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Active Distribution Systems and Distributed Energy Resources

10596_2022

Voltage and Current Control of Transmission and Distribution Systems Utilizing Demand-Side DERs

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Introduction

- The introduction of DERs (Distributed Energy Resources) such as PV (Photovoltaic), BESS (Battery Energy Storage System), and EVs (Electrical Vehicles) has been increasing.
- Japanese government aims to make RESs (Renewable Energy Sources) a main power supply and aims for 20~30 % of EV/PHV (Plug-in Hybrid Vehicle) sales in 2030 to achieve 'carbon neutrality' in 2050.
- Future power grids with higher penetration rate of DERs may require whole optimization/management of transmission and distribution systems since active/reactive power change in distribution networks affects voltage and current in transmission systems.
- This paper evaluates voltage and current in a transmission network and distribution networks with a high penetration rate of DERs by numerical simulations. The effectiveness of DER control is also evaluated.

Method

- The control amount of DERs is determined by the DERMS (Distributed Energy Resource Management System), and the control request is sent to DERs through the aggregator system.
- Optimal power flow (OPF) calculation is utilized to determine the PQ control of DERs
- In case optimizing DER control to satisfy both transmission and distribution constraints, Transmission OPF (T-OPF) and Distribution OPF (D-OPF) is implemented hierarchically as below.

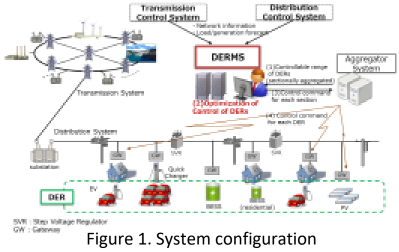

Figure 1. System configuration

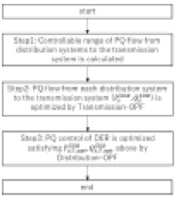

Figure 2. Flowchart of the proposed method

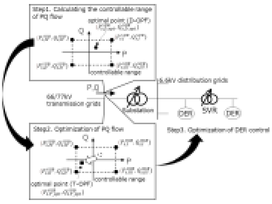

Figure 3. Overview of the proposed method

Numerical simulation setup

- Two simulation results are compared. One is that the control of DER is optimized by TD-OPF and the other is that the control is optimized by only D-OPF.
- The penetration of PV, EVs and BESS in 2030 is assumed (Table II)
- Transmission system model [4](Fig. 5)
  16 extra-high voltage loads, 6 PV sites, 4 small hydroelectric turbines, and 14 distribution substations.
- Distribution system model [5] (Table I, Fig. 6)
- The typical load profile is from [5]. Load is set to that of 11 AM since EV charging in addition to load can cause line overload especially in rainy days.

Table II. DER penetration rate setting

DER		Capacity	Penetration rate
PV	Residential	4kW	30% of low voltage residences
	Commercial	2,000kW	Connected to Provincial 1 distribution line
BESS	Residential	2kW/8kWh	30% of low voltage residences
	DSO belongings	500kW	Connected to Provincial 1 distribution line
EV	EV	40kWh	25% of low voltage residences
	Residential EV-PCS	6kW	25% of low voltage residences
	Quick Charger	300kW (50kW×6)	Connected to Provincial 1, Provincial 2 distribution line

-> All the BESS units discharge active power equal to the residential load. Quick-chargers and 50 % of residential EV-PCS units charge in the simulation.

Table I. Distribution line information

Distribution line	Distance (km)	High-voltage Load		Low-voltage load	
		# of customers	Load (kW) (1 customer)	# of customers	Load (kW) (1 customer)
Suburb	4.4	11	110	1500	0.651
Provincial 1	19.9	6	102	1000	
Provincial 2	19.9	12	120	1000	

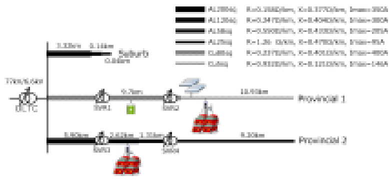

Figure 6. 6.6 kV distribution system model

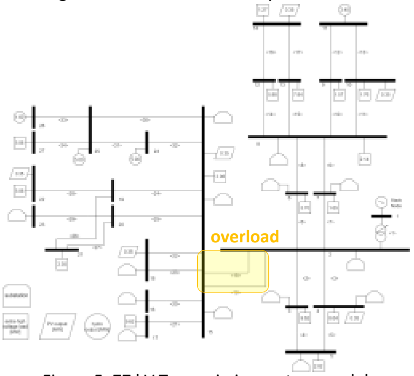

Figure 5. 77 kV Transmission system model

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continued

Test results & Discussion

- Without DER control, overload occurred in the transmission network, and voltage deviation and overload occurred in the distribution networks
- In this simulation, the forward active power flow was relatively large because PV generation was limited, since it was the condition of rainy days, in addition to EV charging
- In distribution networks, voltage deviation occurred since line resistance is relatively large, thus reactive power control was mainly necessary to satisfy distribution network constraints.
- TD-OPF satisfied both the transmission and distribution system constraints by optimizing control of the DERs (Fig. 8~10)
- Forward active power flow of the substations which are connected to the overloaded transmission line was decreased TD-OPF to prevent an overload on the transmission system (Fig. 7)
- Overload in the transmission system was not resolved when control of DERs were determined to satisfy the distribution system constraint only(D-OPF) (Fig. 8)
- This is because D-OPF did not adequately control active power, and mainly controls reactive power to satisfy the voltage constraint in the distribution system (Fig. 9~12)

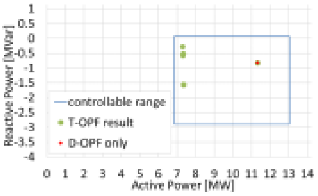

Figure 7. power flow of distribution substations (by TD-OPF and D-OPF)

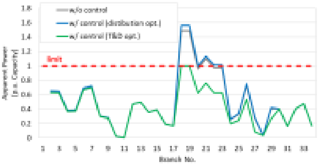

Figure 8. Power flow in the transmission system

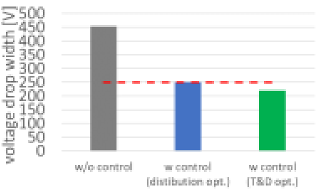

Figure 9. Voltage drop width of the OLTC section in the provincial 2 distribution system

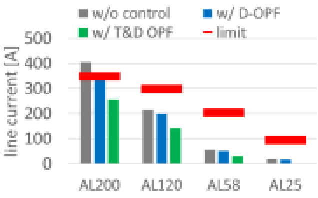

Figure 10. Line current in the provincial 2 distribution system

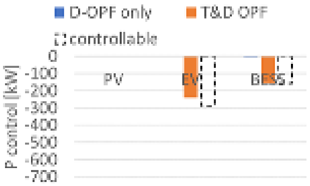

Figure 11. DER of OLTC section in the provincial 2 distribution system

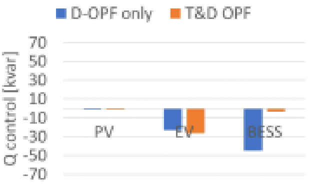

Figure 12. reactive power control of DER of OLTC section in the provincial 2 distribution line

Conclusion

- This paper developed and evaluated a TD-OPF approach to determine active and reactive power control of DERs connected to distribution systems.
- The numerical simulation results using the standard transmission and distribution system models showed that the proposed method satisfy both transmission and distribution system operation constraints although the overload occurred when control of DERs were optimized by only D-OPF.

[4] IEEJ (The Institute of Electrical Engineers of Japan) “Sub-transmission Network Models” ([Online]. Available at: http://denki.iee.jp/pes/?page_id=175 (access: Sep/02/2021))
[5] Electric Technology Research Association “Advancement of distribution automation system technology” ((in Japanese), October 2016)