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An approach for evaluating the impact of an intermittent renewable energy source on transmission expansion planning

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- ❖ Due to the electric load growth, transmission line expansion (TEP) is needed to resolve the electricity inadequacy problem by the minimal associated investment cost.
- ❖ The Ministry of Energy (Thailand) has proposed an implementation of renewable energy resources in electricity generation with the target of 13,927 MW in the year 2021 (4,494 MW in the year 2014).
- ❖ Its intermittent attribute can affect the system operation which results in TEP especially **solar and wind sources**.
- ❖ This paper proposes a new methodology of transmission expansion planning which is robust for all intermittent renewable energy generation and loads.
- ❖ The impact of an intermittent renewable energy source on TEP, especially in terms of a cost comparison, is taken into account.

Main problem

Objective function

$$\min \left(\sum_{k=1}^{n_c} c_{ij}^k x_{ij}^k + \sum_{g=1}^{n_g} c_g P_g \right)$$

Constraints

$$V_i^{\min} \leq V_i \leq V_i^{\max}, \quad i \in \Omega^b, \quad i = 1, 2, \dots, n_b$$

$$\sqrt{(P_{ij}^m)^2 + (Q_{ij}^m)^2} \leq S_{ij_lim}^m, \quad ij \in \Omega^{tl}, \quad m = 1, 2, \dots, n_l$$

$$P_g^{\min} \leq P_g \leq P_g^{\max}, \quad g \in \Omega^g, \quad g = 1, 2, \dots, n_g$$

$$Q_g^{\min} \leq Q_g \leq Q_g^{\max}, \quad g \in \Omega^g, \quad g = 1, 2, \dots, n_g$$

$$Q_{Ci}^{\min} \leq Q_{Ci} \leq Q_{Ci}^{\max}, \quad i \in \Omega^b, \quad i = 1, 2, \dots, n_b$$

$$Q_{INi}^{\min} \leq Q_{INi} \leq Q_{INi}^{\max}, \quad i \in \Omega^b, \quad i = 1, 2, \dots, n_b$$

$$P_{ij}^m + iQ_{ij}^m = |V_i|^2 \left(g_{ij} - i \left(b_{ij} + \frac{1}{2} b_{sh_ij} \right) \right)$$

$$-V_i V_j^* (g_{ij} - i b_{ij}), \quad ij \in \Omega^{tl}, \quad i \in \Omega^{n_b}, \quad m = 1, 2, \dots, n_l$$

Constraints (continue)

$$\sum_{k=1}^{n_c} x_{ij}^k \leq n_c, \quad ij \in \Omega^{tc}$$

$$x_{ij} = \begin{cases} 0, & ij \notin \Omega^{tc}, \\ 1 \text{ or } 0 \text{ (depending on the randomness} \\ \text{in the process)}, & ij \in \Omega^{tc}. \end{cases}$$

$$P_{Gi} + (P_{Ri}(u) - P_{RCi}(u)) - (P_{Di}(u) - P_{DCi}(u)) \\ = \sum_{j \in N(i)} P_{ij}(1 + x_{ij}), \quad i \in \Omega^b, \quad i = 1, 2, \dots, n_b$$

$$Q_{Gi} - (Q_{Di}(u) - Q_{DCi}(u)) \\ = \sum_{j \in N(i)} Q_{ij}(1 + x_{ij}), \quad i \in \Omega^b, \quad i = 1, 2, \dots, n_b$$

$$0 \leq P_{RCi}(u) \leq P_{Ri}(u), \quad i \in \Omega^b, \quad i = 1, 2, \dots, n_b$$

$$0 \leq P_{DCi}(u) \leq P_{Di}(u), \quad i \in \Omega^b, \quad i = 1, 2, \dots, n_b$$

Subproblem

Objective function

$$\min \left(\sum_{g=1}^{n_g} c_g P_g + \sum_{i=1}^{n_b} rc_i P_{RCi} + \sum_{i=1}^{n_b} oc_i P_{DCi} \right)$$

Constraints

$$\begin{aligned} P_{Gi} + (P_{Ri} - P_{RCi}) - (P_{Di} - P_{DCi}) \\ &= \sum_{j \in N(i)} P_{ij} (1 + x_{ij}), \quad i \in \Omega^b, \quad i = 1, 2, \dots, n_b \\ Q_{Gi} - (Q_{Di} - Q_{DCi}) \\ &= \sum_{j \in N(i)} Q_{ij} (1 + x_{ij}), \quad i \in \Omega^b, \quad i = 1, 2, \dots, n_b \\ V_i^{\min} \leq V_i \leq V_i^{\max}, \quad i \in \Omega^b, \quad i = 1, 2, \dots, n_b \\ \sqrt{(P_{ij}^m)^2 + (Q_{ij}^m)^2} \leq S_{ij_lim}^m, \quad ij \in \Omega^{tl}, \quad m = 1, 2, \dots, n_1 \\ P_g^{\min} \leq P_g \leq P_g^{\max}, \quad g \in \Omega^g, \quad g = 1, 2, \dots, n_g \\ Q_g^{\min} \leq Q_g \leq Q_g^{\max}, \quad g \in \Omega^g, \quad g = 1, 2, \dots, n_g \end{aligned}$$

Constraints (continue)

$$\begin{aligned} Q_{Ci}^{\min} \leq Q_{Ci} \leq Q_{Ci}^{\max}, \quad i \in \Omega^b, \quad i = 1, 2, \dots, n_b \\ Q_{INi}^{\min} \leq Q_{INi} \leq Q_{INi}^{\max}, \quad i \in \Omega^b, \quad i = 1, 2, \dots, n_b \\ 0 \leq P_{RCi} \leq P_{Ri}, \quad i \in \Omega^b, \quad i = 1, 2, \dots, n_b \\ 0 \leq P_{DCi} \leq P_{Di}, \quad i \in \Omega^b, \quad i = 1, 2, \dots, n_b \\ P_{ij}^m + iQ_{ij}^m = |V_i|^2 \left(g_{ij} - i \left(b_{ij} + \frac{1}{2} b_{sh_ij} \right) \right) \\ -V_i V_j^* (g_{ij} - i b_{ij}), \quad ij \in \Omega^{tl}, \quad i \in \Omega^{n_b}, \quad m = 1, 2, \dots, n_1 \\ \sum_{k=1}^{n_c} x_{ij}^k \leq n_c, \quad ij \in \Omega^{tc} \\ x_{ij} = \begin{cases} 0, & ij \notin \Omega^{tc}, \\ 1 \text{ or } 0 \text{ (depending on the randomness} \\ \text{in the process)}, & ij \in \Omega^{tc}. \end{cases} \end{aligned}$$

Indicator for selecting significant scenarios for planning

For renewable energy source

$$SSIRG_h = \sum_{i=1}^{n_b} P_{RCi,h} / \sum_{i=1}^{n_b} P_{Ri,h}$$

For load

$$SSIL_h = \sum_{i=1}^{n_b} P_{DCi,h} / \sum_{i=1}^{n_b} P_{Di,h}$$

Robustness

$$\text{Robustness} = \frac{H}{n_{hy}} \times 100\%$$

Simulation results

Table 5 Results of RTEP

Method	Solution	Number of considered scenarios	PV_{inv} ($\times 10^6$ US\$)	PV_{opr} ($\times 10^6$ US\$)	Total cost ($\times 10^6$ US\$)	Robustness (%)	Calculation time (min)
RTEP_MIN_MAX	$n_{6-10}=2, n_{7-8}=2, n_{2-8}=2, n_{1-8}=1, n_{8-9}=1, n_{17-18}=2, n_{10-11}=1, n_{4-9}=1, n_{1-5}=2, n_{5-10}=1, n_{15-16}=1, n_{14-16}=1, n_{6-7}=2, n_{14-23}=1$	4	477.95	4985.23	5463.18	74.50	155.79
RTEP_TOAT	$n_{6-10}=2, n_{7-8}=3, n_{2-8}=1, n_{1-8}=1, n_{8-9}=1, n_{3-24}=1, n_{8-10}=1, n_{16-17}=2, n_{9-11}=1, n_{14-16}=1, n_{6-7}=1, n_{12-23}=1, n_{19-20}=1$	32	509.28	5224.79	5734.06	87.48	1068.79
RTEP_PROPOSED	$n_{6-10}=2, n_{7-8}=2, n_{2-8}=1, n_{1-8}=1, n_{8-9}=1, n_{10-12}=1, n_{20-23}=1, n_{1-2}=2, n_{4-9}=1, n_{17-18}=1, n_{3-24}=1, n_{14-16}=2, n_{6-7}=2, n_{16-19}=1, n_{19-23}=1, n_{1-3}=1$	2	536.96	6696.52	7233.48	100	67.04

Table 6 Results of RTEP_RE

Case	Solution	PV_{inv} ($\times 10^6$ US\$)	PV_{opr} ($\times 10^6$ US\$)	Total cost ($\times 10^6$ US\$)	Robustness (%)
RTEP_PROPOSED-1	$n_{6-10}=1, n_{7-8}=1, n_{2-8}=1, n_{8-9}=1, n_{4-9}=1, n_{10-11}=1, n_{1-5}=2, n_{8-10}=3, n_{5-10}=1, n_{15-16}=1, n_{12-13}=1, n_{14-16}=1$	382.50	8419.50	8802.00	100
RTEP_PROPOSED-2	$n_{6-10}=2, n_{7-8}=2, n_{2-8}=1, n_{1-8}=1, n_{8-9}=1, n_{10-12}=1, n_{20-23}=1, n_{1-2}=2, n_{4-9}=1, n_{17-18}=1, n_{3-24}=1, n_{14-16}=2, n_{6-7}=2, n_{16-19}=1, n_{19-23}=1, n_{1-3}=1$	536.96	6696.52	7233.48	100
RTEP_PROPOSED-3	$n_{7-8}=2, n_{1-5}=1, n_{20-23}=2, n_{2-4}=1, n_{17-18}=1, n_{16-17}=1, n_{2-8}=2, n_{12-13}=1, n_{15-16}=1, n_{9-11}=1, n_{3-9}=1, n_{2-6}=1, n_{13-14}=1, n_{14-16}=3, n_{8-9}=1$	551.53	6030.14	6581.67	100

- ❖ Nonlinear programming based on the interior point method is used to solve the subproblem which is formulated by an AC model to obtain a more accurate result.
- ❖ The proposed robust optimization approach can guarantee a 100% system robustness of the expansion planning, among the intermittent renewable energy generation and loads, while the robustness of the expansion plans of other methods is less than 100%.
- ❖ The results show that the installation of a renewable energy source in a system will increase the cost of the expansion plan compared with the cost arising from installing a conventional generator.