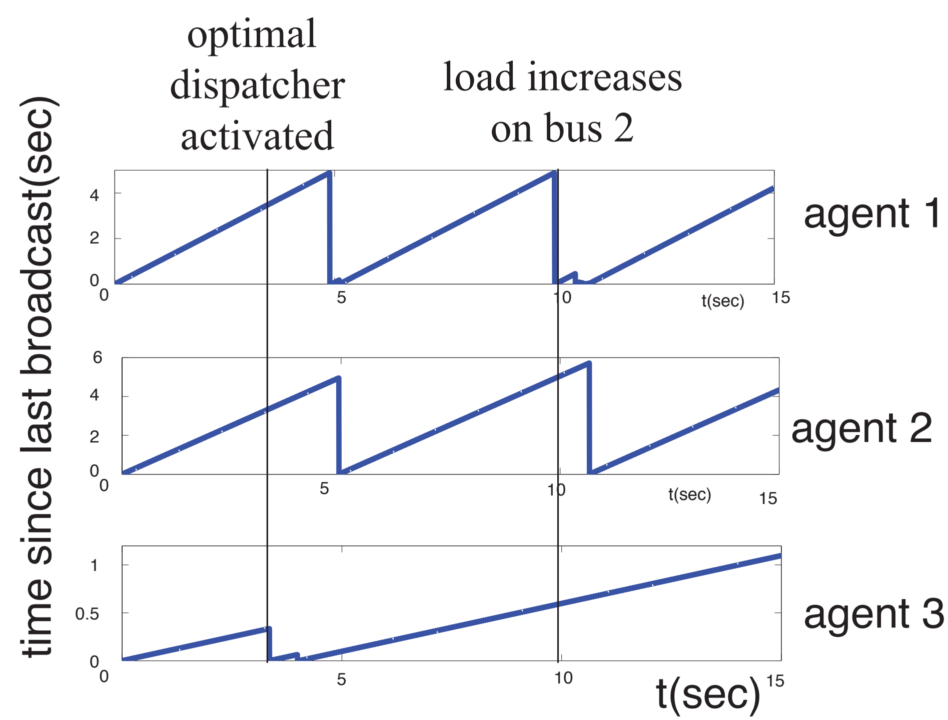




Case Study: event-triggered power dispatch in microgrids

- Communication triggered by local "events" at each source
- Power dispatch with great reduction in network message passing
  - message passing reduction can be by several orders of magnitude over periodically triggered distributed optimization method



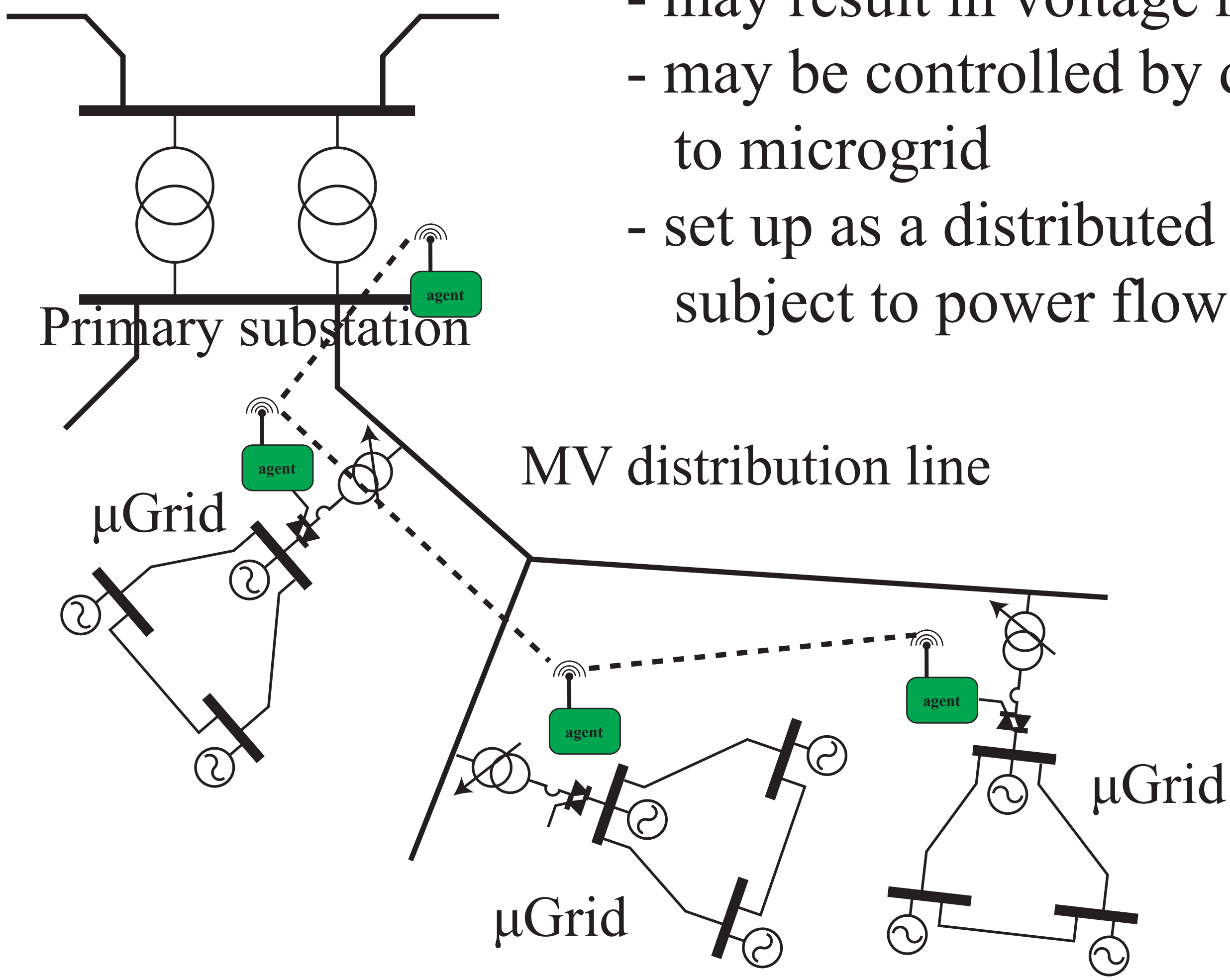


Sporadic transmissions between agents occur in response to changes in system

Microgrids and Distributed Energy Resources

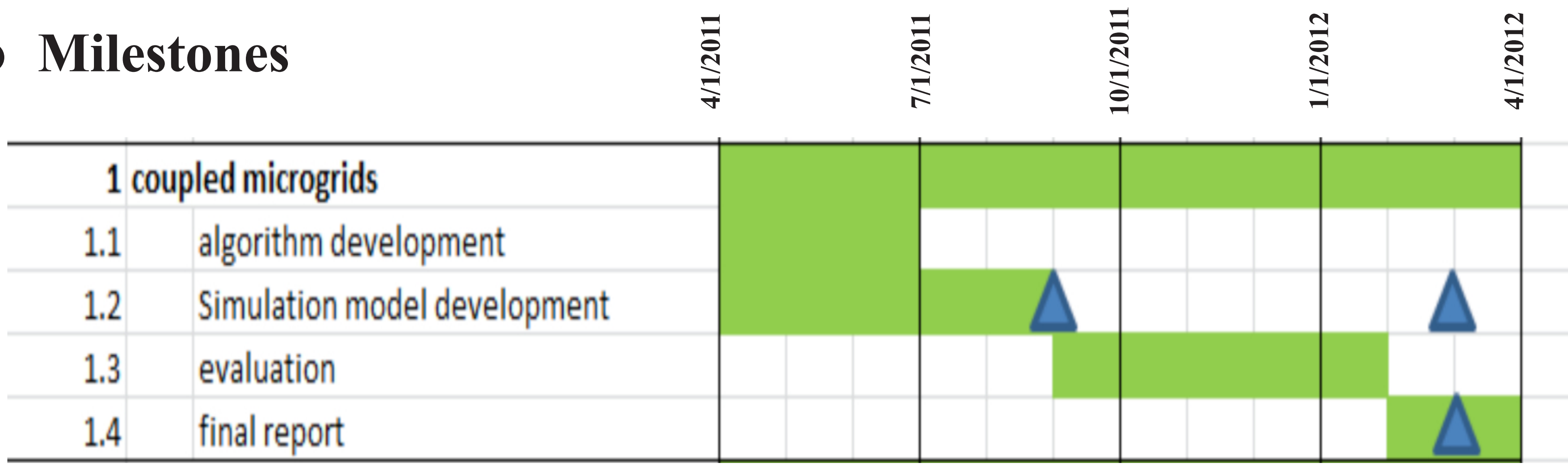
Voltage Rise Problem

- occurs when microgrid exports power to grid
- may result in voltage rise at primary substation
- may be controlled by delivering reactive power to microgrid
- set up as a distributed optimization problem subject to power flow constraints



Supporting Tasks, Deliverables, Milestones

- **Supporting Tasks**
  - Distributed Estimation of State in MV Distribution Line
  - Powerline Communication
- **Deliverables**
  - Interim Report (9/1/2011)
  - Final Report (3/15/2012)
  - simPower Simulation Files (3/15/2012)
- **Milestones**



What GE can provide

- Specifications on more realistic MV distribution line
  - Cable impedances, scale of loads and generation
  - Specifications on GE microgrid controller
  - DO management policies
  - Specifications on existing control devices.
- Systems engineering perspective on smart-grid
  - Business constraints
  - Regulatory constraints