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A Robust Approach for Active Distribution Network Restoration Based on Scenario Techniques Considering Load and DG Uncertainties

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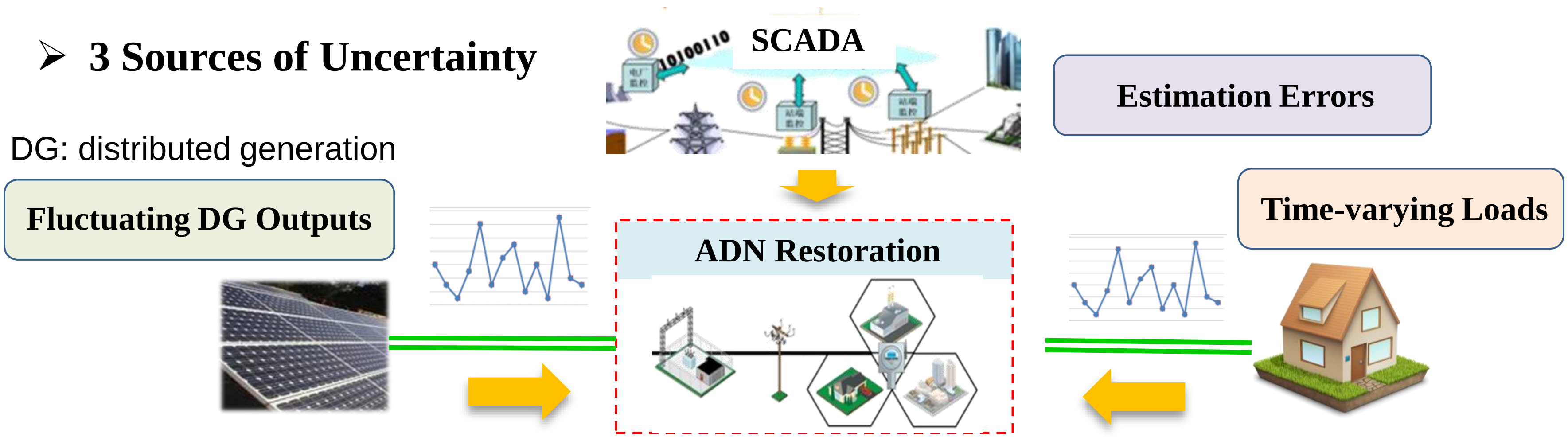
Background

- **Power Supply Restoration** is one of the most important functions in the operation of active distribution networks (**ADNs**). Outage power in unfaulted but out-of-service areas can be restored through tuning the status of branch switches.

- It is time-consuming to complete a restoration task, while there exist **uncertainty problems** during this process.

➤ 3 Sources of Uncertainty



➤ Uncertainty Risks

Infeasible restoration schemes.

Longer interruption duration.
Higher outage cost.
…

Method

- This paper proposes a **robust ADN restoration approach** based on **scenario techniques**, considering both DG uncertainty and load uncertainty.

DRM → 1-Uncertainty Set Building → 2-Scenarios Generation → 3-Scenarios clustering → **RRM**

DRM: Deterministic Restoration Model. RRM: Robust Restoration Model.

- ADN restoration problem is modeled using mathematical programming.

DRM

- **Objective Function**:
  Maximizing total restored outage power.
- **Subject to:**
  - Radial Operation Constraint.
  - Power Balance Constraint at Buses.
  - Power Flow Equality Constraint.
  - Branch Capacity Constraint.
  - Voltage Security Constraint.

Mixed Integer Linear Programming

$$Obj.\ \underset{y}{\mathrm{Max}}\ \boldsymbol{c}^{\mathrm{T}}\boldsymbol{x}$$

$$s.t.\begin{cases}\boldsymbol{Ax} \le \boldsymbol{b} \\ \boldsymbol{Bx} + \boldsymbol{Cy} \le \boldsymbol{g}\end{cases}$$

$\boldsymbol{x}$: power flow variables. $\{P_{ij}, Q_{ij}, U_i\}$

$\boldsymbol{y}$: status of each branch. $y_{ij} \in \{0,1\}$

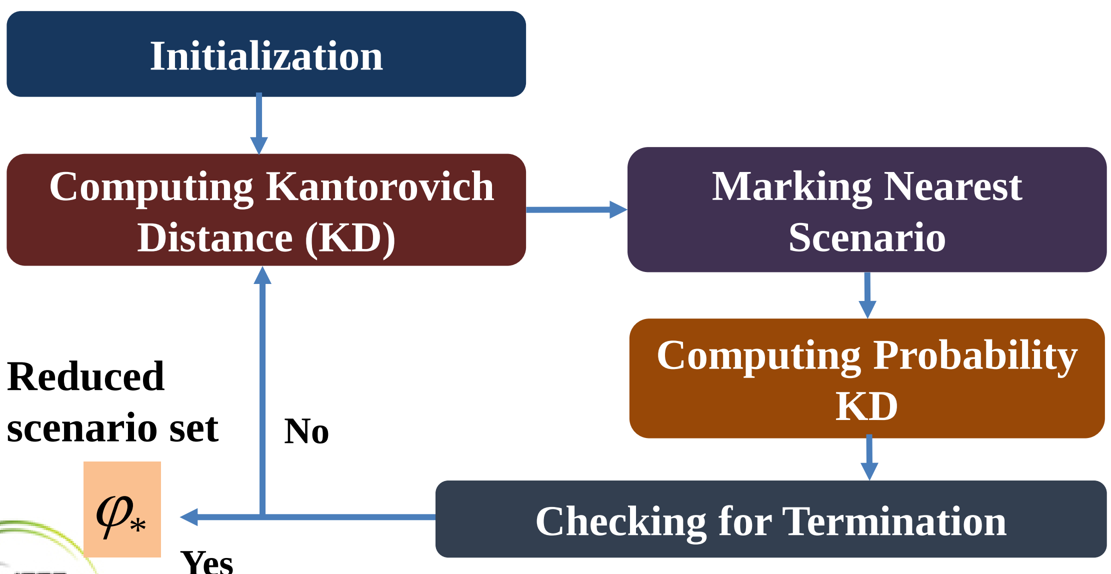
Method

- According to the profiles of historical data, the **uncertainty sets** of DG outputs and load demands are established as Ω ,and assumed to follow **normal distributions**.

$$\Omega=\begin{cases}\tilde{P}_{L,i} \in \left[\underline{P}_{L,i},\overline{P}_{L,i}\right], \forall i \in \Psi_{con} \\ \tilde{P}^{m}_{G,i} \in \left[\underline{P}^{m}_{G,i},\overline{P}^{m}_{G,i}\right], \forall i \in \Psi_{DG}\end{cases} \qquad \begin{cases}\tilde{P}_{L,i} \sim \boldsymbol{N}\left(P^{E}_{L,i}, \sigma^{2}_{L,i}\right), \forall i \in \Psi_{con} \\ \tilde{P}^{m}_{G,i} \sim \boldsymbol{N}\left(P^{E,m}_{G,i}, \sigma^{m,2}_{G,i}\right), \forall i \in \Psi_{DG}\end{cases}$$

- Generating masses of **stochastic scenarios** accordingly to simulate the uncertainty.
- Using the **backward scenario reduction technique** to cluster scenarios in order to alleviating the computation burden .

$$\varphi^{E}_{*}=\varphi_{*}\cup\left\{\left(\overline{P}_{L,i},\underline{P}^{m}_{G,i}\right),\left(\underline{P}_{L,i},\overline{P}^{m}_{G,i}\right)\right\}$$



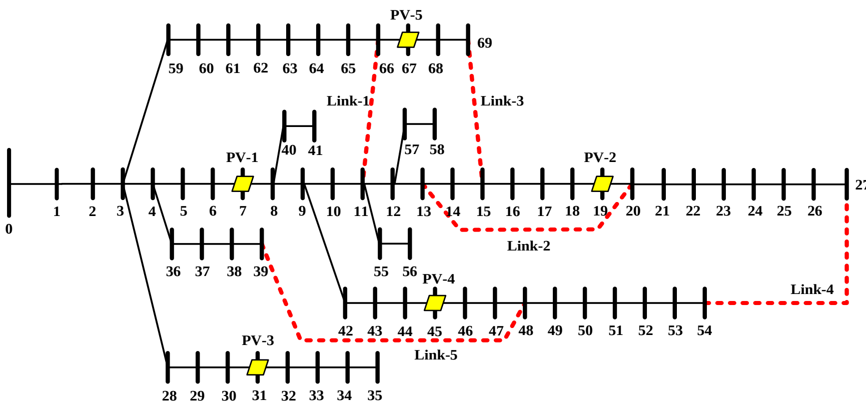
RRM

$$Obj.\ \underset{y}{\text{Max}} \sum_{s\in\varphi_{*}}\left(\Pr_{s}\cdot \boldsymbol{c}^{\mathrm{T}}\boldsymbol{x}_{s}\right)$$

$$s.t.\begin{cases}\boldsymbol{Ax}_{s} \le \boldsymbol{p}_{s}, \forall s \in \varphi^{E}_{*} \\ \boldsymbol{Bx}_{s}+\boldsymbol{Cy} \le \boldsymbol{g}_{s}\end{cases}$$

Results

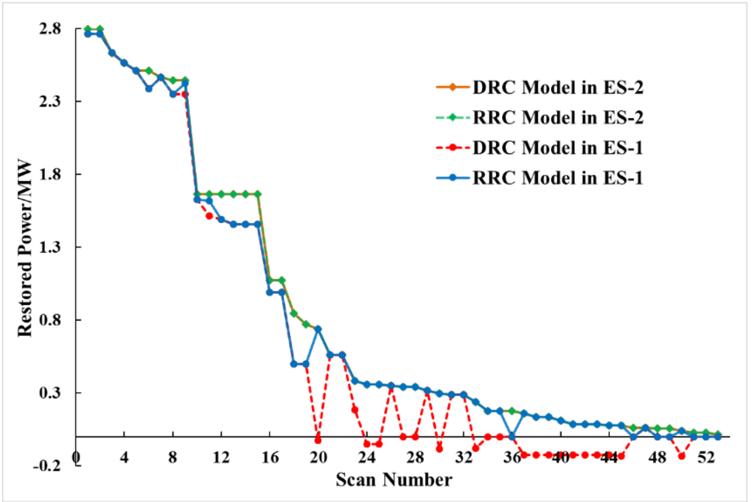
☐ Test System.



Modified PG&E 69-bus distribution system.

- ✓ DRM fails many times and leads to less restored power and higher infeasible ratio.
- ✓ RRM keeps feasible all the times with much better restoration performance.

☐ **Case-1** "N-1" Scan in Extreme Scenarios (ES).



☐ **Case-2** Monte Carlo Simulation Tests.

Faulty Branch	Method	Infeasible Times	Infeasible Ratio	Expected Restored Power/MW
ln19to20	RRC	0	0	0.1765
	DRC	5	0.25%	0.1747
ln60to61	RRC	0	0	0.1338
	DRC	24	1.2%	0.1314
ln63to64	RRC	0	0	0.0857
	DRC	26	1.3%	0.0842
ln68to69	RRC	0	0	0.0392
	DRC	22	1.1%	0.0385
ln38to39	RRC	0	0	0.3847
	DRC	0	0	0.3836

Conclusions

- In this paper, a robust ADN restoration method based on the scenario techniques is proposed to deal with the existing uncertainty problems.
- Simulation tests are carried out on a modified PG&E 69-bus system; they verify the robustness and optimality of this proposed robust method, with the comparisons against a deterministic restoration model.
- In our future work, more optimization methods, such as robust optimization, distributionally robust optimization etc, will be investigated to capture the uncertainty factors in ADN planning and operation.