Rongrit Chatthaworn, Surachai Chaitusaney, 2015. An approach for evaluating the impact of an intermittent renewable energy source on transmission expansion planning. *Frontiers of Information Technology & Electronic Engineering*, **16**(10):871-882. [doi:10.1631/FITEE.1500049]

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

Key words: Adaptive tabu search, Renewable energy generation, Robust optimization, Transmission expansion planning

Corresponding author: Surachai Chaitusaney

E-mail: surachai.c@chula.ac.th

Introduction

- 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

$$V_i^{\min} \le V_i \le V_i^{\max}, \quad i \in \Omega^{\mathrm{b}}, \quad i = 1,2,\ldots,n_{\mathrm{b}}$$

$$\sqrt{(P_{ij}^m)^2 + (Q_{ij}^m)^2} \le S_{ij\_\lim}^m, \quad ij \in \Omega^{\mathrm{tl}}, \quad m = 1,2,\ldots,n_1$$

$$P_g^{\min} \le P_g \le P_g^{\max}, \quad g \in \Omega^{\mathrm{g}}, \quad g = 1,2,\ldots,n_{\mathrm{g}}$$

$$Q_g^{\min} \le Q_g \le Q_g^{\max}, \quad g \in \Omega^{\mathrm{g}}, \quad g = 1,2,\ldots,n_{\mathrm{g}}$$

$$Q_{\mathrm{C}i}^{\min} \le Q_{\mathrm{C}i} \le Q_{\mathrm{C}i}^{\max}, \quad i \in \Omega^{\mathrm{b}}, \quad i = 1,2,\ldots,n_{\mathrm{b}}$$

$$Q_{\mathrm{IN}i}^{\min} \le Q_{\mathrm{IN}i} \le Q_{\mathrm{IN}i}^{\max}, \quad i \in \Omega^{\mathrm{b}}, \quad i = 1,2,\ldots,n_{\mathrm{b}}$$

$$P_{ij}^m + \mathrm{i}Q_{ij}^m = |V_i|^2\left(g_{ij} - \mathrm{i}\left(b_{ij} + \frac{1}{2}b_{\mathrm{sh}\_ij}\right)\right)$$
$$-V_i V_j^*(g_{ij} - \mathrm{i}b_{ij}), \quad ij \in \Omega^{\mathrm{tl}}, \quad i \in \Omega^{n_{\mathrm{b}}}, \quad m = 1,2,\ldots,n_1$$

Constraints (continue)

$$\sum_{k=1}^{n_c} x_{ij}^k \le n_{\mathrm{c}}, \quad ij \in \Omega^{\mathrm{tc}}$$

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

$$P_{\mathrm{G}i} + \left(P_{\mathrm{R}i}(\boldsymbol{u}) - P_{\mathrm{RC}i}(\boldsymbol{u})\right) - \left(P_{\mathrm{D}i}(\boldsymbol{u}) - P_{\mathrm{DC}i}(\boldsymbol{u})\right)$$
$$= \sum_{j \in N(i)} P_{ij}(1 + x_{ij}), \quad i \in \Omega^{\mathrm{b}}, \quad i = 1,2,\ldots,n_{\mathrm{b}}$$

$$Q_{\mathrm{G}i} - \left(Q_{\mathrm{D}i}(\boldsymbol{u}) - Q_{\mathrm{DC}i}(\boldsymbol{u})\right)$$
$$= \sum_{j \in N(i)} Q_{ij}(1 + x_{ij}), \quad i \in \Omega^{\mathrm{b}}, \quad i = 1,2,\ldots,n_{\mathrm{b}}$$

$$0 \le P_{\mathrm{RC}i}(\boldsymbol{u}) \le P_{\mathrm{R}i}(\boldsymbol{u}), \quad i \in \Omega^{\mathrm{b}}, \quad i = 1,2,\ldots,n_{\mathrm{b}}$$

$$0 \le P_{\mathrm{DC}i}(\boldsymbol{u}) \le P_{\mathrm{D}i}(\boldsymbol{u}), \quad i \in \Omega^{\mathrm{b}}, \quad i = 1,2,\ldots,n_{\mathrm{b}}$$

Subproblem

Objective function

$$\min\left(\sum_{g=1}^{n_g} c_g P_g + \sum_{i=1}^{n_b} \mathrm{rc}_i P_{\mathrm{RC}i} + \sum_{i=1}^{n_b} \mathrm{oc}_i P_{\mathrm{DC}i}\right)$$

Constraints

$$P_{\mathrm{G}i} + (P_{\mathrm{R}i} - P_{\mathrm{RC}i}) - (P_{\mathrm{D}i} - P_{\mathrm{DC}i}) = \sum_{j\in N(i)} P_{ij}(1+x_{ij}),\ \ i\in\Omega^{\mathrm{b}},\ \ i=1,2,\ldots,n_{\mathrm{b}}$$

$$Q_{\mathrm{G}i} - (Q_{\mathrm{D}i} - Q_{\mathrm{DC}i}) = \sum_{j\in N(i)} Q_{ij}(1+x_{ij}),\ \ i\in\Omega^{\mathrm{b}},\ \ i=1,2,\ldots,n_{\mathrm{b}}$$

$$V_i^{\min} \le V_i \le V_i^{\max},\ \ i\in\Omega^{\mathrm{b}},\ \ i=1,2,\ldots,n_{\mathrm{b}}$$

$$\sqrt{(P_{ij}^m)^2 + (Q_{ij}^m)^2} \le S_{ij\_\lim}^m,\ \ ij\in\Omega^{\mathrm{tl}},\ \ m=1,2,\ldots,n_1$$

$$P_g^{\min} \le P_g \le P_g^{\max},\ \ g\in\Omega^{\mathrm{g}},\ \ g=1,2,\ldots,n_{\mathrm{g}}$$

$$Q_g^{\min} \le Q_g \le Q_g^{\max},\ \ g\in\Omega^{\mathrm{g}},\ \ g=1,2,\ldots,n_{\mathrm{g}}$$

Constraints (continue)

$$Q_{\mathrm{C}i}^{\min} \le Q_{\mathrm{C}i} \le Q_{\mathrm{C}i}^{\max},\ \ i\in\Omega^{\mathrm{b}},\ \ i=1,2,\ldots,n_{\mathrm{b}}$$

$$Q_{\mathrm{IN}i}^{\min} \le Q_{\mathrm{IN}i} \le Q_{\mathrm{IN}i}^{\max},\ \ i\in\Omega^{\mathrm{b}},\ \ i=1,2,\ldots,n_{\mathrm{b}}$$

$$0 \le P_{\mathrm{RC}i} \le P_{\mathrm{R}i},\ \ i\in\Omega^{\mathrm{b}},\ \ i=1,2,\ldots,n_{\mathrm{b}}$$

$$0 \le P_{\mathrm{DC}i} \le P_{\mathrm{D}i},\ \ i\in\Omega^{\mathrm{b}},\ \ i=1,2,\ldots,n_{\mathrm{b}}$$

$$P_{ij}^m + \mathrm{i}Q_{ij}^m = |V_i|^2\left(g_{ij} - \mathrm{i}\left(b_{ij} + \frac{1}{2}b_{\mathrm{sh}\_ij}\right)\right) - V_i V_j^*(g_{ij} - \mathrm{i}b_{ij}),\ \ ij\in\Omega^{\mathrm{tl}},\ i\in\Omega^{n_{\mathrm{b}}},\ m=1,2,\ldots,n_1$$

$$\sum_{k=1}^{n_{\mathrm{c}}} x_{ij}^k \le n_{\mathrm{c}},\ \ ij\in\Omega^{\mathrm{tc}}$$

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

Indicator for selecting significant scenarios for planning

For renewable energy source

$$\mathrm{SSIRG}_h = \sum_{i=1}^{n_b} P_{\mathrm{RC}i,h} \Big/ \sum_{i=1}^{n_b} P_{\mathrm{R}i,h}$$

For load

$$\mathrm{SSIL}_h = \sum_{i=1}^{n_b} P_{\mathrm{DC}i,h} \Big/ \sum_{i=1}^{n_b} P_{\mathrm{D}i,h}$$

Robustness

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

Simulation results

Table 5 Results of RTEP

Method	Solution	Number of considered scenarios	pv_{inv} ($\times10^6$ US$)	pv_{opr} ($\times10^6$ US$)	Total cost ($\times10^6$ US$)	Robust-ness (%)	Calcula-tion 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_PRO-POSED	$n_{6-10}=2$, $n_{7-8}=2$, $n_{2-8}=1$, $n_{1-8}=1$, $n_{8-9}=1$, $n_{10-12}=1$, $n_{20-23}=1$, $n_{1-2}=2$, $n_{4-9}=1$, $n_{17-18}=1$, $n_{3-24}=1$, $n_{14-16}=2$, $n_{6-7}=2$, $n_{16-19}=1$, $n_{19-23}=1$, $n_{1-3}=1$	2	536.96	6696.52	7233.48	100	67.04

Table 6 Results of RTEP_RE

Case	Solution	pv_{inv} ($\times10^6$ US$)	pv_{opr} ($\times10^6$ US$)	Total cost ($\times10^6$ US$)	Robust-ness (%)
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

Conclusions

- 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.