Siting and Sizing of DG Units Considering Energy Equity: Model, Solution, and Guidelines

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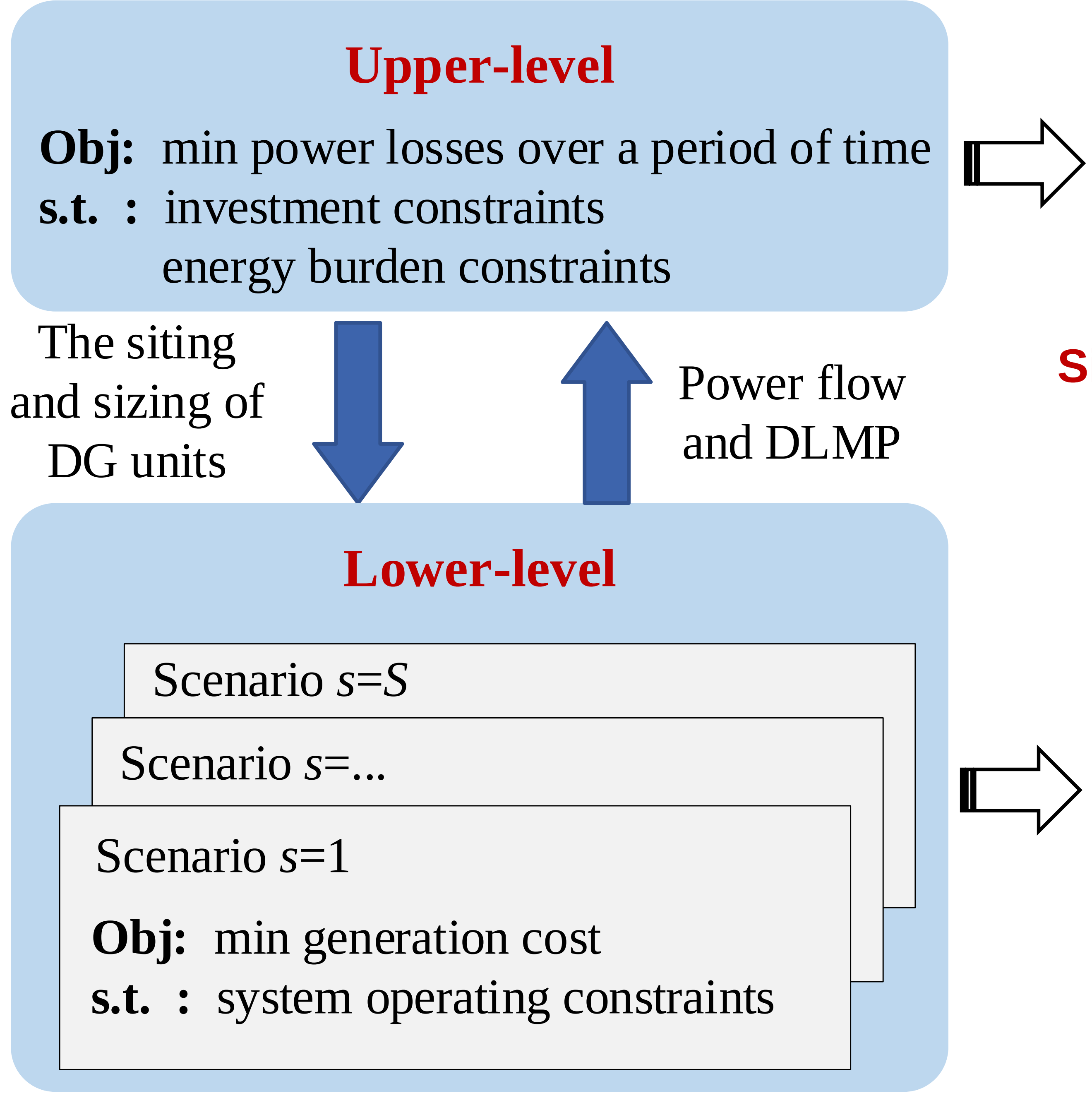
Background & Motivation

- Energy equity is an important emerging factor which needs to be considered in energy transition, aiming to achieve the reduction in greenhouse gas emissions. However, there are various types and degrees of energy inequities in the current power system.
- A planning method for siting and sizing DG units with an energy equity constraint model is proposed, where the energy equity is quantified by energy burden.
- High-level planning guidelines are obtained for the DG units' siting and sizing problem to facilitate the achievement of energy equity.

Problem Formulation



Upper-level

Obj: min power losses over a period of time
s.t. **:** investment constraints
energy burden constraints

The siting and sizing of DG units

Power flow and DLMP

Lower-level

Scenario *s*=*S*

Scenario *s*=...

Scenario *s*=1

Obj: min generation cost
s.t. **:** system operating constraints

$$\min \; 365\cdot\sum_{s\in\Omega_S}\sum_{t\in\Omega_T}\rho_s\cdot P_t^{L,s}$$

$$\begin{aligned}
\text{s.t.}\quad & 0\le P_i^R \le P_{\max}^{DG}\cdot k_i,\forall i\in\Omega_N && 0\le\sum_{i\in\Omega_N}k_i\le N_{DG},\forall i\in\Omega_N\\
& \sum_{i\in\Omega_N}\alpha\cdot P_i^R+\beta\cdot k_i\le c_{dg} && 365\cdot\sum_{s\in\Omega_S}\sum_{t\in\Omega_T}\rho_s\cdot\frac{\pi_{i,t,s}\cdot P_{i,t}^{D,s}}{I_i}\le e_i^0,\forall i\in\Omega_H
\end{aligned}$$

Energy equity constraint (energy burden)

Siting and sizing results

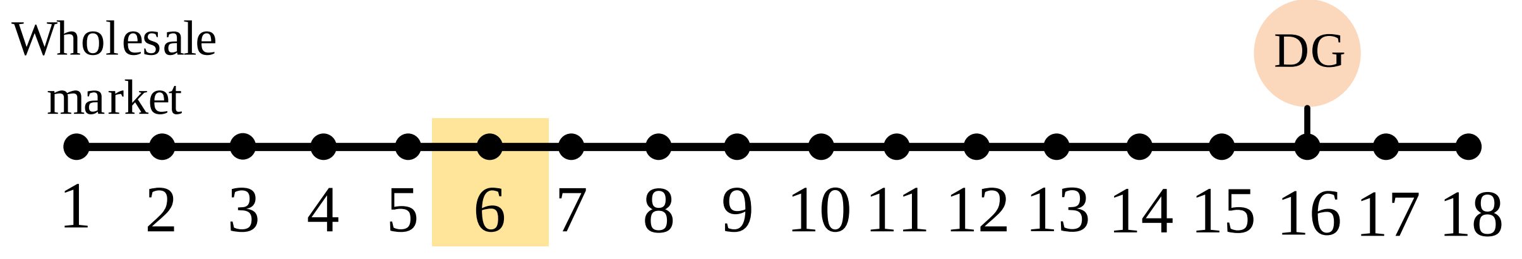
DLMP $\pi_{i,t}^s=\lambda_t^{P,s}+\lambda_t^{P,s}\cdot\frac{\partial P_t^{L,s}}{\partial P_{i,t}^{D,s}}+\lambda_t^{Q,s}\cdot\frac{\partial Q_t^{L,s}}{\partial P_{i,t}^{D,s}}+\sum_{j\in\Omega_N}\left(\omega_{j,t}^{v\min,s}-\omega_{j,t}^{v\max,s}\right)\cdot Z_{j,i}^P,\forall i\in\Omega_N$

$$\min\sum_{t\in\Omega_T}\left(\sigma_{Sub,t}^{P,s}\cdot P_{Sub,t}^{G,s}+\sigma_{Sub,t}^{Q,s}\cdot\widehat{Q}_{Sub,t}^{G,s}+\sum_{i\in\Omega_G}\left(\sigma_{i,t}^{P,s}\cdot P_{i,t}^{G,s}+\sigma_{i,t}^{Q,s}\cdot\widehat{Q}_{i,t}^{G,s}\right)\right)$$

$$\begin{aligned}
\text{s.t.}\quad & P_{Sub,t}^{G,s}+\sum_{i\in\Omega_G}P_{i,t}^{G,s}-\sum_{i\in\Omega_N}P_{i,t}^{D,s}-P_t^{L,s}=0:\lambda_t^{P,s} && Q_{Sub,t}^{G,s}+\sum_{i\in\Omega_G}Q_{i,t}^{G,s}-\sum_{i\in\Omega_N}Q_{i,t}^{D,s}-Q_t^{L,s}=0:\lambda_t^{Q,s}\\
& V^{\min}\le V_{i,t}^s\le V^{\max}:\omega_{i,t}^{v\min,s},\omega_{i,t}^{v\max,s},\forall i\in\Omega_N && P_i^{G,\min}\le P_{i,t}^{G,s}\le P_i^R:\omega_{i,t}^{P\min,s},\omega_{i,t}^{P\max,s},\forall i\in\Omega_G\\
& Q_i^{G,\min}\le Q_{i,t}^{G,s}\le Q_i^{G,\max}:\omega_{i,t}^{Q\min,s},\omega_{i,t}^{Q\max,s},\forall i\in\Omega_{SC} && -Q_{i,t}^{G,s}\le\widehat{Q}_{i,t}^{G,s},Q_{i,t}^{G,s}\le\widehat{Q}_{i,t}^{G,s}:\kappa_{i,t}^{-,s},\kappa_{i,t}^{+,s},\forall i\in\Omega_G\\
& V_{i,t}^s=V_{Sub,t}^s+\sum_{j\in\Omega_N}Z_{i,j}^P\cdot\left(P_{j,t}^{G,s}-P_{j,t}^{D,s}\right)+\sum_{j\in\Omega_N}Z_{i,j}^Q\cdot\left(Q_{j,t}^{G,s}-Q_{j,t}^{D,s}\right),\forall i\in\Omega_N\\
& Q_i^{G,\min}\le Q_{i,t}^{G,s}\le P_{i,t}^{G,s}\cdot\tan\left(\text{arc}\;\cos\theta_i\right):\omega_{i,t}^{Q\min,s},\omega_{i,t}^{Q\max,s},\forall i\in\Omega_G
\end{aligned}$$

Case Studies

- Test system: 18-bus system, where low-income community is at Bus 6 and Bus 18, respectively.



(a) Low-income Community at Bus 6

(b) Low-income Community at Bus 18

Fig.1. 18-bus system with a low-income community and a planned DG

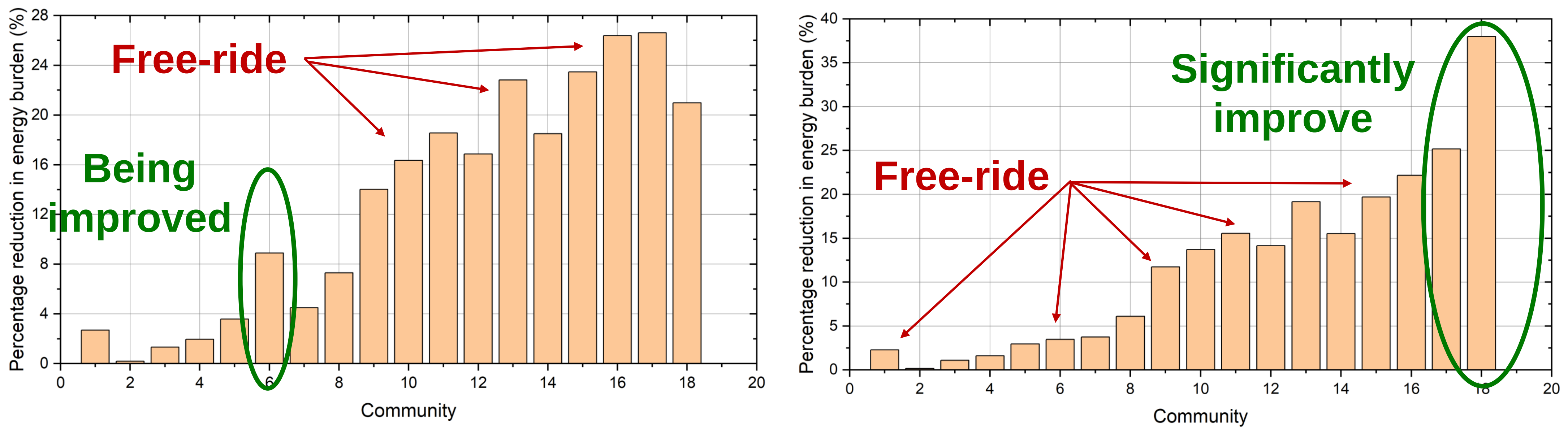


Fig.2. Percentage reduction in energy burden of each community. (Left: low-income community at Bus 6. Right: low-income community at Bus 18)

TABLE RESULTS OF CASES WITH DIFFERENT ENERGY BURDEN VALUE (Left: low-income community at Bus 6. Right: low-income community at Bus 18)

Different cases	1.0001*MEB		1.003*MEB		2*MEB		2.5*MEB
DG unit bus (#)	18		17		16		16
Rated power of DG (MW)	2.1		2.1		2.3		2.3
Power losses (MWh)	599.73	>	582.88	>	544.92	=	544.92
Energy burden of low-income community (%)	2.88	<	2.89	<	2.91	=	2.91
Additional cost ($)	1321.20	>	936.43	>	0	=	0

Different cases	1.01*MEB		1.02*MEB		1.1*MEB		1.5*MEB
DG unit bus (#)	16		16		16		16
Rated power of DG (MW)	2.5		2.0		1.8		1.8
Power losses (MWh)	551.03	>	509.66	>	470.30	=	470.30
Energy burden of low-income community (%)	3.86	<	3.89	<	3.91	=	3.91
Additional cost ($)	2330.42	>	1054.40	>	0	=	0

Conclusions

- DG units are not always installed near low-income communities, even considering the energy equity constraint. The decision of whether DG units are installed near low-income communities depends on the communities' location in the system as well as technical constraints.
- When multiple low-income communities are spread throughout a system, it is generally more effective to install DGs near the low-income communities in the downstream of feeders.