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Decentralized Control of Inverter Networks for Voltage Regulation

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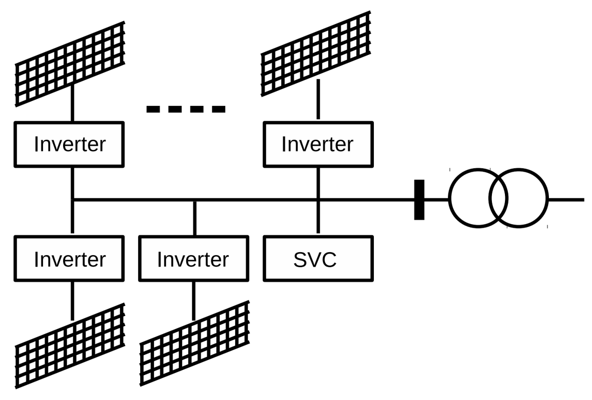
Abstract

Voltage regulation of distribution system becomes necessary as distributed power generation increases reverse power flow. Inverters can contribute to voltage regulation by controlling active as well as reactive power flow. This work proposes distributed control schemes for voltage regulation using inverters.

Photovoltaic (PV) power plant

Control objectives:

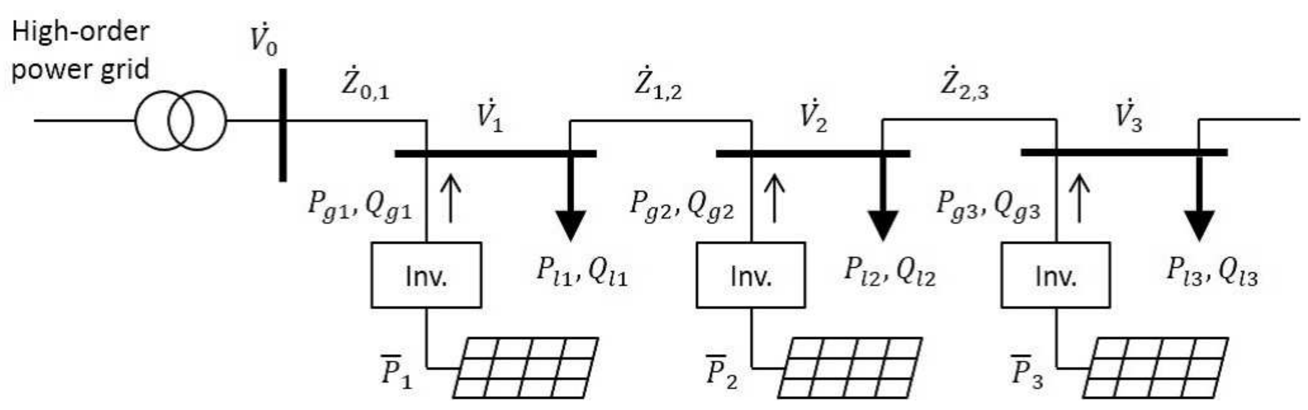
- Assign required amount of reactive power to inverters and SVC for voltage regulation.
- Inverters under severe temperature conditions can share small amount of reactive power.
- Other inverters share equal amount of reactive power.



Residential solar systems

Control objectives:

- Maintain grid voltage
- Inverters of all household can sell surplus power



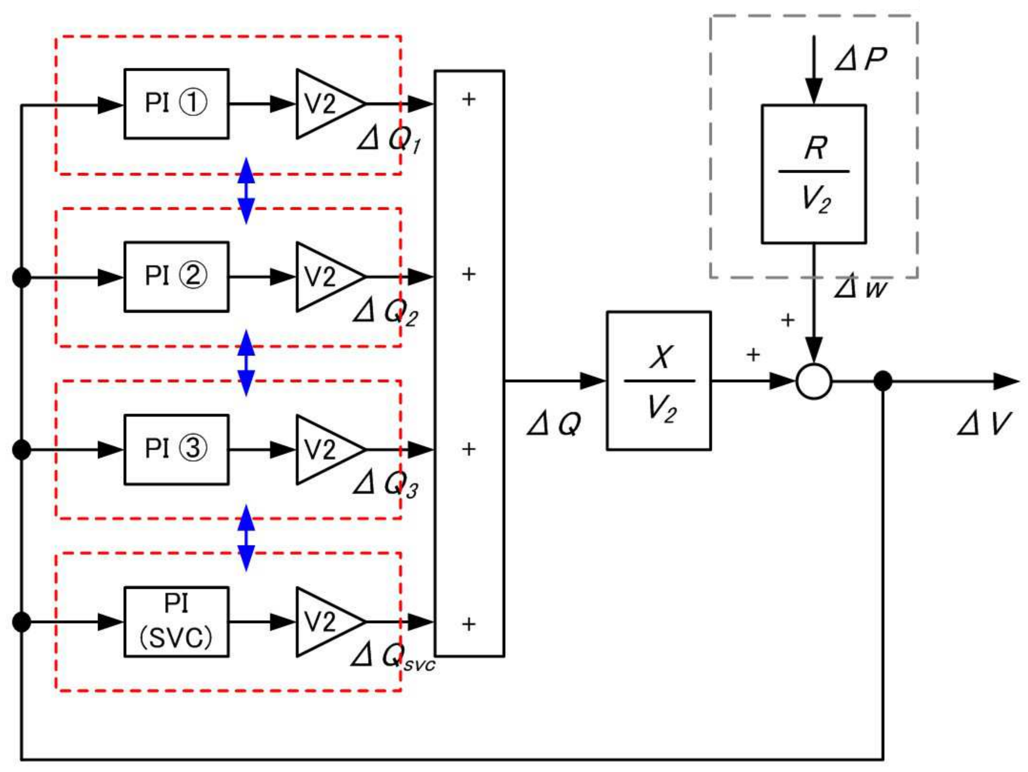
Two decentralized algorithms

Decentralized algorithms

- Centralized algorithm is difficult to implement because the numbers of generators and consumers are large.
- Easy to adapt when local topology changes.

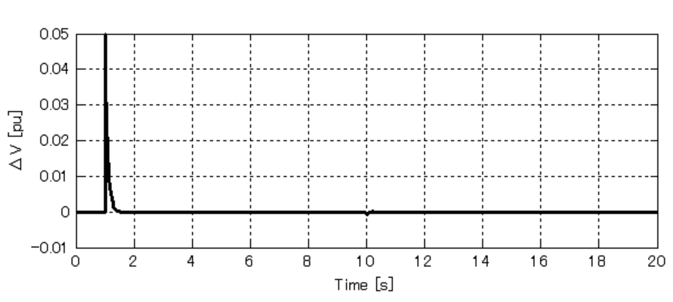
Consensus algorithm

- Outer feedback structure computes amount of reactive power required to compensate voltage change.
- Consensus algorithm equalizes required reactive power for each inverter

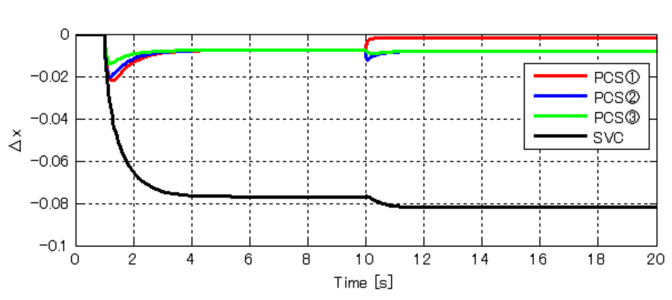


Simulation (consensus algorithm)

- At $t = 1$, active power increases stepwise.
- At $t = 10$, the capacity of PCS 1 decreases.



Voltage



Reactive power

- Voltage is regulated, and required reactive power is shared by PCSs and an SVC.

Real-time pricing algorithm

Centralized problem

$$\min_{P^{\mathrm{ref}},Q^{\mathrm{ref}}} \sum_i w_{P_i}\left(P_i^{\mathrm{ref}}-\bar{P}_i\right)^2+\left(Q_i^{\mathrm{ref}}\right)^2$$

subject to

$$\left(P^{\mathrm{ref}}\right)^2+\left(Q^{\mathrm{ref}}\right)^2\le S^2$$
$$-\gamma P^{\mathrm{ref}}\le Q^{\mathrm{ref}}\le \gamma P^{\mathrm{ref}}$$
$$V=V_0$$

V_0 grid voltage

Each household

$$\min_{P_i^{\mathrm{ref}},Q_i^{\mathrm{ref}}} w_{P_i}\left(P_i^{\mathrm{ref}}-\bar{P}_i\right)^2+\left(Q_i^{\mathrm{ref}}\right)^2 + p_{P_i}P_i^{\mathrm{ref}} + p_{Q_i}Q_i^{\mathrm{ref}}$$

subject to

$$\left(P_i^{\mathrm{ref}}\right)^2+\left(Q_i^{\mathrm{ref}}\right)^2\le S_i^2$$
$$-\gamma P_i^{\mathrm{ref}}\le Q_i^{\mathrm{ref}}\le \gamma P_i^{\mathrm{ref}}$$

$\bar{P}_i$ Active power bound
S_i PCS capacity
γ Power factor

Real-time price (KKT condition)

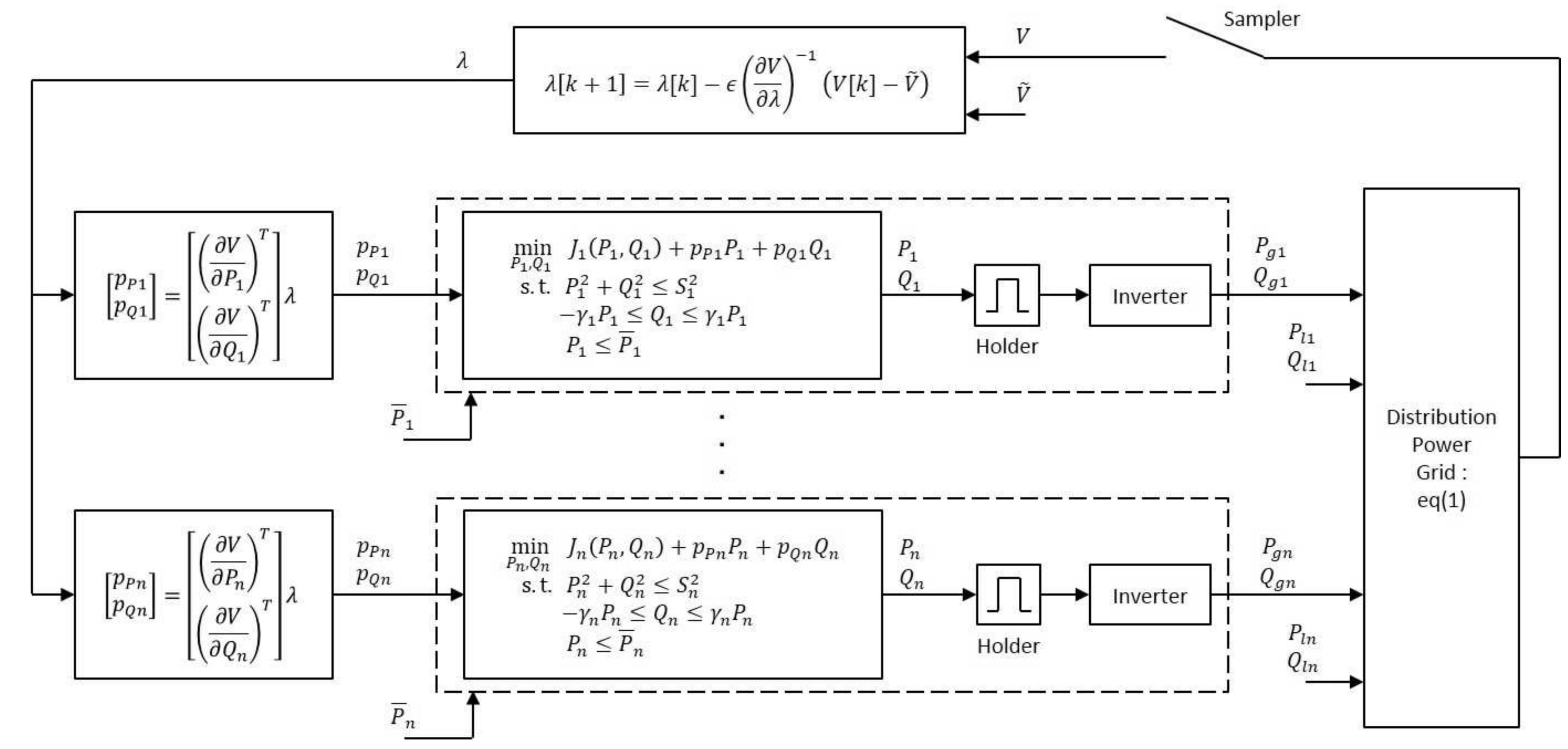
Price of active power

$$p_{P_i}=\sum_k \lambda_k \frac{\partial V_k}{\partial P_i}=\left(\frac{\partial V}{\partial P_i}\right)^{\mathrm{T}}\lambda$$

Price of reactive power

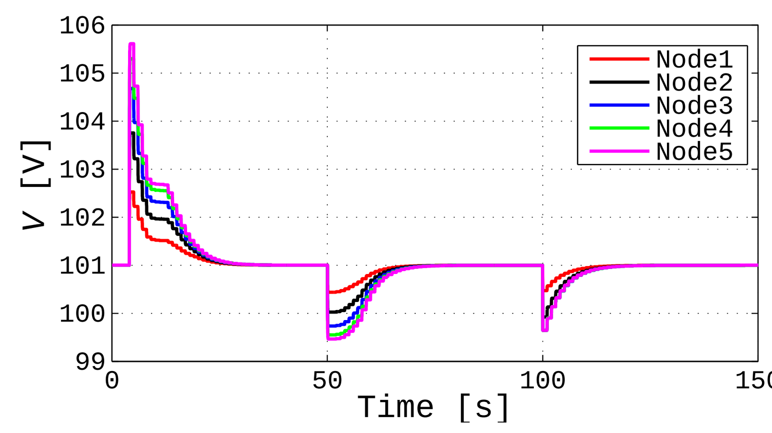
$$p_{Q_i}=\sum_k \lambda_k \frac{\partial V_k}{\partial Q_i}=\left(\frac{\partial V}{\partial Q_i}\right)^{\mathrm{T}}\lambda$$

Price update

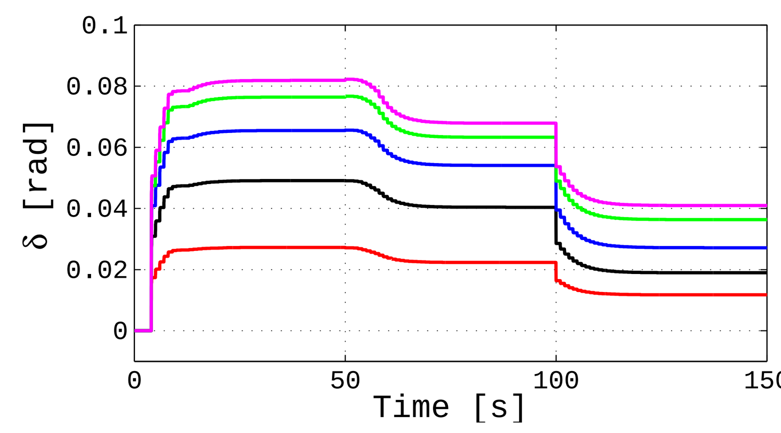


Simulation (real-time pricing algorithm)

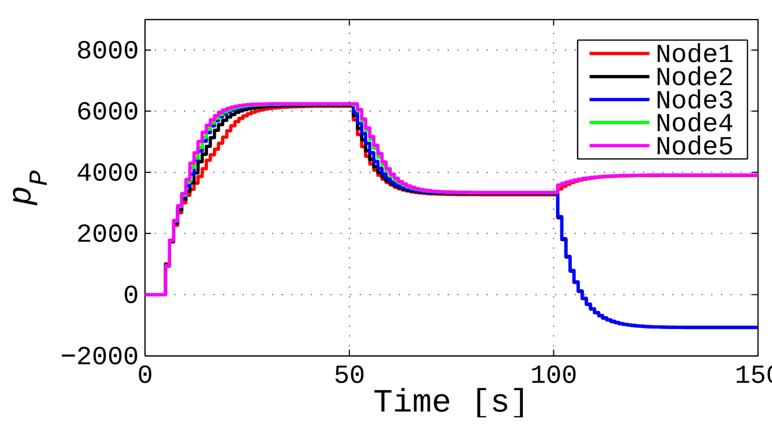
- Sample period for Lagrangian multipliers is $t_s = 1$.
- At $t = 4, 50$ and 100, the upper limit and the load of active power change.



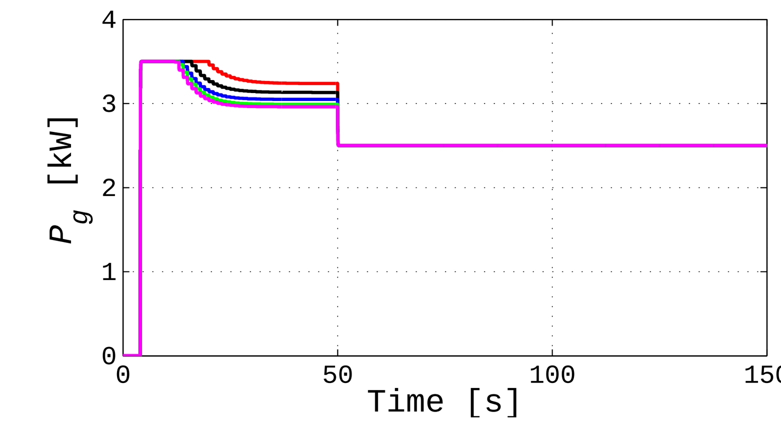
voltage



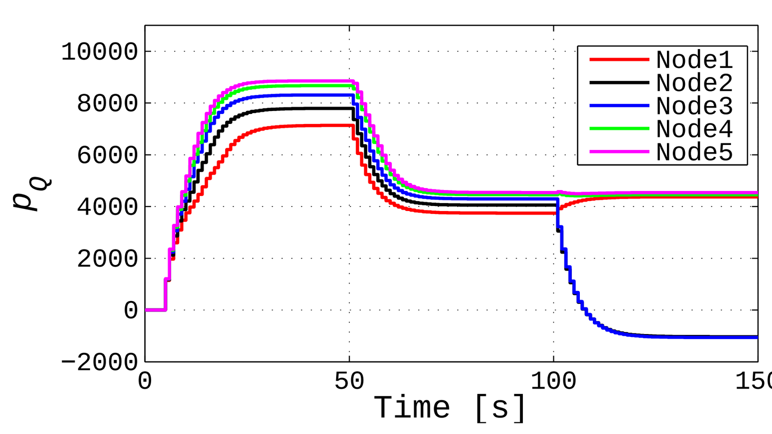
phase



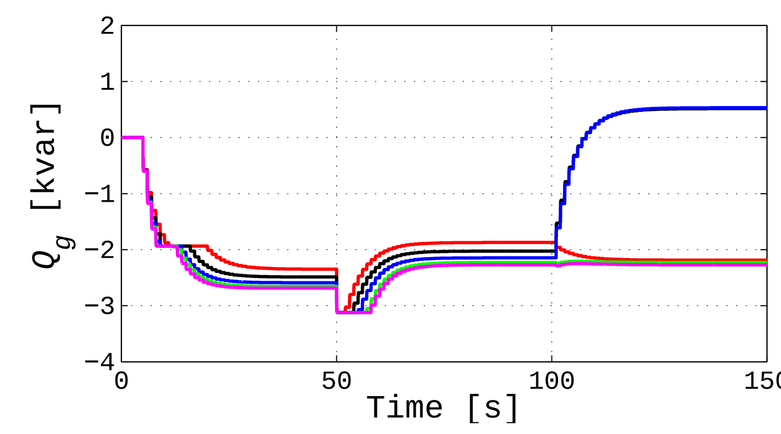
price of active power



output of active power



price of reactive power



output of reactive power

- Voltage regulation is successful.
- Active power is utilized as much as possible.

Conclusions

The two algorithms for voltage regulation of power line having distributed power generators are proposed. Inverters are controlled to yield required reactive power in a decentralized manner. Numerical experiments show the efficacy of the methods.

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