A FIVE-LEVEL MILP MODEL FOR FLEXIBLE TRANSMISSION NETWORK PLANNING UNDER UNCERTAINTY: A MIN-MAX REGRET APPROACH

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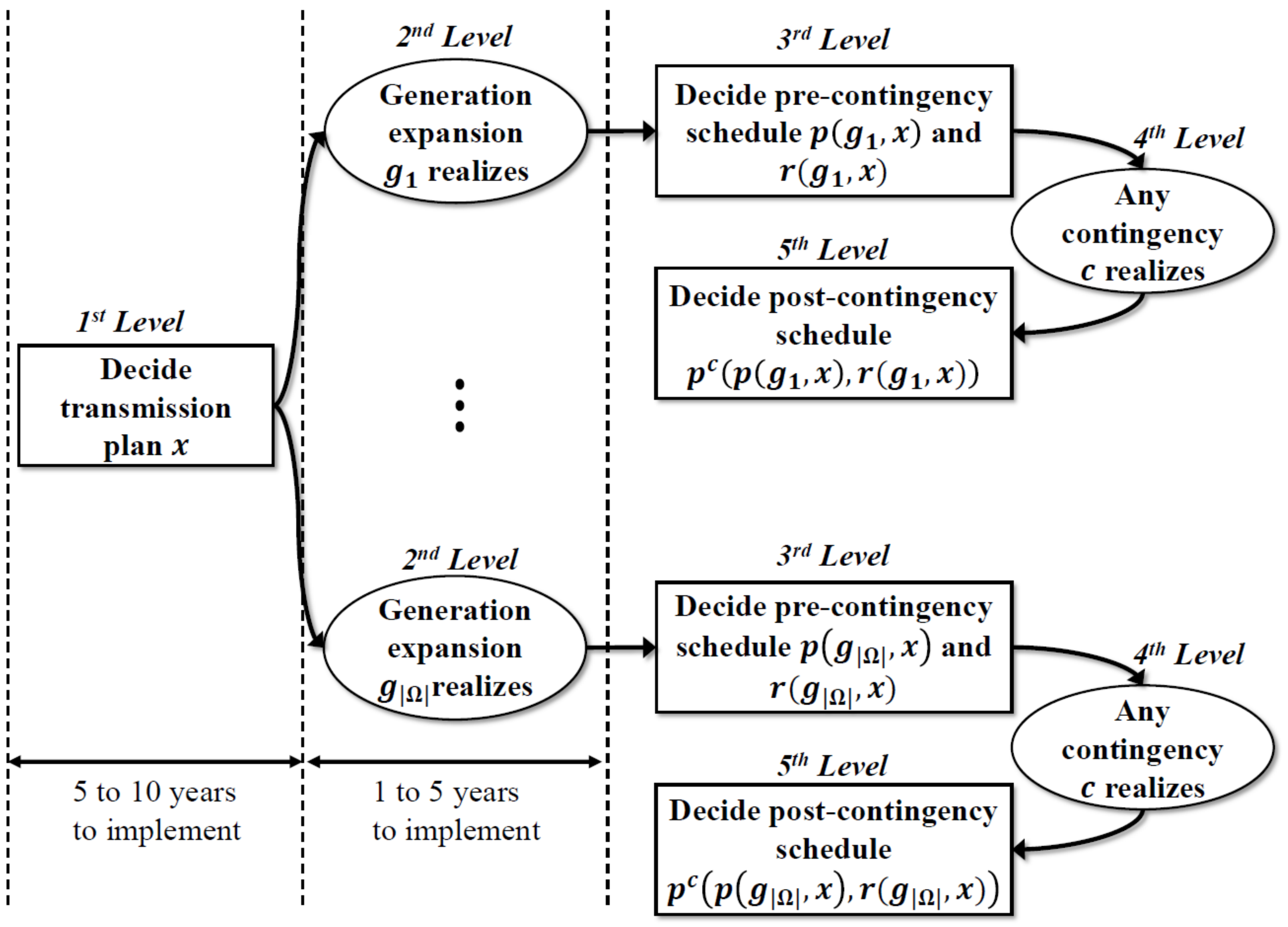
INTRODUCTION

The benefits of new transmission investment significantly depend on deployment patterns of renewable electricity generation that are characterized by severe uncertainty. In this context, this paper presents a novel methodology to solve the transmission expansion planning (TEP) problem under generation expansion uncertainty in a min-max regret fashion, when considering flexible network options and n-1 security criterion. To do so, we propose a five-level mixed integer linear programming (MILP) based model.

5-LEVEL FRAMEWORK

As discussed in [1], the time required to install new renewable generation can be considerably shorter than that required to build new network infrastructure. As a result, network planners may have to take transmission expansion decisions in advance of generation investments (and therefore under uncertainty). In this context, the proposed framework (illustrated in Fig.1) minimizes exposure to the two following conditions that may lead to increased regret: (i) cost of stranded network assets in case that future generation is not fully deployed, and (ii) increased congestion and renewable resource curtailment costs in case that new RES is deployed without the adequate network investment.

FIGURE 1



1st Level
Decide transmission plan x

2nd Level
Generation expansion g_1 realizes

3rd Level
Decide pre-contingency schedule $p(g_1, x)$ and $r(g_1, x)$

4th Level
Any contingency c realizes

5th Level
Decide post-contingency schedule $p^c(p(g_1,x), r(g_1,x))$

⋮

2nd Level
Generation expansion $g_{|\Omega|}$ realizes

3rd Level
Decide pre-contingency schedule $p(g_{|\Omega|}, x)$ and $r(g_{|\Omega|}, x)$

4th Level
Any contingency c realizes

5th Level
Decide post-contingency schedule $p^c(p(g_{|\Omega|},x), r(g_{|\Omega|},x))$

5 to 10 years to implement

1 to 5 years to implement

MATHEMATICAL FORMULATION

$$\underset{(\boldsymbol{v},\boldsymbol{f}^C)\in\mathcal{X}}{\text{Minimize}}\; MaxReg(\boldsymbol{v},\boldsymbol{f}^C) \tag{1}$$

subject to:

$$MaxReg(\boldsymbol{v},\boldsymbol{f}^C) = \max_{s\in\Omega}\Big\{ I(\boldsymbol{v},\boldsymbol{f}^C) + \sum_{t\in T} d_t\Big[\min_{(\boldsymbol{p},\boldsymbol{r})\in\mathcal{P}(\boldsymbol{v},\boldsymbol{f}^C,\boldsymbol{g}_{ts})}\{c^{op}(\boldsymbol{p},\boldsymbol{r})\}\Big] - c_s^*\Big\}, \tag{2}$$

where

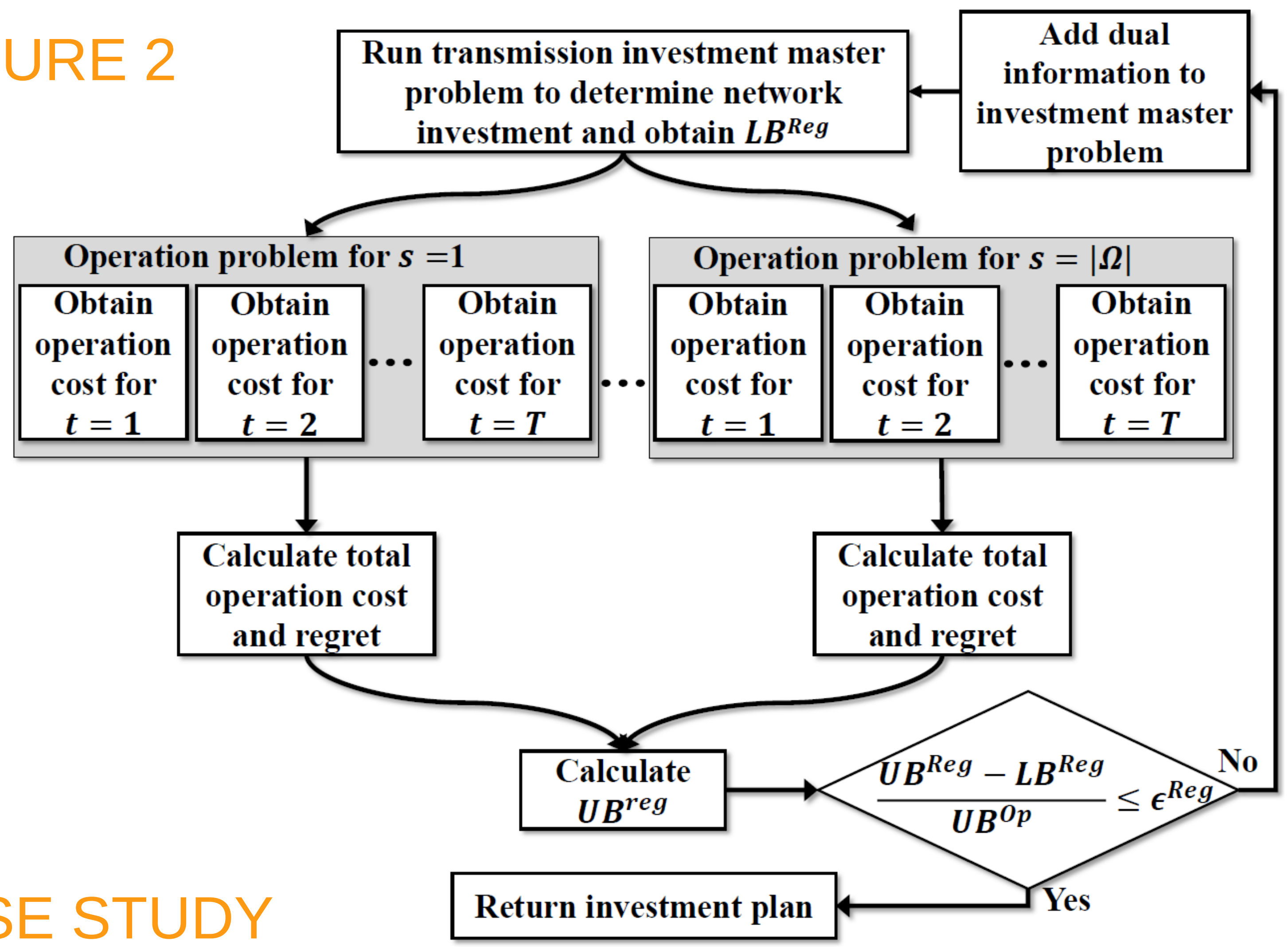
$$\mathcal{X} = \left\{ \begin{array}{c} \boldsymbol{v}\in\{0,1\}^{|\mathcal{L}^{PS}\cup\mathcal{L}^C|}, \\ \boldsymbol{f}^C\in\mathbb{R}^{|\mathcal{L}^C|} \end{array} \;\middle|\; \begin{array}{c} 0\le f_l^C \le \overline{f}_l^C v_l; \\ \forall l\in\mathcal{L}^C \end{array} \;\middle|\; \right\}.$$

In the model (1)-(2), the objective function to be minimized (1) is the maximum regret among all scenarios of future generation capacity. This maximum regret is mathematically represented by expression (2).

SOLUTION METHODOLOGY

This solution method briefly described in Fig. 2 is based on Benders decomposition to obtain the optimal transmission expansion plan and on column and constraint generation to impose a deterministic security criterion.

FIGURE 2



Run transmission investment master problem to determine network investment and obtain LB^{Reg}

Operation problem for s =1
Obtain operation cost for $t = 1$
Obtain operation cost for $t = 2$
…
Obtain operation cost for $t = T$

…

Operation problem for $s = |\Omega|$
Obtain operation cost for $t = 1$
Obtain operation cost for $t = 2$
…
Obtain operation cost for $t = T$

Calculate total operation cost and regret

Calculate total operation cost and regret

Calculate UB^{reg}

$\frac{UB^{Reg} - LB^{Reg}}{UB^{Op}} \le \epsilon^{Reg}$

No

Add dual information to investment master problem

Yes

Return investment plan

CASE STUDY

IEEE 118-Bus System with 181 existing transmission lines, 23 candidate transmission assets (7 candidate phase shifters and 16 candidate lines), 54 conventional generators, and 4 potential new renewable units to be located in buses 101, 109, 113, and 115.

TABLE 1

Case	Decision	Computing Time(s)
S1	31-32(PS), 11-117(13MW), 17-113(100MW), 27-114(50MW)	9948.05
S2	11-117(11MW), 114-115(50MW)	3880.77
S3	31-32(PS), 11-117(14MW), 27-114(50MW), 109-110(100MW)	10499.80
S4	31-32(PS), 11-117(12MW), 27-114(50MW), 100-101(100MW)	11295.50
S5	11-117(18MW), 17-113(141MW), 114-115(50MW)	3832.68
S6	31-32(PS), 11-117(30MW), 27-114(50MW), 109-110(100MW), 101-102(100MW)	9607.17
S7	11-117(17MW), 17-113(100MW), 114-115(50MW), 108-109(100MW), 100-101(100MW)	6361.07
MMR	31-32(PS), 11-117(21MW), 32-113(98MW), 27-115(50MW), 114-115(100MW), 108-109(94MW), 101-102(100MW)	45314.70

Table I presents the results that demonstrate the need for further transmission assets to provide security of supply and the need for further investment options to deal with uncertainty.

For the sake of comparison, we developed an equivalent single-level MILP that explicitly enumerates all scenarios and contingencies. With this model, no feasible solution was found for n-1 within one week.

CONCLUSIONS

A 5-level model is formulated to determine the transmission plan that leads to the minimum maximum regret under uncertainty in future generation expansion. The proposed formulation also considers occurrence of system outages, securing operation through a deterministic n-1 criterion.

We demonstrated that there are specific investment decisions which are revealed only when uncertainty is explicitly modelled and that flexible transmission investment options may remain unseen when network infrastructure is planned through considering deterministic scenarios.

REFERENCE

[1] V. Rious, Y. Perez, and J. Glachant, “Power transmission network investment as an anticipation problem,” Rev. Netw. Econ., vol. 10, no. 4, pp. 1–21, 2011.

ACKNOWLEDGEMENTS

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