A new transmission expansion planning framework and cost allocation method considering financial transmission rights

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A New Transmission Expansion Planning Framework and Cost Allocation Method Considering Financial Transmission Rights

H. Khazaei, and M. Sabounchi

***Abstract*— In this paper, we propose a transmission expansion planning (TEP) framework combined with a cost allocation method based on cooperative game theory. It is a two-step model in which the first step includes the procedure of transmission expansion plan and the latter is comprised of cost allocation process. TEP is derived based on two criteria: reliability and the economic benefits and we use the cost of expected energy not supplied (EENS) to measure the cost of reliability. Both the energy markets and transmission rights are considered in calculation of the economic benefits of the transmission expansion plan on the market participants. Then the cost of the new/upgraded transmission facilities is allocated based on the cooperative game theory. The use of cooperative game theory and the proposed payment allocation method helps to distribute the social welfare gains among the market participants justly. A 6-bus test system is used to illustrate the effectiveness of the proposed TEP framework.**

***Index Terms*—Transmission expansion planning (TEP), expected energy not supplied (EENS), reliability, cooperative game theory, Shapley value.**

I. INTRODUCTION

THE transmission expansion planning (TEP) problem can be divided into two subcategories: expansion plan implementation and how to allocate the cost of new or upgraded facilities. Before introduction of deregulation in 1990, the structure of the electrical systems was a vertically integrated system which the transmission expansion was derived centrally without considering the effects of new facilities on the payoff of market participants. The main driver of transmission expansion was the network reliability and the cost of these expansions was usually recovered using fixed rates. In the midst of restructuring the electricity markets, another criterion for transmission expansion was introduced: improving the market efficiency. Also the problem of how to cost allocate the cost of the new facilities between participants in the deregulated markets arises.

Several articles have been published on TEP up to this time. In [1] a TEP framework is proposed which assumes that only the generation sector is regulated. In [2] and [3] the expansion planning for both generation and transmission is proposed. In [4] the TEP problem considering the losses of system is solved using a mixed-integer linear programming approach. In [5] a TEP model is proposed with the objective of reducing weighted standard deviation of locational marginal prices (LMPs).

In order to strike the cost allocation problem, traditional methods define rates, based on the contributions of participants to network flows in order to recover the costs of expansion [6]. These methods fail to reflect the real value of new or upgraded transmission facilities on the players. The more efficient class of methods allocates the costs based on the economic benefits that the participants receive from the new/upgraded transmission facilities.

An important feature of a TEP framework is that it should partially redistribute the social welfare throughout the grid to gain the consent of all players. Here, we proposed a TEP method along with an allocation method based on the cooperative game theory which is a two-step method. In the first step, the transmission system operator (TSO) or the independent system operator (ISO) uses the reliability and economic effects as two main tools for choosing the optimal transmission expansion plan. In this step, we used the cost of expected energy not supplied (EENS) to measure the reliability [2].

First, the reliability and the economic effects of transmission facilities are used as the main criteria for finding the optimal transmission expansion plan. Then in the second step, the cost of the transmission expansion plan must be allocated between the participants using cooperative game theory via an algorithm introduced in [7] in which a coalition of participants is found that are willing to pay the cost of new facilities. Those who are not in the coalition only pay a small portion of the costs for the increment in the reliability of the system. Some players even may receive a payment because the new facilities may cost them a great deal and cause a significant loss. This will help to distribute the social welfare gains among the participants and gain the consent of all players.

The paper is organized as follows: The proposed transmission expansion planning framework is introduced in

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section II. Section III presents the proposed payment allocation method based on cooperative game theory. The validity of the proposed method is examined in a six-bus test system. Section IV discusses representative quantitative results using a six-bus test system. Finally, concluding remarks are provided in Section V.

II. The Proposed Transmission expanssion Planning (TEP) Framework

In this paper, we propose a method for transmission expansion in which we consider financial rights and a reliability factor in decision making model. Reliability is an important factor which has not been considered in the previous models for transmission expansion. The reason of this is the fact that from players' point of view, considering reliability in decision making model is difficult and expensive. The probability of occurrence of a line outage is relatively low so players usually ignore it. The only cases that players need to include reliability, is in the formulation of the auctions clearing models. Unlike players, the ISO gives a high priority to reliability in its decision making procedure. In other word, some expansions in the transmission system have economical values. These expansions benefit the players. Some other expansions have reliability values which are of interest for the ISO.

The transmission expansion is formulated as follows:

$$\max\ \mathrm{SW} = \sum_{n=1}^{N} \mathrm{SW}_n^b + \mathrm{SW}_n^s + \sum_{\ell^c=1}^{L^c} \left\{ \mathrm{CR}_{-\ell^c}^{\mathrm{H}} - \mathrm{CR}_{+\ell^c}^{\mathrm{H}} \right\} - \sum_{\ell^c=1}^{L^c} n^c \mathrm{Q}^c \tag{1}$$

Where

SW_n^b	The social welfare of the buyer on node n
SW_n^s	The social welfare of the seller on node n
$\mathrm{CH}_{-\ell^c}^{\mathrm{H}}$	Cost of reliability for the time horizon H before building or upgrading ℓ^c
$\mathrm{CH}_{+\ell^c}^{\mathrm{H}}$	Cost of reliability for the time horizon H after building or upgrading ℓ^c
N	Number of nodes
L^c	Number of candidate lines to build or upgrade
Q^c	The cost of building or upgrading the line ℓ^c
n^c	A integer number: 1 = line ℓ^c is going to be built or upgraded, 0 = otherwise
H	The time horizon in the transmission planning

Where the SW_n^b and SW_n^s are calculated as follows:

$$\mathrm{SW}_n^b = \sum_{h\in H} \left(\beta_{n,h}^b \left(P_{n,h}^b \right) - \mathrm{LMP}_n^h \times P_{n,h}^b \right) + \sum_{\substack{i\in \mathrm{OB}_n^b \\ j\in \mathrm{OP}_n^b \\ k\in \mathrm{FG}_n^b}} \left(\mathrm{INC}_{i,n,b}^{\mathrm{OB,H}} + \mathrm{INC}_{j,n,b}^{\mathrm{OP,H}} + \mathrm{INC}_{k,n,b}^{\mathrm{FG,H}} \right) \tag{2}$$

$$\mathrm{SW}_n^s = \sum_{h\in H} \left(\mathrm{LMP}_n^h \times P_{n,h}^s - \beta_{n,h}^s \left(P_{n,h}^s \right) \right) + \sum_{\substack{i\in \mathrm{OB}_n^s \\ j\in \mathrm{OP}_n^s \\ k\in \mathrm{FG}_n^s}} \left(\mathrm{INC}_{i,n,s}^{\mathrm{OB,H}} + \mathrm{INC}_{j,n,s}^{\mathrm{OP,H}} + \mathrm{INC}_{k,n,s}^{\mathrm{FG,H}} \right) \tag{3}$$

Where

$P_{n,h}^b, P_{n,h}^s$	The power that the s_n/b_n buys/sells at hour h
$\beta_{n,h}^b, \beta_{n,h}^s$	The bid function of s_n/b_n
$\mathrm{OB}_n^b, \mathrm{OP}_n^b, \mathrm{FG}_n^b$	Set of OB-PTP, OP-PTP and FG rights of b_n
$\mathrm{OB}_n^b, \mathrm{OP}_n^b, \mathrm{FG}_n^b$	Set of OB-PTP, OP-PTP and FG rights of s_n
$\mathrm{INC}_{i,n,b}^{\mathrm{OB,H}}, \mathrm{INC}_{j,n,b}^{\mathrm{OP,H}}, \mathrm{INC}_{k,n,b}^{\mathrm{FG,H}}$	The income of ith OB-PTP, jth OP-PTP and kth FG right of the b_n for time horizon H.
$\mathrm{INC}_{i,n,s}^{\mathrm{OB,H}}, \mathrm{INC}_{j,n,s}^{\mathrm{OP,H}}, \mathrm{INC}_{k,n,s}^{\mathrm{FG,H}}$	The income of ith OB-PTP, jth OP-PTP and kth FG right of the s_n for time horizon H.
LMP_n^h	LMP at node n at hour h.

The first term in (1) is the aggregate social welfare which is defined as the difference between all of buying and selling bids. The second term is the summation of all players' incomes from transmission rights, including obligation point-to-point (OB-PTP) financial transmission rights (FTRs), option point-to-point (OP-PTP) FTRs and flowgate (FG) transmission rights. By including this term, we consider the effect of construction of new lines on those players who benefit from contingencies through transmission rights. This becomes extra important for those players who have previously made investments in these cases and installed new lines on the grid because ISO awards them with transmission rights for their investments [8]. The third term is the cost of reliability which includes the effect of construction of new lines on the reliability factor and the last term is the cost of building new or upgraded lines.

A. Transmission rights

Transmission rights are the financial instruments that are used to hedge the risk of volatile prices [9]. There are two main classes of transmission rights: point-to-point (PTP) and flowgate (FG). PTP transmission rights define financial rights between two nodes or two set of nodes. On the other hand, the FG rights define financial rights based on transmission facility itself.

The PTP-rights are also categorized into two classes: Obligation (OB) and Option (OP). In the cases that price difference between the injection and withdrawal nodes becomes negative, OB-PTP rights are considered as liabilities. Unlike the OB-PTP, the OP-PTP rights do not obligate their owners to pay the loss. When the price difference between injection and withdrawal nodes is positive, these two classes are alike.

The income of OB-PTP rights, OP-PTP rights and FG-rights are formulated as follows:

$$\mathrm{INC}_{i,n}^{\mathrm{OB,H}} = \sum_{i\in SOB_n}\sum_{h\in HOB_{i,n}} \Delta LMP_i^h \times OBR_{i,n} \tag{4}$$

$$\mathrm{INC}_{i,n}^{\mathrm{OP,H}} = \sum_{i\in SOP_n}\sum_{h\in HOP_{i,n}} \max\left(\Delta LMP_i^h, 0\right)\times OPR_{i,n} \tag{5}$$

$$\mathrm{INC}_{i,n}^{\mathrm{FG,H}} = \sum_{i\in SFG_n}\sum_{h\in FG_{i,n}} \lambda_i^h \times FGR_{i,n} \tag{6}$$

Where

$OBR_{i,n}, OPR_{i,n}, FGR_{i,n}$	the amount of *i*th OB-PTP, OP-PTP and FG right owned by s_n/b_n.
SOB_n, SOP_n, SFG_n	Set of OB-PTP, OP-PTP and FG rights owned by s_n/b_n.
$HOB_{i,n}, HOP_{i,n}, FG_{i,n}$	Set of hours that the player *n* owns the *i*th OB-PTP, OP-PTP and FG right.
$\Delta\mathrm{LMP}_i^h$	The LMP difference on the path of PTP right *i* at hour *h*.
λ_i^h	Shadow price of FG-right *i* at hour *h*.

B. Cost of reliability

Reliability is an important factor in transmission expansion which indirectly impacts the players' income. Broadly speaking, there are two ways to measure the reliability: deterministic and probabilistic. The deterministic criterion which is also called as (N-1) criterion is widely used in transmission expansion methodologies; however it is unable to consider the stochastic nature of line failures. On the other hand, the (N-1) criterion fails to consider the economic aspects of transmission expansion [10]. The probabilistic criterion includes the stochastic nature of line failures in which the effects of different line outages are included simultaneously [11].

In this paper, we use the cost of expected energy not supplied (EENS) to measure the reliability [2]. When line outages occur, a part of load needs to be curtailed, which its cost is a good instrument to measure the reliability of the system. The second term of (1) is the increase in the reliability by constructing or upgrading transmission lines. The EENS depends on the states of the system before and after the curtailment occurs. In both states the energy market is cleared based on an OPF optimization. The general formulation of this OPF for hour *t* is as follows [12]:

$$\min \sum_{i=1}^{N} \beta_{i,t}^{s}\left(P_{i,t}^{s}\right) + \sum_{j=1}^{N} \beta_{j,t}^{cur}\left(P_{j,t}^{cur}\right)$$

$$\text{s.t.} \tag{7}$$

$$0 \le P_{i,t}^{s} \le P_i^{s,\max} \qquad i = 1,\ldots,N \tag{8}$$

$$0 \le P_{j,t}^{cur} \le P_j^{cur,\max} \qquad j = 1,\ldots,N \tag{9}$$

$$-R_i^s \le P_{i,t}^{s} - P_{i,t-1}^{s} \le R_i^s \qquad i = 1,\ldots,N \tag{10}$$

$$P_{i,t}^{s} + P_{i,t}^{cur} + \sum_{j\ne i} f_{ij,t} = D_{i,t} \qquad i, j = 1,\ldots,N \tag{11}$$

$$\sum_{ij\in SLL(\ell)} f_{ij,t} \times x_{ij} = 0 \qquad \ell \in SIL \tag{12}$$

Where

$\beta_{j,t}^{cur}\left(P_{j,t}^{cur}\right)$	The bid function of load *j* for curtailing its load at hour *t*.
$P_{i,t}^{s}$	The power of the s_n at hour *t*.
$P_i^{s,\max}$	Maximum amount of power the s_i can sell.
$P_{j,t}^{cur}$	The amount of demand the b_j curtails at hour *t*.
$P_j^{cur,\max}$	Maximum amount of demand the b_j can curtail.
R_i^s	The ramp-rate of s_i.
$D_{i,t}$	The total demand of b_i at hour *t*.
$f_{ij,t}$	Flow on line *ij* at hour *t*.
x_{ij}	Reactance of line *ij*.
SIL	Set of all independent loops
$SIL(\ell)$	Set of lines in the loop ℓ.

When a line outage occurs, depending on the topology of the system and state of the network, the line flows will be redispatched which may lead to a curtailment in some loads. The reason of these load curtailments is the inability of generators to respond accordingly. The speed rates of the generators' responses are limited by ramp-rate limits, i.e. R_i^s. Consequently, some loads would be obligatorily curtailed, so to calculate EENS at each time interval *t* for each contingency line outage *c*, two OPFs are needed: one for calculation of the normal state of the system (i.e. *t*-1) and other one for calculating the system's state after the line outage (i.e. *t*). The result is the set of all obligatory curtailed loads caused by contingency line outage *c*, $\left(P_j^{cur,t,c} - P_j^{cur,t-1,c}\right)$. The probabilistic sum of these obligatory curtailed loads, for all loads and all contingency scenarios in the time horizon of planning is the EENS:

$$\mathrm{EENS} = \sum_{c}\sum_{t}\sum_{j=1}^{N} \rho_c \times \left(P_j^{cur,t,c} - P_j^{cur,t-1,c}\right),\ t \in HC_c \tag{13}$$

Where HC_c is the set of hours that the contingency scenario *c* is happening and ρ_c is the probability of occurrence of the contingency scenario *c*.

The probabilities needed to calculate the EENS are derived from old outage rates from historical information database of the system and are assumed to be known. A methodology for deriving these probabilities is proposed in [2].

In order to include the EENS in the transmission expansion planning, they must be shaped in a monetary form. The cost of EENS is calculated as:

$$\mathrm{CR}^{H} = \sum_{c}\sum_{t}\sum_{j=1}^{N} \rho_c \times C_j^{cur}\left(P_j^{cur,t,c} - P_j^{cur,t-1,c}\right) \quad (14)$$

Where C_j^{cur} is the cost of curtailed load at node j.

We call this term as *cost of reliability* (CR). In our proposed model for transmission expansion in (1), we use this term as a tool for measuring the reliability and including it in the model. For each line which is meant to be built or upgraded, the CR is calculated before and after constructing (or upgrading) that line for the time horizon of the planning, i.e. $\mathrm{CH}_{-\ell^c}^{H}$ and $\mathrm{CH}_{\ell^c}^{H}$. The difference between these two is the increase rate in CR caused by building (or upgrading) that line.

III. The Proposed Payment Allocation Method

After solving (1) and determining which lines are needed to be built, the next step is to allocate the cost of those lines to the players. Some players are interested in building these new lines because this will increase their expected income, while others may suffer from loss because these new lines decrease their expected income. To solve this issue we can compensate the loss of those who suffer from loss by excluding them from paying the main part of the fee in the process of building new lines and for those who gain from these new constructions an extra tax should be enforced. Note that the cost of reliability is paid by all players and the remaining cost, if any, would be paid by the coalition [13]. The question is: 'which players form the coalition?' and what is the share of each player in this cost?

In this paper, we use a modified version of the proposed method in [7] which is based on cooperative game theory to allocate the costs. The difference is in fact that unlike [7], players who face loss from new lines also pay a (small) share of costs for the increment in the system's reliability which they also benefit from.

Solving (1), the lines that are going to be built are identified and the cost of these new lines must be paid by players. Note that the identified lines in (1) are *proposed* lines that the players must decide whether to build or not. Some of the players benefit from these new lines and some others don't. In the process of voting for building these new lines, each player has a power to effect the decision of players as a whole. There may be scenarios that a coalition of unwilling players may vote not to build the new lines and the optimal transmission expansion does not take place. In order to handle this, [7] propose a cost allocation method that no player should face a worse condition after building new lines and as a result, the players will obviously vote to build the new lines. In this method, those players who face loss from new lines receive a fine to meet their forfeiture and the end of the day no player will face any loss. The modified method is as follows:

The players' influence on the expansion decision is modeled using parameters $m_n^b, m_n^s \in [0,1]$, where $\sum_n m_n^b + m_s^n = 1$.

There are two classes of players. Those who gain profit from building the new lines or at least the new lines do no affect their profits $\left(F^b, F^s\right)$ and those who face loss $\left(O^b, O^s\right)$. The First class will vote to build the new lines and the second class would deny this demand and votes against it. The criterion of determining the winning class is the parameter λ which is usually considered between 0 and 1. The new lines will be built if:

$$\sum_{n:\{b,n\}\in F^b} m_n^b + \sum_{n:\{s,n\}\in F^s} m_n^s \geq \lambda \quad (15)$$

And they won't be built if:

$$\sum_{n:\{b,n\}\in O^b} m_n^b + \sum_{n:\{s,n\}\in O^s} m_n^s < \lambda \quad (16)$$

If the players vote to build the new lines, then the cost is simply allocated between all players or those who benefit from the new lines. This is dependent on the allocation method. The problem surfaces when the players vote not to build the new lines. In this case, the following method, which is a modified version of the proposed method in [7], is proposed to solve the cooperative game. Before presenting the method following definitions are needed [14]:

Coalition: a coalition C is a subset of players. A game with N players has 2^N coalitions, which is the number of subsets of $\{1,\ldots,N\}$.

Coalition structure: for a cooperative game G with N players, the coalition structure is a set of non-empty coalitions: $CS = \{C_1,\ldots,C_k\}$ such that each player appears in only one coalition.

Characteristic function: for the cooperative game G with N players, the characteristic function $\sigma : 2^N \to \mathbb{R}$ assigns a value to each possible coalition of the game.

Note that a value which is defined by characteristic function for a coalition is assigned to that coalition as a whole, not to the players who are participating in that coalition. The problem of how to divide the value of a coalition between players who are participating in that coalition is answered using solution concepts. One of the most used solution concepts is the "*Shapley value*".

Shapley value: the Shapley value is a method which divides the value of a coalition between the players of that coalition based on their contribution on the value of coalition. Since, the contribution of players on the value of a coalition depends on the selection order of players; some situations may happen that symmetric players in a game acquire different values. To handle this problem, Shapley [15] uses averages over all possible permutations of players to calculate the value, which is called the Shapley value.

Let Π_N denotes the set of all possible permutations of players: $\{1,\ldots,N\}$. For a permutation $\pi \in \Pi_N$, S_π^i denotes the set of players that are predecessors of player i in the π.

In a cooperative game G with N players and the characteristic function σ, Shapley value for player i is calculated as:

$$\varphi_i = \frac{1}{N!}\sum_{\pi\in\Pi_N} \sigma\left(S_\pi^i \cup \{i\}\right) - \sigma\left(S_\pi^i\right) \quad (17)$$

The summation over different permutations considers all possible coalitions in the game.

A. The proposed characteristic function and payment allocation model

The key step in modeling the cooperative game is to define the characteristic function. Unlike [7], we assume that those players who face loss from the new lines also should pay a portion (α) of the cost of new lines. The new lines increase the reliability of system and consequently, from this point of view, they benefit all of the players. Based on this argument, the characteristic function is defined as follows:

$$\sigma(C)=\begin{cases}\sum_{n:\{b,n\}\in C}\mathrm{SW}_n^{b0}+\mathrm{SW}_n^{s0}-\alpha\times\sum_{\ell^c=1}^{L^c}n^c\times\mathrm{Q}^c \\ \qquad\qquad \text{if } \sum_{n:\{b,n\}\in C}m_n^b+\sum_{n:\{s,n\}\in C}m_n^s\le\lambda \\ \\ \sum_{n:\{b,n\}\in C}\mathrm{SW}_n^{b0}+\mathrm{SW}_n^{s0}+\mathrm{SW}^{*}-\mathrm{SW}^{0}+\alpha\times\sum_{\ell^c=1}^{L^c}n^c\times\mathrm{Q}^c \\ \qquad\qquad \text{if } \sum_{n:\{b,n\}\in C}m_n^b+\sum_{n:\{s,n\}\in C}m_n^s>\lambda\end{cases} \quad (18)$$

After calculation of characteristic function and Shapley value, the payment rates should be addressed. The following payment allocation is used to allocate the costs:

$$\psi_i = SW_i - \varphi_i \quad (19)$$

IV. NUMERICAL EXAMPLE

We use a 6-node system in Fig.1 to illustrate the performance of our proposed method. In this system, there are 3 generation units and 3 individual loads.

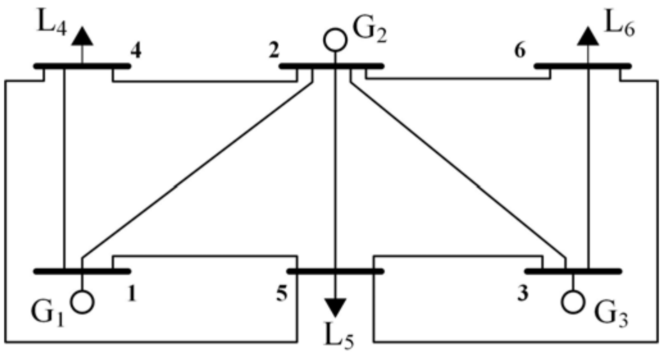

Fig. 1. The 6-bus test system

The data of the lines are listed in Table I.

TABLE I
TRANSMISSION LINES DATA

Line NO #	From	To	Reactance (p.u.)	Limit (MW)
1	1	2	0.04	40
2	1	4	0.2	60
3	1	5	0.3	40
4	2	3	0.25	30
5	2	4	0.1	40
6	2	5	0.04	30
7	2	6	0.2	30
8	3	5	0.26	20
9	3	6	0.1	40
10	4	5	0.08	20
11	5	6	0.06	40

Also, the cost of generators and curtailable loads are presented in Table II.

TABLE II
GENERATORS DATA

		cost parameters aP^2+bP+c			P^{max}
	node	a (\$/MWh)	b (\$/MWh)	c (\$/MWh)	MW
Generators	1	0.00533	11.669	213.1	280
	2	0.00889	10.333	200	220
	3	0.00741	10.833	240	250
Loads	4	0.01	12.5	-	-
	5	0.0095	13	-	-
	6	0.009	12.7	-	-
Interruptible Loads	4	0.011	25	15	30
	5	0.15	22	20	30
	6	0.13	20	25	30

The forecasted loads for a time period of 15 years are shown in Fig. 2. Note that it is assumed that the generation units are able to meet the increase in demand.

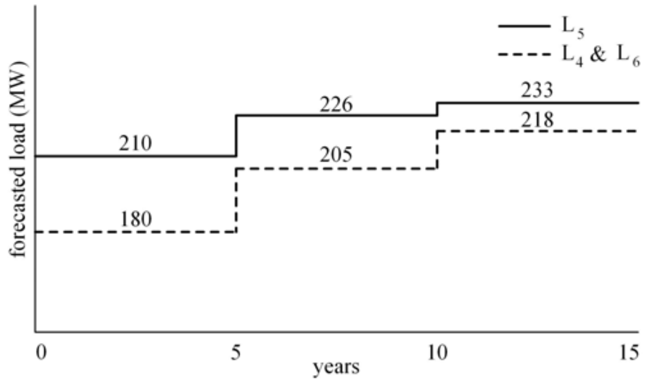

Fig. 2. Forecasted loads for 15 years

The transmission rights are listed in the Table III:

TABLE III
TRANSMISSION RIGHTS DATA

owner	PTP-OB,OP		FG	amount (MW)	Duration (years)	type
	from	to	Path			
L_4	1	5	-	60	7	PTP-OB
G_1	1	3	-	60	7	PTP-OP
L_6	-	-	T_2	50	7	GR

There are three paths for building or upgrading the transmission lines:

- From node 1 to node 4 for 40 MW.
- From node 3 to node 5 for 40 MW
- From node 3 to node 4 for 30 MW.

Note that on the first and the second paths, there are previously installed lines (T_2 & T_8). These lines can be upgraded or new lines can be installed along with these previously installed lines. For the last path, there is no previously installed line.

The cost of building new lines and upgrading the previously installed lines are visible in Table IV.

TABLE IV
THE COST OF CANDIDATE LINES

Path	Type of investment	Cost (in 10^5\$)
From node 1 to node 4	Upgrading the T_2	112.7

	Building a new line	174.5
From node 3 to node 5	Upgrading the T_8	118.4
	Building a new line	180
From node 3 to node 4	Building a new line	194.1

We consider two scenarios: in the First scenario, the transmission expansion problem in (1) is solved without considering the cost of reliability and in the second one, we solve the transmission expansion problem considering the cost of reliability. The outage of line T_5 in considered as the contingency scenario. In the low demand hours, the lines T_2 and T_3 are congested, but in the peak-demand hours, the lines T_8 and T_9 become congested.

The results for the two scenarios (without the CR and with the CR) are listed in Table V.

TABLE V
THE RESULTS OF TEP FOR TWO SCENARIOS

Path	Type of investment	Status	
		Without the CR	With the CR
1-4	Upgrading the T_2	✓	✓
	Building a new line	×	×
3-5	Upgrading the T_8	✓	×
	Building a new line	×	✓
3-4	Building a new line	×	✓

For the path 3-5, without including the cost of reliability in the decision model, the model prefers to upgrade the previously installed lines instead of building new parallel lines, because the cost of upgrading the lines is relatively lower than the cost of building a new line. Also, the model which does not include the reliability parameters does not consider the contingency scenarios and consequently does not vote to build a new line from node 3 to node 4, but by considering the reliability parameters, this line is going to be built. The effect of the expansion on the players' surplus in shown in Table VI.

TABLE VI
THE PLAYERS' SURPLUS BEFORE AND AFTER THE EXPANSION (10^7 \$)

Player	Weight	Initial surplus	Without the CR		With the CR	
			Surplus after	Payment	Surplus after	Payment
G_1	0.27	7.21	7.91	0.336	7.15	0.341
G_2	0.12	4.49	4.70	0.2042	4.65	0.2105
G_3	0.19	5.02	5.02	-0.2414	4.97	-0.2266
L_4	0.13	4.11	4.11	-0.1409	4.07	-0.1297
L_5	0.17	6.70	7.12	0.15215	7.03	0.1601
L_6	0.12	4.45	4.61	0.11495	4.51	0.1307

Note that in both scenarios (without CR), the players G_1, G_2, L_5 and L_6 cooperate and they pay for the expansion costs. In the first scenario, the rest of players do not pay for the expansion. But in the second scenario, a small portion of the costs is paid by the rest of players, because they benefit from the increase in reliability caused by new and upgraded facilities too. Note that none of the players face a great loss from the transmission expansion plan (Table VI). A small loss that some players face is due to the cost of reliability which is charged to all players. This signifies that the social welfare is distributed among all participants.

The role of transmission rights is most significant in the case of player L_4. The expansion of the system reduces the nodal prices which decreases the payments of L_4 for energy. Since L_4 owns a PTP transmission right and obviously the expansion plan reduces L_4's income and as a result in both scenarios, L_4 does not vote for new transmission planning.

V. SUMMARY AND FURTHER WORK

In this paper we proposed a new framework for transmission expansion planning (TEP) problem. By using the cost of expected energy not supplied (EENS) we shape the reliability in a monetary form which can be easily entered in the TEP framework. Also we showed that the transmission rights needs to be included in the model because they are directly relating to the congestion in the transmission networks. Consequently they significantly affect the players' reactions to the transmission expansion plans. Also, we showed that including the reliability in the TEP framework leads to more reliable transmission expansion plans.

Future work will mainly try to include strategic behavior of participants and the role of market power in TEP models.

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